FRA/ORD-80/86

AN EVALUATION OF THE COSTS AND BENEFITS OF RAILROAD ELECTRIFICATION

MARCH 1981
FINAL REPORT

Prepared in Accordance with Section 901(7) of the Railroad Revitalization and Regulatory Reform Act of 1976 (P.L. 94-210)

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Washington, D.C. 20590

TO THE READER

The original draft of this report was prepared in 1977 by the Federal Railroad Administration, Office of Research and Development, under the authorship of Mr. John Harrison who then was an employee of the Office of Passenger Systems, RRD-20. It was prepared in accordance with Section 901(7) of the Railroad Revitalization and Regulatory Reform Act of 1976, and was issued with limited distribution strictly for the purpose of review. The information was used in a U.S. Department of Transportation report titled, "A Prospectus for Exchange in the Freight Railroad Industry." The recent resurgence of interest in railroad electrification makes publication of this report desirable at this time. Please address all comments to: Mr. Richard Novotny, RRD-20, Federal Railroad Administration, 400 Seventh Street, S.W., Washington, D.C. 20590.

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16. Abstract

This report responds to issues raised in Section 901(7) of the Railroad Revitalization and Regulatory Reform Act (4R Act) and discusses how electrification might contribute to or detract from meeting the objectives of this Act. This report is primarily limited to an evaluation of the potential costs and benefits of railroad electrification; discusses energy effects, with special emphasis on oil fuel economies and the required amounts of coal and other fossil fuels; environmental effects; impact on electric utilities; economic impact on railroads; feasibility of widespread electrification; financing; and required research and development and national implications.

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I. FOREWORD

Railroads in the United States carry more ton-miles than any other mode, 794 billion ton-miles in 1976. The bill for this freight was $18.6 billion, an average of about 2.6 cents per ton-mile. Conversely, however, the railroads now rank near the bottom of U.S. industry in terms of rate of return, averaging a scant 1.49 percent return on investment in 1976. Since the mid-1950's, earnings of the rail industry have steadily declined, undermining its ability to replace worn out assets and advance technologically. Continued financial and physical deterioration threaten the survivability of some railroads and place the future of the entire industry in jeopardy. It is with this background that the Railroad Revitalization and Regulatory Reform Act of 1976 (4R Act) was enacted to avert a collapse of the industry, rehabilitate the physical facilities and restore the financial stability of the railway system. It is the stated intent of this act to provide the means for the railroads to remain viable in the private sector of the economy.

One result of the Act has been a major reassessment of electrification and its potential role in future railroad operations in the United States. Under Title VII, Amtrak's existing electrification facilities in the Northeast Corridor will be rehabilitated and extended from New Haven to Boston. Another provision of the 4R Act allots $200 million in federal guarantees to support Conrail, should it decide to extend its electrified freight routes. Federal assistance is also available to railroads for improvement projects, such as electrification, under Title V, "Railroad Rehabilitation and Improvement Financing." Finally, as addressed in this report, Title IX calls for the Secretary of Transportation to conduct a comprehensive study of the American railway system, including the potential benefits of railroad electrification.

This study responds to the issues raised in Section 901(7) and discusses how electrification might contribute to or detract from meeting the objectives of the 4R Act.

The Act declares that it is the policy of Congress "to provide the means to rehabilitate and maintain the physical facilities, improve the operations and structure and restore the financial stability of the railway systems of the United States."

Electrification is one long-range alternative for improving railroads. As such it should be evaluated in comparison to other possible long-range improvements. This study does not include a complete analysis of alternatives. Rather its focus is limited primarily to an evaluation of the potential cost and benefits of railroad electrification.

II. SUMMARY AND CONCLUSIONS

The following issues are addressed in this report:

- Cost to electrify, including estimated unit capital and operating costs and nationwide costs to electrify high traffic density routes;
- Energy defects of railroad electrification with special emphasis on oil fuel economies and the amount of coal and other fossil fuels required with electrification;
- Environmental effects of widespread electrification, including the advantages to the environment in terms of reduced fuel consumption and air pollution and disadvantages from the increased use of fuel such as coal;
- Impact of railroad electrification on the electric utility system and ability of existing power facilities to supply the additional power required;
- Impact of electrification on railroads, particularly the economic impact and feasibility of widespread electrification from the railroad point of view;
- Financing railroad electrification, and evaluating of the railroads' and the utilities' ability to finance their share of the cost;
- Research and development required for potential extensive electrification, and national implications of widespread electrification.

Based on the data examined throughout the course of this study, the following conclusions were reached:

- Electrification would be the largest investment in roadway and structures that the railroads have made since laying the original track in the nineteenth century.
- The capital investment required to electrify a rail line necessitates high utilization in order to provide an attractive economic return or a substantial energy benefit.
- The viability of railroad electrification depends primarily on savings generated by reduced operating costs.
- Electric locomotives because of their simplicity can demonstrate considerably longer economic lives than diesels.
- Without modifications, the signaling systems designed and built for steam and diesel operations are almost invariably unsuited for electric operations.
- The change in fuel supply, brought about by electrification, would be from the exclusive use of oil (diesel fuel) to a mix, including approximately 50 percent coal and 25 percent nuclear.

- Based on a comparison of relative conversion efficiencies, there would be little or no net energy savings with electrification, although substantial cost savings in energy could be expected.
- The localized environmental effects of electrification would be substantial. Natural systems, social systems and safety would all be affected, but, from a national perspective, the environmental effects of railroad electrification, in comparison with other alternatives, would not be significant.
- Widespread railroad electrification could be accommodated by the U.S. electric utility system without any severe consequence. There would be unique requirements, but it is assumed that utilities would have sufficient time to plan for and construct needed facilities.
- The greatest concerns railroads have in regard to electrification are in the areas of financial and business uncertainties. Electrification's success depends on a strong, growing market for rail transportation services over the project life (30-50 years).
- Estimates for electrifying U.S. railroads, at present dollar values, are about $217,500 per single-track and $371,000 per double-track per route-mile.
- Nationwide railroad electrification is estimated to cost between $3 billion and $10.5 billion. Another $4 to $12 billion might be required to provide and deliver the electrification power.
- U.S. railroads cannot, with their own resources, finance the billions of dollars necessary for a national program of railroad electrification.
- Federal assistance is available to the railroads for electrification projects under Title V of the 4R Act through either the purchase of preference shares or the guarantee of low interest loans by the Government.
- A major factor in deciding to electrify is whether the system, when electrified, would operate as well or better than the present diesel system. In order to minimize the impact of the conversion, it may be desirable to limit the amount of change in operations during the initial stages. In the long run, however, it is expected that operations would be adapted to maximize the advantages of the operating characteristics of the electric locomotive.
- Studies need to be carried out in order to 1) define the reliability, safety, and maintainability requirements of the system; 2) establish common technical requirements (standards) for optimum interchangeability of equipment; 3) develop a data base to increase the credibility of railroad electrification feasibility studies; 4) improve the railroad/utility interface; 5) improve the cost and performance of the equipment; and 6) innovate with long-range research and development.
- A site-specific study should be conducted before proceeding to electrify any particular route.

- While unresolved technical questions should not prevent a railroad from electrifying, they must be addressed before an electrified line could experience complete success.
- No technological breakthroughs are needed to implement railroad electrification in this country.

III. OBJECTIVE

This study examines the potential costs and benefits of railroad electrification of high density routes within the United States. These costs and benefits, together with other aspects of electrification, constitute a highly complex and controversial subject involving a great variety of technical, economic, institutional, social, and environmental issues.

IV. METHODOLOGY

The basic research methods used in this study have included reviewing and assessing the literature; using standard techniques of data collection and analysis; conferring with private consultants; and interviewing knowledgable individuals in Government, industry, and academia.

The study mandate outlined in Section 901(7) of the Act was broad in nature, requiring a complete investigation of railroad electrification to satisfy the study request. The most recent prior Government evaluation of the subject was embodied in an FRA report entitled "A Review of Factors Influencing Railroad Electrification (Ref. 1), which was based on work conducted in the early 1970's, including en economic analysis, performed by the Pan-Technology Consulting Corporation. (Ref. 2) These documents were relied on to provide a starting point for the current study.

In addition, when the study began, the Northeast Corridor Improvement Program (NECIP) was getting underway. NECIP involves an extensive up-grading and extension of the existing electrification facilities in the Northeast. A close liaison with that project office has contributed significantly to this study.

The first investigative effort in the study was a series of workshops held by FRA with representatives of the railroad supply industry, the Association of American Railroads (AAR), electric utility companies and consultants to establish the technical state-of-the-art and to record the viewpoints of industry on railroad electrification.

A number of railroads have recently performed in-depth studies of railroad electrification. This study also relies heavily on information prepared under contract to FRA by Arthur D. Little, Inc.; Mitre Corporation; The Transportation Systems Center; and Unified Industries, Inc. (Ref. 3 thru 7)

The energy implications of electrification were studied in cooperation with the Federal Energy Administration and coordinated with the Energy Research and Development Administration, and again, drawing upon the resources available through consultants, the railroads, and the electric utility industry.

A draft of this report was circulated to the principal study contributors and to those Government entities which have regulatory and/or administrative influence over the subject matter. The comments received were considered and incorporated, as appropriate.

V. FINDINGS

A. Background of Electric Railroads

The use of electricity in railway motive power is neither unusual nor new. Attempts to drive a rail vehicle by electric power were reported as early as 1835. However, it was not until 1879 that W. Siemens built and successfully demonstrated an electric locomotive at an exhibition in Berlin. (Ref. 8) In competing with the steam locomotive, the use of electricity from a stationary generating plant offered an attractive alternative on mountain lines and in underground railroads. In the United States, electrification projects were undertaken as early as 1985 to overcome various operational problems. Terminal and trunk line tunnels were electrified to eliminate smoke, soot, and noise associated with steam locomotives. This led to electrification of the adjoining track. Passenger terminal and suburban services were electrified to speed services and increase track capacity through utilization of the high acceleration capability of electric traction. Heavy freight routes were electrified in mountain territory to increase efficiency, speed, and tractive power, resulting in widespread savings on operation, overhead, and maintenance in comparison with steam operation.

Prior to World War II, the United States led the world in electrified railroads, with its 2,500 electrified route miles constituting one-fifth of the world total. (Ref. 9 & 10) After World War II, the picture changed. The European nations, faced with rebuilding their fixed plant as well as replacing equipment, undertook extensive electrification, aided by the availability of hydro-electric power in mountainous regions in Italy, West Germany, Switzerland, Norway, and Sweden. North American railroads, faced with replacing only worn motive equipment, combined the electrical drive with the diesel engine in the diesel-electric locomotive units that now dominate their motive power fleets. Today, of all the major nations in the world, only the North American countries do not have sizeable portions of track electrified, as shown in Tables 1 and 2. (Ref. 11)

United States railroads and the Federal Government have shown a recent interest in the factors affecting railroad electrification. A joint government/industry task force examined the subject in 1973 and arrived at the following conclusions (Ref. 1):

- Railroad electrification is the only available alternative to diesel-electric operations on high-density, long-haul railroad lines.
- Electrification offers the only feasible means to utilize coal or nuclear power for intercity movements of general freight and passengers.
- Modern rail electrification technology is available for application.

TABLE 1

WORLDWIDE RAILROAD ELECTRIFICATION

COUNTRY	ROUTE MILES ELECTRIFIED	PERCENT OF TOTAL ROUTE MILES
Soviet Union	22,780	27
France	5,520	24
West Germany	5,160	28
Italy	4,950	48
Sweden	4,350	61
Japan	3,860	29
Poland	2,180	15
England	2,070	17
Spain	1,970	23
Switzerland	1,790	99
Norway	1,420	54
Austria	1,320	39
Czechoslovakia	1,210	10
United States	1,162	0.05
Netherlands	1,010	52
Belgium	700	24
Portugal	470	27
Canada	-	nil
Mexico	-	nil

TABLE 2

CURRENT UNITED STATES RAILROAD ELECTRIFICATION

RAILROAD	ROUTE MILES	PROPULSION POWER
Illinois Central Gulf	37	1,500 V DC
Chicago South Shore & South Bend	76	1,500 V DC
Conrail/Amtrak		
ex-Erie Lackawanna	80	3,000 V DC
ex-Penn Central	762	11 KV, 25 HZ AC
ex-Reading	88	12 KV, 25 HZ AC
Muskingum Electric	15	25 KV, 60 HZ AC
Black Mesa & Lake Powell	78	50 KV, 60 HZ AC
Texas Utilities Co.	11	25 KV, 60 HZ AC
	15	25 KV, 60 HZ AC
Present total U.S. electrified miles	1,162	

- While electrification has been shown to have a positive rate of return on the projected investment, electrification of high-density lines has not been widely adopted by American railroads because of more pressing capital requirements or more attractive investment opportunities.
- Railroad electrification presents a number of, as yet, unresolved regulatory problems for railroads and utilities.
- The development of railroad electrification in an orderly and efficient manner can best be facilitated by a joint government/industry program where substantial improvements in national transportation efficiency can be achieved.

B. Cost to Electrify

1. Introduction:

This section presents an analysis of the costs involved in railroad conversion to electrified operations. The major cost factors, which would determine the economic viability of railroad electrification in the United States, are investment items such as catenary, substations, locomotives, civil reconstruction, signaling and communications modifications, and cost items such as diesel fuel, electrical energy, locomotive maintenance and power delivery system maintenance. Ranges of value for unit cost and investment factors were developed and are summarized in this section.

High traffic density rail routes were identified for the purpose of establishing networks of rail routes that are considered potential candidates for electrification. These candidate networks, described in this section, are used as the basis for computing nationwide costs to electrify.

2. System Description:

Railroad electrification in this report denotes using electric locomotives that draw current from an overhead wire by a system of transmission lines and substations, as shown schematically in figure 1.

There is a trend in the thinking of the railroad industry, both carriers and equipment suppliers, toward standardizing on high-volume, single-phase alternating current (AC) power distribution at commercial frequency, 60 Hertz (Hz). Modern railroad electrification, it is generally agreed, would involve supplying either 25 or 50 kilovolts (KV), single-phase, AC power through an overhead wire system, known as catenary, to high-horsepower, silicon-controlled rectifier (SCR) or thyristor locomotives. It is, therefore, this type of system that is discussed in the following sections.

Where overhead clearances are not a problem, the industry would probably standardize on 50 KV, the highest voltage presently used in any railroad electrification to date. (50 KV is being used successfully on the Black Mesa and Lake Powell (BM&LP) Railroad in Arizona.) Use of 50 KV allows substations to be spaced 30 to 40 miles apart on the average, instead of the 15 to 20 mile spacing required at 25 KV. Where overhead clearances are a problem (or existing catenary could be utilized without major modification), it would probably be desirable to electrify at 25 KV.

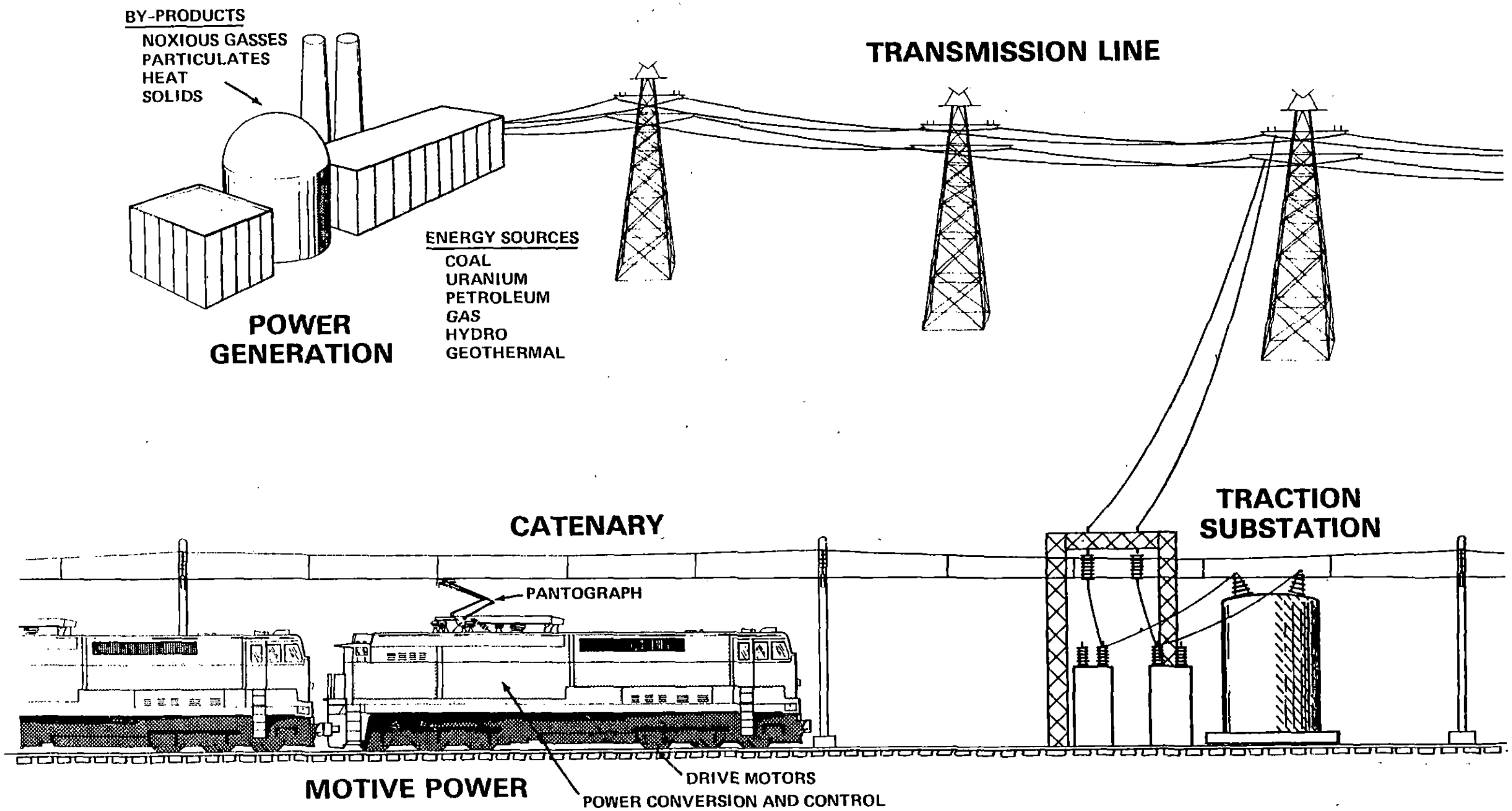


FIGURE 1: COMPONENTS OF AN ELECTRIFIED RAIL SYSTEM

One consideration in picking the voltage level would be to provide the maximally possible interchangeability of equipment. It would be desirable to standardize on 12.5, 25, and 50 KV, which are two-times multiples. Thus, one basic design could be used to accommodate various voltage levels. The majority of the U.S. Class I railroads that have studied electrification have determined that 50 KV would be the most economical voltage level available, except where clearance is a problem.

The freight route parameters selected as a baseline for comparative purposes in this study are listed in table 3.

3. Capital Cost Factors:

It is not possible to establish specific unit costs to electrify existing diesel-electric operations without considering a wide variety of factors that are unique to each railroad. Electrification costs can vary significantly from route to route, even by as much as 3 or 4 to 1, depending on the route characteristics. Ranges of costs were developed for this report representing normal cost variations that could be estimated in each category of investment cost.

While it would be inadvisable to draw conclusions about electrifying any specific route using "average costs", a simple arithmetic average of the "high" and "low" costs developed below provides an accurate "order of magnitude" estimate of the nationwide cost to electrify. A site-specific study should be conducted before proceeding to electrify any particular route. The capital cost factors developed herein are estimated for freight operations only. Electrifying for high-speed passenger service could increase the cost of catenary up to 15 percent above the figures for freight, shown below.

The costs presented in this section are quoted in 1977 dollars and include the cost of engineering, which can vary in the range of five to 15 percent of the actual construction and equipment cost, depending on the complexity and nature of the work involved.

a. Catenary

The installation of catenary is a major factor to be considered when estimating the cost to electrify. There are numerous designs to choose from (Ref. 12); however, for the purposes of this report a constant-tensioned, simple catenary design was assumed (See figure 2).

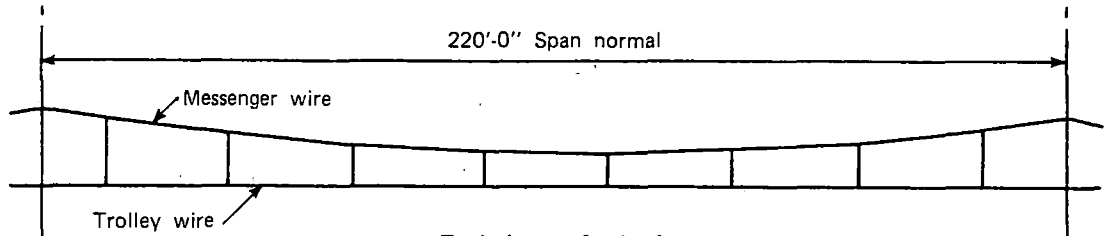
TABLE 3

FREIGHT ROUTE ELECTRIFICATION PARAMETERS

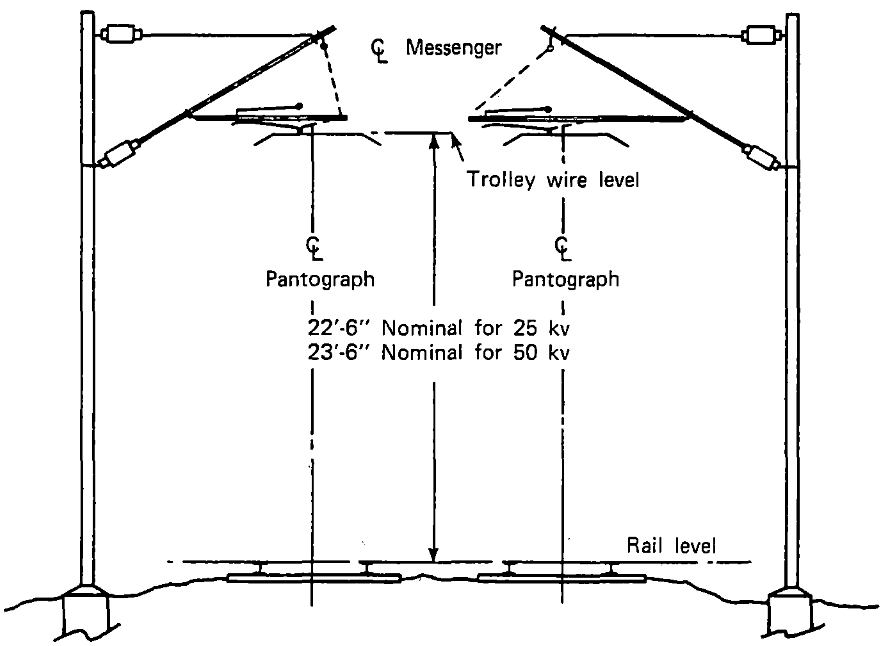
Nominal Voltage	25 KV* or 50 KV
Supply Frequency	60 HZ
Continuous Catenary Rating	1200 Amps @ 25 KV 850 Amps @ 50 KV
Typical Catenary Span (80% Tangent; 20% Medium Curve)	200 feet
Catenary Style (Constant Tension)	80 mph simple
Support Structures	Steel
Contact Wire Height	22' - 6" @ 25 KV; 23' - 6" @ 50 KV
Air Clearance: +Static	10½ inches @ 25 KV; 21 inches @ 50 KV
+Passing	8 inches @ 25 KV; 16 inches @ 50 KV
Substation Ratings: at 25 KV	20 MVA, single track 40 MVA, double track
at 50 KV	40 MVA, single track 80 MVA, Double track
Substation Spacing (average)	20 miles @ 25 KV 40 miles @ 50 KV
Signal System Modifications	Convert to 100 HZ AC track circuits
Signal & Communication Cable	Install underground and/or shield

* Northeast sector routes only.

+ Per American Railway Engineering Association (AREA) recommendations.



Typical span of a simple catenary
The supports may be cantilevers
portals or headspans



Typical catenary cantilever supports (tangent track)

FIGURE 2: SIMPLE CATENARY

At 25 KV, the cost range per route-mile including engineering has been estimated at (Ref. 3, pp 30-32, updated to 1977 dollars):

(1) Single-track route: $64,000 to $143,000/route-mile
(2) Double-track route: $106,000 to $275,000/4oute-mile

The lower figures are for very easy terrain, with access roads throughout, essentially all off-track construction. The higher figures assume rocky, hilly terrain requiring up to 25 percent on-track installation, and include the cost of flagmen, road crews and work trains. Raising catenary voltage to 50 KV could increase costs up to seven percent, but the reduction in costs usually more than offset this amount. The substitution of wood poles could reduce the initial cost of catenary systems, but eventual higher maintenance costs and the likelihood of consequential reduced pole spacing would not encourage their widespread use on major railroad routes. The substitution of concrete poles would usually increase the initial cost of catenary systems. Their use could have a beneficial effect on eventual maintenance costs. (Ref. 3, p. 27).

b. Traction Substation

Power supply to the catenary system of an electrified railroad is accomplished by way of a traction substation which transforms the utilities' transmission voltage, generally ranging from 115 to 345 KV, to the railroad utilization voltage of either 50 KV or 25 KV. There are many site-specific factors which determine the ultimate configuration of a traction substation. The ranges of substation costs estimated for this study are shown in table 4 for single and double track (Ref. 3, p. 40 & 109, updated to 1977 dollars). The variability in costs reflects the degree of flexibility and reliability available to the railroad in operating during failure of poor equipment and the requirement of the utility in certain applications for protection during railroad faults. Substation cost is also dependent on track complexity.

c. Motive Power

The fundamental differences between diesel-electric and straight electric locomotives are shown diagramatically in figure 3. Electric locomotives eliminate the need for a diesel engine and all the associated engine support equipment, using instead, a pantograph and on-board static power conversion equipment to provide the power to drive the traction motors. In today's market, electric locomotives cost more than diesel-electrics by a factor of approximately two to one; however, they are usually twice as powerful, so the cost per rail horsepower (i.e., horsepower available for traction purposes) is roughly equivalent (currently in the range of $180 to $200 per rail horsepower). (Ref. 3, p. 111) On the basis of tractive effort, U.S. built electric locomotives cost about 65 percent more per pound of tractive effort than diesel-electrics. (Ref. 3, p. 19) According to an A.D. Little, Inc. report, this factor works against electric locomotives in low speed service.

TABLE 4

ESTIMATED RANGE OF SUBSTATION COSTS

(Including breaker stations)

	Single Transformer Single-Track-20MVA	Double Transformer Double-Track-40MVA
Estimated cost per substation (25 KV)	$636,000 to $954,000	$1,166,000 to $1,712,000
Estimated cost per route-mile (25 KV @ 20-mile spacing)	$ 31,800 to $47,700	$ 58,300 to $84,800

	Single Transformer Single-Track-40MVA	Double Transformer Double-Track-80MVA
Estimted cost per substation (50 KV)	$813,000 to $1,219,000	$1,569,000 to $2,353,000
Estimated cost per route-mile (50 KV @ 40-mile spacing)	$ 20,300 to $30,500	$ 39,200 to $58,300

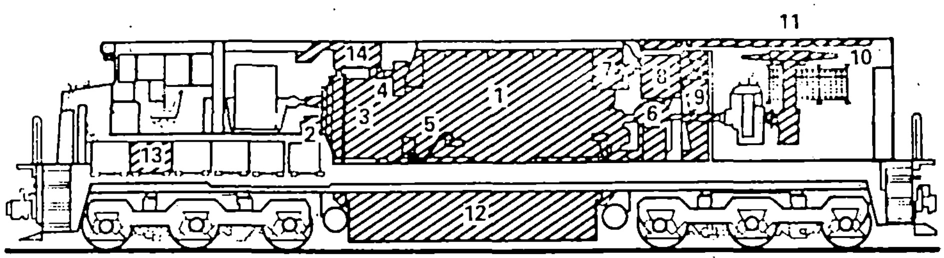
To evaluate properly the economics of an electrification project, it is necessary to determine the quantity and horsepower of diesel locomotives which would be replaced by a similarly determined quantity and horsepower of electric locomotives. On the average, the following quantities of locomotives are required to move 1,000 million gross ton-miles (MMGTM) of freight annually (Ref. 13):

Electric locomotives/1,000 MMGTM

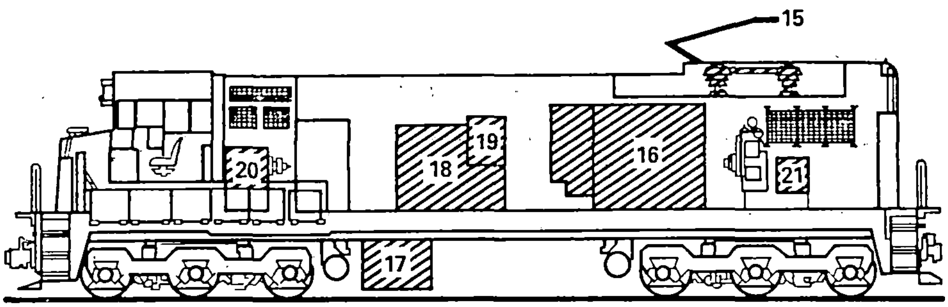
Minimum	Maximum	Weighted Average
1.94	4.22	3.6

Diesel locomotives/1,000 MMGTM

Minimum	Maximum	Weighted Average
2.80	9.90	6.8



Diesel-electric locomotive



Electric locomotive

Electric locomotives eliminate the need for:

1. Diesel engine
2. Auxiliary generator
3. Traction alternator
4. Engine control governor
5. Fuel pump & filter
6. Lube oil cooler & filter
7. Turbocharger
8. Water storage tank
9. Engine air filters
10. Radiator fan
11. Radiator
12. Fuel tank
13. Excitation system
14. Power rectifier

Electric locomotives require:

15. Pantograph
16. Transformer
17. Smoothing reactor
18. Rectifiers
19. SCR and phase control
20. Equipment blower motor
21. Air compressor motor

FIGURE 3: COMPARISON OF ELECTRIC AND DIESEL-ELECTRIC LOCOMOTIVES

If a railroad were able to phase-in the purchase of electric locomotives in lieu of normal diesel-electric locomotive purchases (needed for growth and replacement of old units), then the net cost of new power chargeable to an electrification project would be minimal. This is case-specific and would vary from railroad to railroad. Unless there were an accelerated electrification program in this country, it is anticipated that displaced diesel locomotives could be absorbed by the owning railroad or sold, and the proceeds applied as an offsetting credit against the purchase of new electric locomotives. The resale price would depend on the state of the economy and the demand for diesel motive power at the time the units were placed on the market. If there were an accelerated program to electrify railroads in this country, there must be excess diesel-electric locomotives that could not be absorbed in existing operations. Under these circumstances, net new motive power would represent another cost chargeable to the electrification project.

The economic life of diesel-electric and electric locomotives has been a matter of controversy for many years. (Throughout the study the term economic life is defined as that point at which a locomotive is retired from line-haul operation and either scrapped, rebuilt, or placed in limited local service.) Retirement can be brought about by technical obsolescence, mechanical wear out of major and generally irreplaceable components, or reaching a point at which the cost and time required for maintenance is excessive.

Opinions on the economic life of a modern diesel-electric locomotive vary from 15 to 25 years. For tax purposes, diesels are generally depreciated to scrap value in 11 to 14 years. However, for purposes of this study, an average economic life of 18 years for diesel-electric units was assumed.

Electric locomotives, because of their simplicity (primarily the absence of a diesel engine to wear out), can demonstrate considerably longer economic lives than diesels. On the basis of U.S. and foreign experience, 30 years appears to be an acceptable economic life for electric locomotives and is adopted for the purpose of this study. However, it should be noted that high horsepower electric locomotives would not be suitable for application on secondary lines after being retired from line-haul operation, but diesel-electrics would be

d. Civil Reconstruction

An important cost-factor in railroad electrification is the need to provide adequate vertical clearances. There are two types of clearances to be considered: 1) the distance between the rails and the energized contact wire to permit passage of the anticipated maximum vertical loading gauge (car plus load), and 2) the distance between fixed overhead obstructions and energized catenary. Existing railroad clearances vary considerably. The American Railway Engineering Association (AREA) has suggested a maximum load gauge of 21 feet. While not formally adopted by AREA, a maximum load gauge of 21 feet has been consistently used in recent railway electrification committee correspondence on the subject. However, earlier construction standards resulted in load gauges which have ranged downward to less than 16 feet. The resulting wide variation of clearances would become an important issue on many railroads if they were to become electrification candidates. In anticipation of electrification, the Federal Highway Administration (FHWA) has amended the Federal Aid Highway Program Manual (Ref. 14) to permit clearances in new bridge construction over railroads adequate to accommodate electrified operation with a load gauge of 21 feet. The least-cost option would be to raise bridges or undercut the track only as required to maintain the existing vertical load gauge. However, if increased load gauge were desired subsequent to electrification, the additional modification cost at that time would have to include increasing the catenary height. In such a case, it might be more cost effective to require all bridges to be raised the extra amount at the time of electrification to accommodate future load gauge requirements, but the extra cost of this should not be charged to the electrification project.

For the purposes of this study, detailed estimates of several representative routes were used to develop order-of-magnitude cost factors to provide the necessary overhead clearances. Of all of the costs to electrify, this is the most site-specific, and therefore the most difficult to estimate without surveying the route closely. A mix of the figures can be used on a judgmental basis for each route. The basic cost estimates used are:

Highly developed areas:
$50,000 to $75,000/route-mile
Principally rural areas:
$5,000 to $7,500/route-mile

Tunnel modifications might severely impact this cost in a specific sector but do not represent a major consideration in a nationwide electrification study. Because of the detail of analysis necessary, and the limited number of tunnels involved, tunnel reconstruction has not been included in this section.

e. Signal System Modifications

Without modification, the signaling systems designed and built for steam and diesel operations are almost invariably unsuited for electric operations. Three components of the signal system are usually affected: the track circuit, the wayside signal head and lineside wire. The track circuit and wayside signal head are discussed below. Lineside wires will be addressed in the next subsection.

Most non-electrified railroads use a direct-current track circuit to detect the presence of trains. These circuits are separated from each other through the use of insulated rail joints in the track. Since an electric railroad uses the rails as part of the return circuit for the propulsion current, a system must be devised which keeps the signal circuits separate while allowing the propulsion current to cross the insulated joints. The technique normally employed is to convert the direct-current track circuit to a 100-Hertz alternating current circuit, installing impedance bonds at each insulated joint. Impedance bonds are essentially filters which block the passage of the 100-Hertz signal current while permitting the 60-Hertz propulsion power to pass freely. Grounding of the impedance bonds also improves the performance of the propulsion system.

Wayside signal heads must frequently be repositioned in order to preserve their visibility to the locomotive engineer after the installation of catenary and catenary poles. Although <u>not</u> required by electrification, cab signals are frequently installed by coding the new 100-Hertz track circuits for pickup in the locomotive cab.

Most circuits activating highway crossing warning devices (gates or flashers) have been converted to audio frequency overlays, although some older direct current installations would need to be modified. While signal conversion costs are particularly site-specific and highly dependent on the complexity of track arrangements (Ref. 3 and 15), the following items would cost between $30,000 and $50,000 per single-track mile and between $50,000 and $80,000 per double-track route-mile:

- A new 100-Hz power supply system and transmission line
- Impedance bonds
- New 100-Hz track circuits and repeater sections if existing block lengths are extremely long (1 per 2 miles)
- Shielded cable (explained in the next subsection, Communications Systems Modifications)
- Repositioning wayside signal heads
- Modifying highway crossing warning circuits (1 per mile)

Audio frequency overlays are generally compatible with electrification and could be utilized as long as they do not use a frequency which is a multiple of the 60-Hertz power system or the 100-Hertz signal system.

f. Communications Systems Modifications

Railroad communications systems presently employ lineside open wire, buried cables, aerial cables, radio and microwave systems. While radio and microwave systems are not affected by electrification, all hard-wire systems are subjected to adverse conditions by electrification. The high-voltage catenary power distribution system produces an electromagnetic field while current is flowing through it. This field induces a voltage in any paralleling conductor proportional to the length of exposure and inversely proportional to the square of the distance from the catenary. Existing lineside wire and unshielded cable, paralleling the catenary for long distances, can pick up voltages which can damage equipment or create a hazard to maintenance personnel. Fortunately, this problem can readily be reduced to safe levels by the installation of shielded cable, either buried or on aerial lines. Buried cable is generally favored because it would reduce ongoing maintenance costs as well as the induced voltage problem. Thus, any signal wires, local railroad telephone lines, long distance railroad cables and other communications circuits would have to be checked and modified to provide the proper shielding.

Modern thyristor-controlled locomotives tend to produce relatively large amounts of frequency harmonics, which are then radiated from the catenary and picked up by parallel conductors in a manner similar to that described above. These harmonics can interfere with the operation of cab signal systems and centralized traffic control systems, or produce a lot of noise in general communications circuits. Proper shielding can reduce the harmonic effects and the installation of frequency filters on the locomotives or at the substations will practically eliminate the problem. Relatively infrequent situations may develop on a site-specific basis with long exposures where modifications to non-railroad communications would be required.

In summary, modifications would be required to much of the existing communications system. Since this system is not significantly affected by the track layouts, cost for the changes is computed on a route-mile basis rather than a track-mile basis. The following items would cost between $10,000 and $15,000 per route mile: (The cost of cable burial was included in the signal system modification cost.) (Ref. 3 and 15)

- o Installation of a microwave trunk line system
- o Installation of a fully shielded local communications cable either buried or on poles, depending on terrain.

g. Summary of Capital Cost Factors

There are wide differences in capital costs brought about by geographic location, local terrain, obstructions to be modified, existing operations and types of service. Table 5 gives a total expected range of these investment items in terms of 1977 dollars.

TABLE 5

SUMMARY OF CAPITAL COST FACTORS

Fixed Plant Investment	Single-Track - Dollars Per Route-Mile		
	Low	High	Arithmetic Average
Catenary	$ 64,000	$143,000	$103,500
Substations and Breaker Stations	20,300	47,700	34,000
Signal & Communications Modifications	40,000	65,000	52,500
Civil Reconstruction	5,000	50,000	27,500
Total	$129,300	$305,700	$217,500

	Double-Track - Dollars Per Route-Mile		
	Low	High	Arithmetic Average
Catenary	$106,000	$275,000	$190,500
Substations and Breaker Stations	39,200	84,800	62,000
Signal & Communications Modifications	60,000	95,000	77,500
Civil Reconstruction	7,500	75,000	41,250
Total	$212,700	$529,800	$371,250

It should be pointed out that the above cost factors have been estimated for freight operations only. They represent the expected net investment required in railroad facilities for electrification, not including new motive power or electric utilities connections. Any investment in new motive power would generally be offset by an equivalent credit for diesel-electric locomotive which would be displaced by electrification.

4. Operating Cost Factors:

The viability of railroad electrification depends primarily on the savings generated by reduced operating costs. The major electrified operating costs are electric energy, electric locomotive maintenance and power delivery system maintenance. The major diesel operating costs which these would replace are diesel fuel and diesel locomotive maintenance.

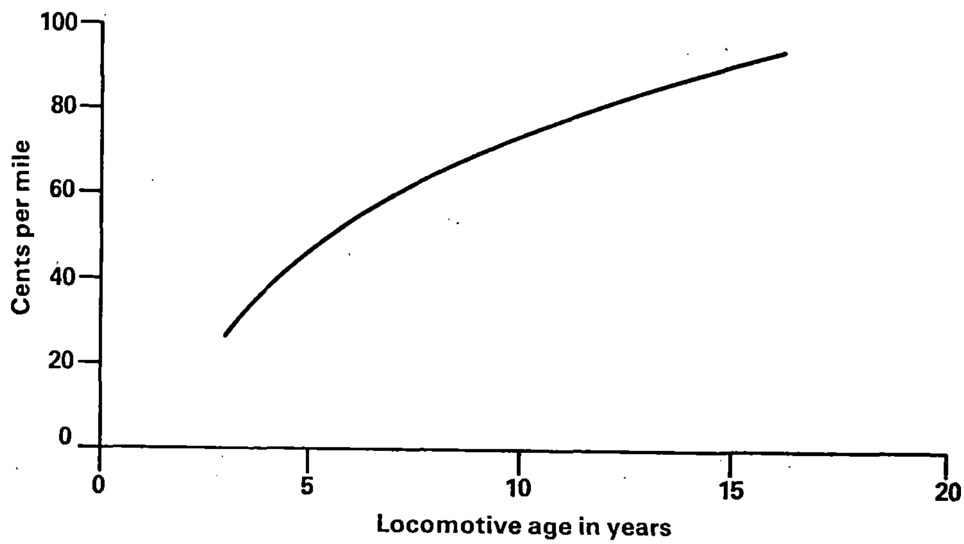
At the present time, the prices for diesel fuel and electric energy are about the same, but there are factors which indicate that this condition is not a stable one. While it appears inevitable that all fuel costs will rise, the relative rates at which they do so is not as certain.

Considered more predictable than fuel costs are the motive power maintenance costs. Usually based on a flat cost-per-locomotive mile, maintenance of an electrified rail system would cost approximately half of a comparable diesel system. (Ref. 16 and 17) With electrification, the fleet size could be reduced by as much as 50 percent causing a corresponding reduction in maintenance time and costs. This is a factor of major consequence when one considers that diesel maintenance is in the same range per unit-mile as fuel. (Ref. 3)

Both fuel and maintenance costs are examined in detail in this section. Catenary and substation maintenance, characteristic of an electrified operation only, is also discussed; however, the impact of this specialized maintenance is minimal when compared to energy and locomotive maintenance costs.

a. Motive Power Maintenance

The maintenance costs of a fleet of electric locomotives would be significantly lower than the maintenance costs of an equivalent fleet of diesel-electric locomotives. Although, there is some disagreement in what constitutes "an equivalent fleet," it is generally believed that, on an equal tractive effort basis, an electric locomotive would have from 40 to 60 percent of the maintenance cost of an equivalent weight diesel-electric locomotive. It is also generally agreed that where tractive effort is not a limiting factor and locomotive units could be assigned based on total consist horsepower (i.e., equal horsepower), it would be possible to use fewer electric units than diesel units, thereby achieving a further maintenance cost advantage. In practice, the actual percentage would depend on many factors including the age, mileage, duty cycle and type of locomotives considered and the kind of service involved. The per-mile cost of diesel locomotive maintenance can vary significantly with unit age. A characteristic curve showing the relationship between age and per-unit maintenance cost is shown in figure 4, derived from a typical railroad's experience, expressed in 1975 dollars. (Ref. 3, p. 91)



Data Source: A.D. Little, Inc., Ref. 28

FIGURE 4: TYPICAL DIESEL LOCOMOTIVE MAINTENANCE COST VARIATION WITH AGE

To be consistent, diesel and electric locomotive maintenance costs should be calculated on a comparable basis. On several railroads the cost of rebuilding a diesel engine is capitalized rather than expensed. There is no major equipment section on an electric locomotive which would be so capitalized during a rebuilding process. To eliminate any ambiguities of this type, we have considered that all routine maintenance, overhaul, and major rebuilding costs would be expensed on a per-mile basis.

Over the expected average age of a locomotive fleet (including the cost of major engine overhauls) and allowing for variations in the level of maintenance for various railroads, a range of $0.53 to $0.71 per mile (in 1977 dollars) appears reasonable. (Ref. 3, p. 90) To this must be added the cost of servicing, which is in the range of ten percent of the above costs. This gives a total maintenance cost estimate in the range of $0.58-$0.78 per unit mile for a typical six-axle 3000 hp diesel, excluding the direct cost of fuel and lube oil. Lube oil runs about five percent of diesel oil costs. The five percent figure assumes that the price of lube oil is four times that of diesel fuel and lube oil consumption is an average 1.25 percent of diesel fuel consumption. Manufacturers have generally indicated somewhat lower figures, but their figures usually do not include engine house servicing and supplies, and are not necessarily representative of locomotive life-cycle maintenance costs. (Ref. 13, p. 648)

There is no established data base for modern electric locomotives in the United States at the present time, so comparisons are difficult to make. An analysis of diesel and electric locomotive components requiring periodic maintenance reveals why the maintenance cost of an electric should be substantially lower than a diesel-electric locomotive. As shown in figure 3, the bulk of the moving, wearing parts and replaceable renewal elements, such as fuel and air filters, are eliminated on an electric locomotive. The parts peculiar to an electric locomotive are, by contrast, generally rugged, static, non-wearing items such as the power transformer and the static thyristor power supply. This equipment is long-lived and requires little maintenance other than routine inspection. The electric locomotive's lower maintenance characteristics also permit a reduced spare parts inventory with the attendant reduction in the carrying cost of that inventory. However, railroads that electrify their main lines would still operate diesels in branch line and local service; thus, two sets of inventory parts -- one for electrics and one for the remaining diesels -- would be required.

It is reasonable to expect that efficient United States railroad shops could achieve a maintenance cost of $0.29 per mile (in 1977 dollars) for modern electric locomotives in high-speed, line-haul service. (Ref. 3, pp. 91-96) Comparing this to the average maintenance cost of $0.68, as computed above, the electric unit maintenance would be about 40 percent of the diesel. (Ref. 13, p. 648). Any reduction in fleet size would have to be applied to the 40 percent figure to arrive at an overall fleet maintenance comparison. While these figures are not necessarily representative of any particular route, they are believed to be reasonable, current averages. In this report's economic analysis, these values are assumed to be base figures and the effect of variations in these assumptions is investigated by means of sensitivity analyses.

Maintenance of electric locomotives would require only a minimum of additional capital equipment. Bays of existing diesel shops or shops scheduled for replacement or expansion could be equipped for this purpose. Because this represents a very small incremental expenditure, most of which would be offset by reducing the need for additional diesel shops, it has not been included as an investment line item.

b. Signal and Communications System Maintenance

The signal and communication systems employed in conjunction with an electrified railroad would generally be more complex and costly to maintain than those currently employed in non-electrified territory. However, the added cost of this maintenance would not be significant compared to the other operating cost factors discussed here and has not been considered in the economic analyses which follow.

c. Catenary and Substation Maintenance

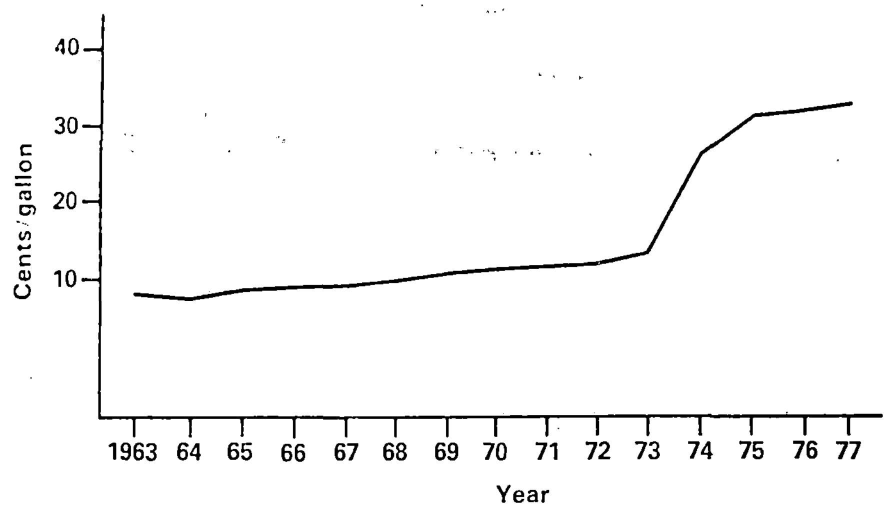
The annual cost of catenary and substation maintenance is subject to variation with terrain, climate, pantograph passes, age, track complexity and numerous other factors. It would not, however, be a major cost item. The combined cost of catenary and substation maintenance has been estimated to be about $1,500 (updated to 1977 dollars) per track-mile per year. (Ref. 3, p. 114)

d. Fuel and Energy

One of the most important, yet least certain, potential operating cost savings with electrification concerns energy. Future prices of energy and fuel are very difficult to predict because of the influence of political and economic pressures, as well as certain supply and demand.

The 1977 prices for energy sources and reasonable projections as to long-term changes which may occur yield a conservative estimate of the savings likely with electrification. Two sources of information, "Energy Costs for Railroad Electrification" by A.D. Little, Inc. (Ref. 4) and the "Federal Energy Administration 1976 National Energy Outlook", (now the Department of Energy) both project a differential in the escalation rates of oil and electricity prices, with oil becoming slowly, but steadily, more expensive than electricity. A.D. Little's estimates are expressed in terms of current (inflated) dollars; DOE's projections are made in terms of real dollars. When this difference is taken into account, their estimates are roughly equivalent.

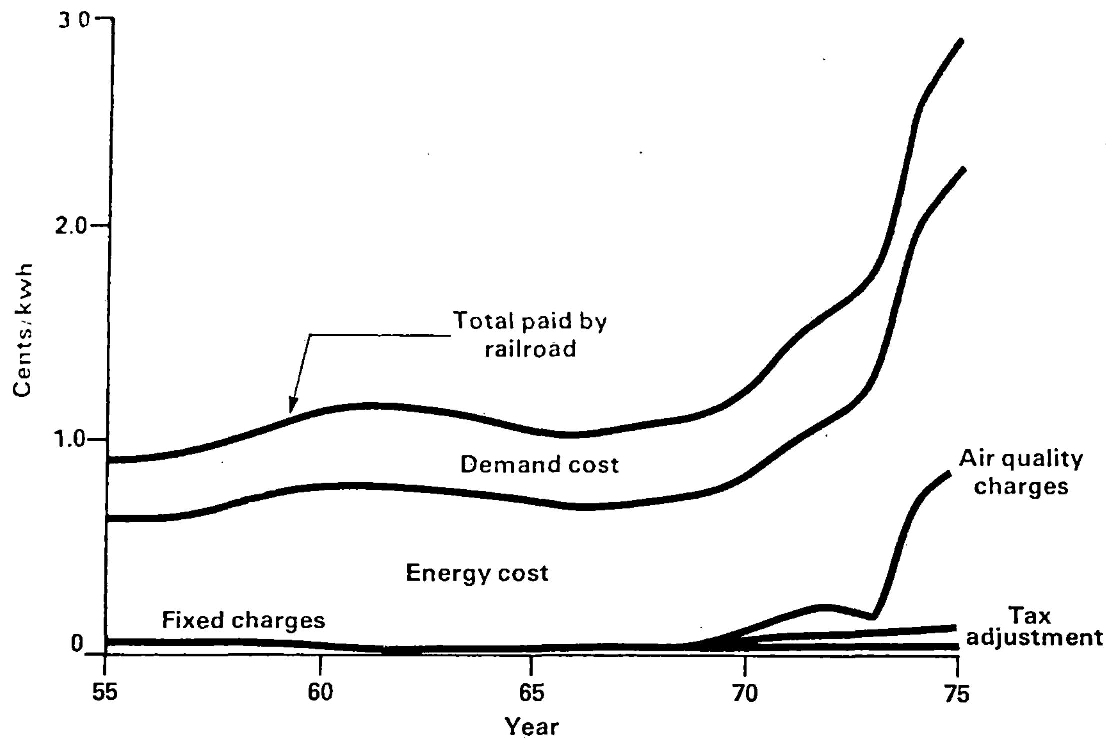
Railroads have historically viewed the amount of fuel consumed a minor item of concern. However, since 1973 the picture has changed with the cost of fuel tripling, as illustrated by figure 5. Fuel now consumes about seven percent of every railroad revenue dollar according to the Association of American Railroads "Yearbook of Railroad Facts," 1977. A.D. Little, Inc., in their report on "Energy Costs for Railroad Electrification," predicts that railroad diesel fuel prices (in current dollars) will increase at an average annual rate of 7.6 - 7.9 percent per annum over the next 25 years. (Ref. 4) In real dollar terms, DOE predicts oil prices will continue to rise at an average annual rate of about 1.5 percent per year between 1980 and 1990. This projection was made using DOE's "Base Case" assumptions in its Project Independence Evaluation System (PIES) model as of April 14, 1977, and does not include the provisions of the pending National Energy Act.



Source: AAR, Yearbook of Railroad Facts, 1977 edition

FIGURE 5: COST OF DIESEL FUEL TO U.S. RAILROADS

In the past four years, electricity prices have also increased, due, in part, to rising fuel prices, and also to more stringent air quality standards for electric utilities. Figure 6 shows the average cost of electricity for electrified operations of the Penn Central Railroad and reflects how the cost of railroad traction power has virtually tripled in the last 10 years. (Ref. 5)



Data Source: Penn Central Railroad, Ref. 39

FIGURE 6: AVERAGE COST OF ELECTRICITY FOR PENN CENTRAL RAILROAD ELECTRIFIED OPERATIONS

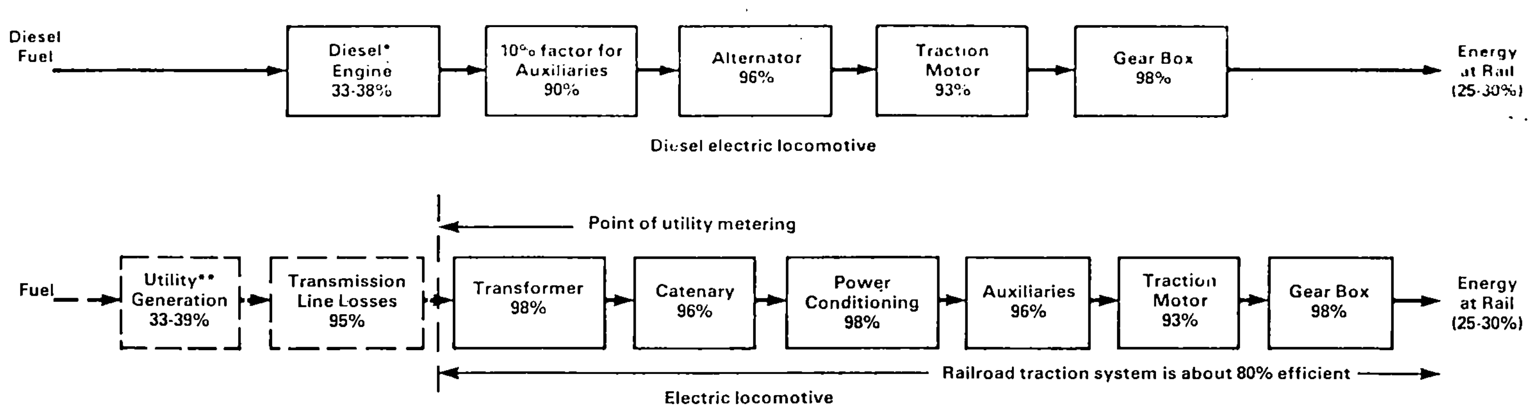
Fuel prices for electric energy generation are expected to continue to rise to varying degrees. The use of coal and uranium as the principal electric generation fuels appears to be necessary for reasons of availability and cost. A.D. Little, Inc. has estimated that coal will escalate in price about 7.5 percent per year, and uranium oxide at a rate of 7.2 percent per year, for the next ten years (Ref. 4). Use of oil and gas for base-load electric power generation is expected to be substantially reduced in this period. The weighted increment of electrical energy production (including hydro) has been estimated (by A.D. Little, Inc.) to escalate at an annual rate of 5.3 percent per year for the next ten years and climb at a compounded annual rate of 6.6 percent thereafter. (Ref. 4) DOE estimates that the price of electricity will increase (in real terms) about one percent per year between 1980 and 1990. DOE projections as of April 14, 1977, were made using their "Base Case" assumptions.

The cost of industrial power varies widely throughout the United States. Because of the uniqueness of the loads that would be imposed on electric utilities by electrified railroads, specialized rate structures would probably be established by the various State regulatory commissions. It is expected railroads would have to pay, on the average, between 6.5 and 10 percent more than the going industrial rate (and up to 20 percent more on lower-density lines) for their traction power. (Ref. 4) The factors affecting rates that would be charged to electrified railroads are discussed in a later section of this report.

To compare the cost of energy consumed by electric and diesel-electric locomotives on an equal basis, both diesel fuel and electric energy costs should be calculated in terms of cost per unit of energy at the drive wheels, i.e., at the rail. Figure 7 shows an estimate of the energy efficiency of the components of diesel-electric and all-electric operation. The net efficiency of each is between about 25-30 percent from the point of fuel "in the tank" to the point of useful work at the rail. For the purposes of this study, a net efficiency of 30 percent was assumed for each system, denoting equal energy consumption per gross ton-mile of freight moved.

Table 6 summarizes projected diesel fuel costs at the rail on a regional and national basis. The cost of fuel in the tank is converted to cost of energy at the rail by dividing by the efficiency factor of 0.30 and assuming 0.14 MMBTU/gal. (Ref. 4, appendix B) Table 7 also summarizes the electric energy costs at the rail on a regional and national basis with the efficiency of electric operation from the point of utility billing to the rail assumed to be 0.80. Figure 8 is a plot of the data shown in the two previous tables, and represents a comparison of the estimated national average cost of energy for diesel and electric operation at the rail, weighted to reflect projected railroad consumption on a regional basis. A crossover is predicted in the 1977-78 time period, after which railroad energy costs are expected to be reduced by converting to electrified operation. (The shaded area represents projected potential savings in energy costs by converting to electric operation.)

In summary, there would be little or no net energy savings with electrification, based on a comparison of relative conversion efficiencies, although substantial savings in energy costs might be realized over time. In the long run,



*Diesel engine conversion efficiencies based on following:
33%—typical railroad duty cycle; 38%—maximum at 8th notch

**Utility conversion efficiencies at full load are based on the following heat rates:
33%—10,500 Btu/kwh; 39%—8,700 Btu/kwh

Data Sources: A.D. Little, Inc., General Electric Company and General Motors Corp. (EMD)

FIGURE 7: RAILROAD ENERGY CONVERSION EFFICIENCY

TABLE 6

DIESEL FUEL COST PROJECTIONS

(¢/KWH AT THE RAIL, CURRENT DOLLARS)

Region	1975	1980	1985	1990	2000
East Coast	2.39	3.83	5.83	8.19	16.21
Gulf Coast & Midwest	2.37	3.39	5.96	8.39	16.62
West Coast	2.36	3.09	5.70	8.03	15.97
Weighted National Average	2.37	3.38	5.85	8.23	16.32
Reference (¢/gal in tank)	(29.18)	(41.61)	(71.89)	(101.21)	(200.71)

Data Source: A.D. Little, Inc., Ref. 46

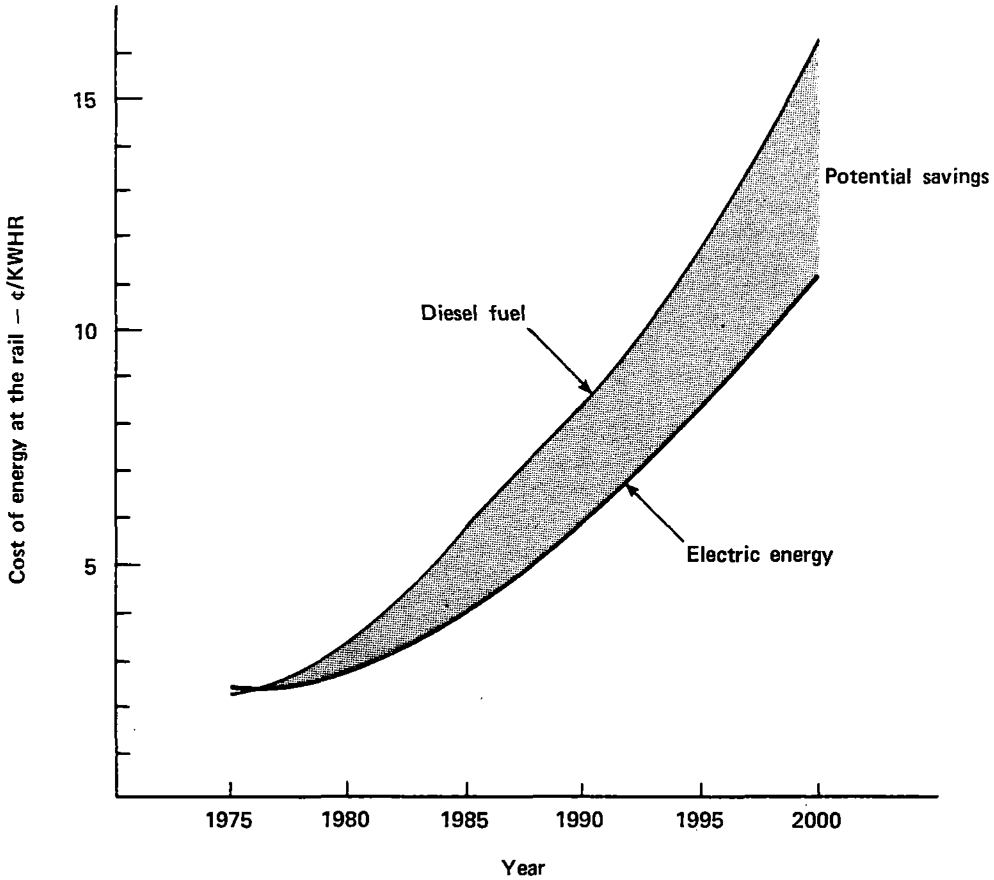
TABLE 7

ELECTRICAL ENERGY COST PROJECTIONS

(¢/KWH AT THE RAIL, CURRENT DOLLARS)

	1975	1985	2000
New England	4.41	6.65	16.84
Middle Atlantic	3.81	5.53	15.12
East North Central	2.74	4.48	12.44
West North Central	2.75	5.22	12.58
South Atlantic	3.08	3.97	13.68
East South Central	2.19	3.78	9.76
West South Central	1.98	3.77	10.17
Mountain	1.91	3.55	9.01
Pacific	1.87	3.35	8.73
Weighted National Average	2.42	4.02	11.10

Data Source: A.D. Little, Inc., Ref. 46.



Data Source:A.D. Little, Inc.
(Ref. 44)

FIGURE 8: COMPARISON OF RAILROAD DIESEL FUEL AND ELECTRIC ENERGY COST PROJECTIONS

electric energy is expected to be less expensive than diesel fuel for railroad operations, although, historically the price of electricity for railroads has risen just as fast as the price of diesel fuel.

e. Summary of Operating Costs

Major operating costs identified in the preceding paragraphs are summarized in table 8. It has been shown that operating costs could be reduced by converting to electrified railroads. However, a major factor related to operating costs is that of traffic density: the higher the traffic density, the greater the potential for savings and the higher the return on investment. Therefore, current traffic levels and projected traffic growth have a major influence on the viability of electrification.

TABLE 8

SUMMARY OF OPERATING COSTS

Average Operating Cost Factors	1977 Cost in Dollars
Diesel Locomotive Maintenance	\$0.68/unit mile
Electric Locomotive Maintenance	\$0.29/unit mile
Catenary & Substation Maintenance	\$1,500.00/track-mile/year
Diesel Fuel (at rail)	\$0.27/KWH
Diesel Engine Lube Oil	5% of fuel cost
Electric Energy (at rail)	\$0.27/KWH

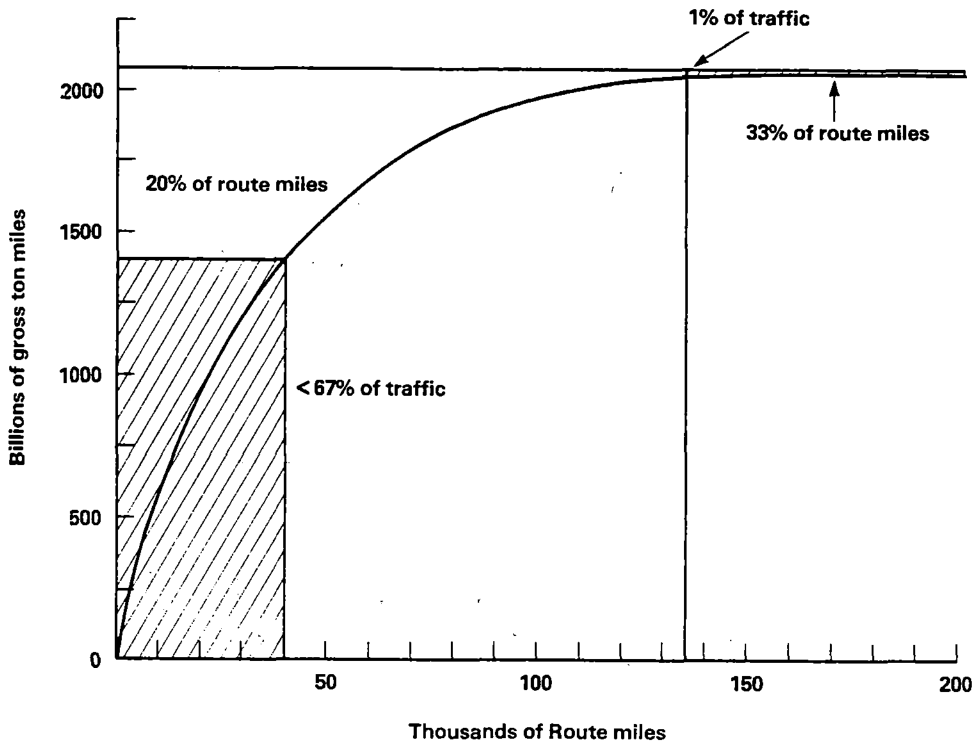
The cost of fuel is another factor affecting any potential savings in operating costs. The most critical aspect of the fuel-factor is the differential in escalation rate between diesel fuel and electric energy.

5. Electrified Railroad Networks:

a. Introduction

In describing the physical characteristics of the U.S. rail system, it is convenient to use the characteristics of the Class I railroads. These companies dominate railroad statistics and provide a good evaluation of the factors that reflect the position of the railroad industry in the United States transportation picture.

The Section 503 Report revealed that Class I railroads operate about 193,500 miles of route. (Ref. 18, p. 52) Total miles of track, including multiple main tracks, sidings, and yard tracks owned by both line-haul and switching and terminal companies, totals about 325,000 miles. Twenty percent of the mileage accounts for over 67 percent of the total traffic. (Ref. 18, pp. A2-2) On the other hand, the most lightly used, one-third of the routes account for only one percent of the traffic. (Figure 9)



Source: FRA 4R Act, Sec. 503 Report

FIGURE 9: A CORRELATION OF RAIL FREIGHT CARRIED AND ROUTE MILES FOR CLASS I RAILROAD LINES IN THE UNITED STATES

The intercity rail passenger network extends over 28,000 route-miles in the 48 contiguous States and uses main lines primarily dedicated to freight. Class I railroads account for almost 60 percent of the total rail passenger-miles, largely in commuter service. Amtrak and Auto-Train TM Corporation account for the remaining 40 percent of total revenue passenger-miles and 77 percent of intercity rail passenger-miles.

The capital investment required to electrify a rail line necessitates high utilization in order to provide an attractive economic return or a substantial energy benefit from electrification. The fixed plant investment is basically a function of the route length and the existing characteristics of the line (i.e., number of tracks, type of signaling system, and proximity to existing commercial power facilities; the sizing of the motive fleet, changes in operating costs, and the energy consumption are largely a function of the traffic). Thus, since a convenient measure of route utilization is traffic density (annual traffic between two points in ton-miles divided by the route length in miles), this study identified these high-density lines with suitable operational characteristics for electrification. The identification of these rail lines was performed at a level of detail sufficient to assess the cost of electrification, the petroleum fuel savings, the electricity demand, and the environmental impact of the conversion.

b. Methodology

For this study, Mitre Corporation identified and documented high-density candidate routes for electrification (Ref. 5). Their primary source of information was the data base compiled by DOT/FRA, Section 503 report (Ref. 18). Line segments with a traffic density of at least 20 MGT per year were identified on a railroad-by-railroad basis, each labeled with an FRA-established Line Identification Code (LIC). The high-density line segments were then developed by Mitre into high-density routes for individual railroads. End points for these routes were established at locations that would be logical terminals for the railroads' electrified operations. These end points were generally major classification yard locations or major traffic generation points. In the process of establishing a route, the logical segments suitable for electrified operations emerged and isolated, high density stretches were dropped.

c. Candidate Networks

Mitre classified the candidate routes over two categories: Service Level 1, denoting routes with a traffic density generally over 40 MGT; and Service Level 2, indicating other high density routes, generally with a traffic density of 20 MGT to 40 MGT which could be suitably operated as electrified lines. Figure 10 shows candidate routes with suitable characteristics for electrified operations.

Service Level 1 routes, taken together, form a fairly basic network of 11 route segments. These 11, with branches and secondary routing totaling 9,817 miles, generally carry 40 MGT annually.

Service Level 2 routes greatly extend the network established by Service Level 1. Sixty-six basic routes are included. These routes, taken together with Service Level 1, would form a system of 39,988 route miles. (The sum of the individual route mileages is somewhat higher because portions of routes are duplicated.)

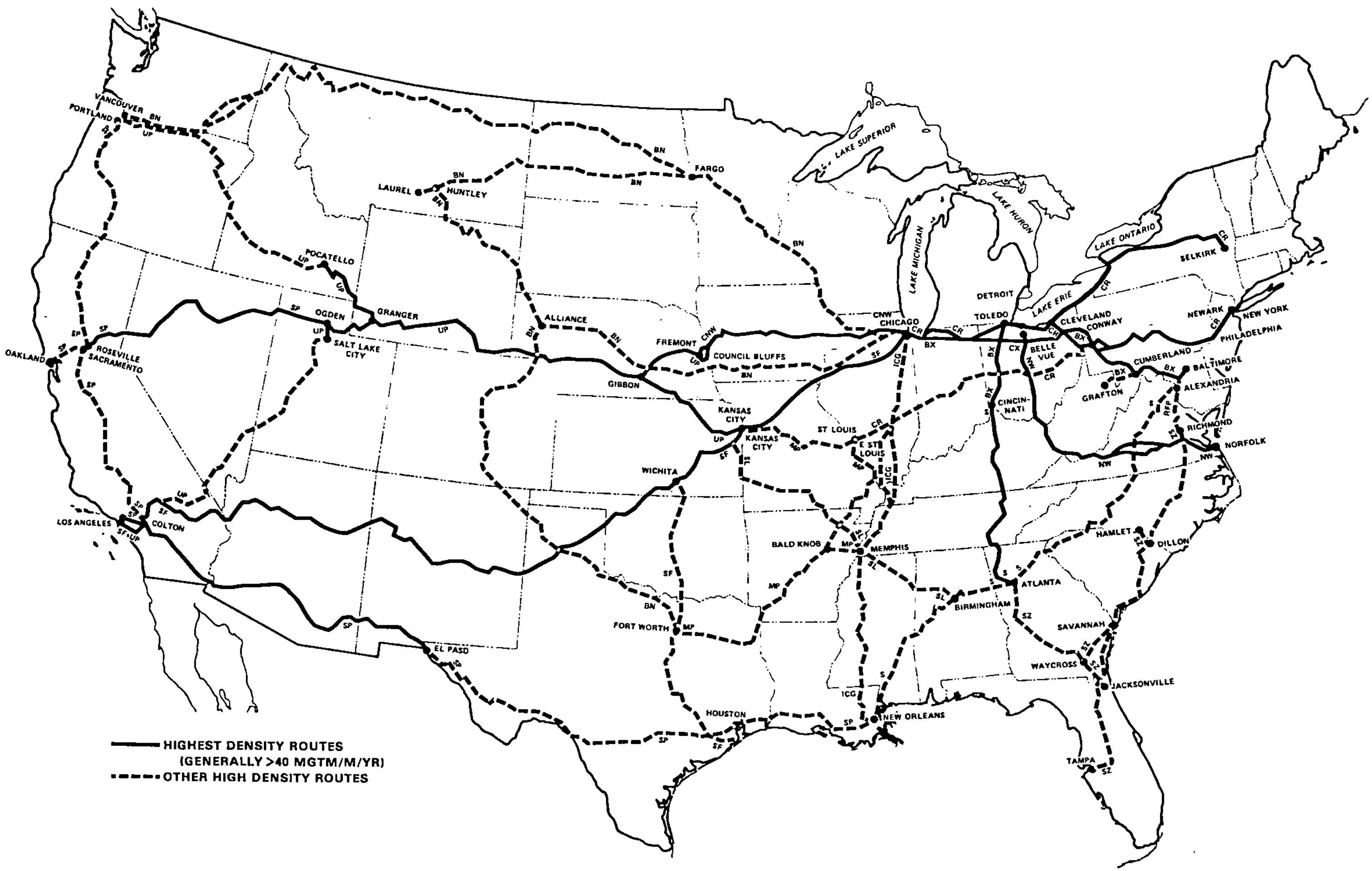


FIGURE 10: BASE NETWORK - ROUTES WITH SUITABLE CHARACTERISTICS FOR ELECTRIFIED OPERATIONS

An intermediate service level, comprised of approximately 26,000 route miles, was established by FRA for the purposes of making further analyses for this study. This network, which carries just over 50 percent of the nation's rail freight traffic (measured in ton-miles) includes all of Mitre's Service Level 1 and about half of its Service Level 2 routes. To simplify their use in the ensuing discussions, these networks will be identified as Networks, 1, 2 and 3. (table 9)

TABLE 9

CANDIDATE NETWORKS

Label	Origin	Route Mileage
Network #1	Mitre Service Level 1	9,817
Network #2	Mitre Data; FRA Route Selection	25,861
Network #3	Mitre Service Levels 1 & 2	39,988

An attempt was made in structuring these networks to reflect each railroad's operation. (The railroad identified for each route indicates the operating railroad.) If a route branches to two or more terminals, the branch routes were included if they support the electrified operations. If a railroad splits its traffic on two separate lines over a portion of a longer route, both lines were included.

The networks developed here represent only an initial attempt to identify a nationwide system of rail routes that are possible candidates for electrification. No further significance should be attributed to this selection.

d. Nationwide Cost to Electrify

The capital cost factors developed earlier in this section were applied to all three networks to arrive at nationwide, order-of-magnitude, cost estimates for electrification. Assuming an arithmetic average cost of $217,500 per single-track route mile and $371,250 per double-track route-mile, and assuming that the networks are composed of the following percentages of single and double track: Network #1: 40 percent single track; 60 percent double-track; Network #2: 60 percent single track; 40 percent double-track; Network #3: 70 percent single track; 30 percent double track; the order of magnitude cost to electrify these networks would be as shown in table 10. These percentages are based on an analysis of the existing route characteristics, compiled by FRA for the 4-R Act Sec. 503 report (Ref. 18) by Line Identification Code (LIC).

TABLE 10

NATIONWIDE COST TO ELECTRICITY

	Approximate Route Miles	Estimated Cost (1977 dollars)
Network #1	10,000	$3 billion
Network #2	26,000	$7 billion
Network #3	40,000	$10.5 billion

These costs represent the expected net investment required in railroad facilities for electrification, and do not include new motive power or electric utility connections.

It is estimated that Network #1 would require a fleet of roughly 1,800 new electric locomotives (rated around 5,000 horsepower each) to handle the 500 billion gross ton-miles of traffic the network currently carries. This assumes 3.6 electric locomotives would be required per annual one billion gross ton-miles of freight moved, and is based on estimated 1975 traffic levels. At today's price of roughly $1 million per locomotive, this would represent an investment of $1.8 billion. In turn, it is estimated that about 3,400 diesel-electric locomotives (rated around 3,000 horsepower each) would be displaced or not purchased with the complete electrification of Network #1. This assumes 6.8 diesel-electric locomotives would be displaced per annual one billion gross ton-miles of freight moved by electrics. These would be phased-in over the period of construction, which would probably be about 15 years, assuming an installation rate of about 1,000 route miles per year and a five-year lead time prior to initial operation.

On the same basis, Network #2 would require a fleet of roughly 3,400 new electric locomotives (rated around 5,000 horsepower each) to handle 945 billion gross ton-miles of freight, at a price tag of about $3.4 billion. Approximately 6,400 diesel-electrics would be displaced or not purchased with complete Network #2 electrification. The cost of new electric motive power is expected to be largely offset by an equivalent credit in diesel motive-power investment which could be saved when electrifying. Network #3 motive power was not calculated since this network does not appear economical under any foreseeable circumstances.

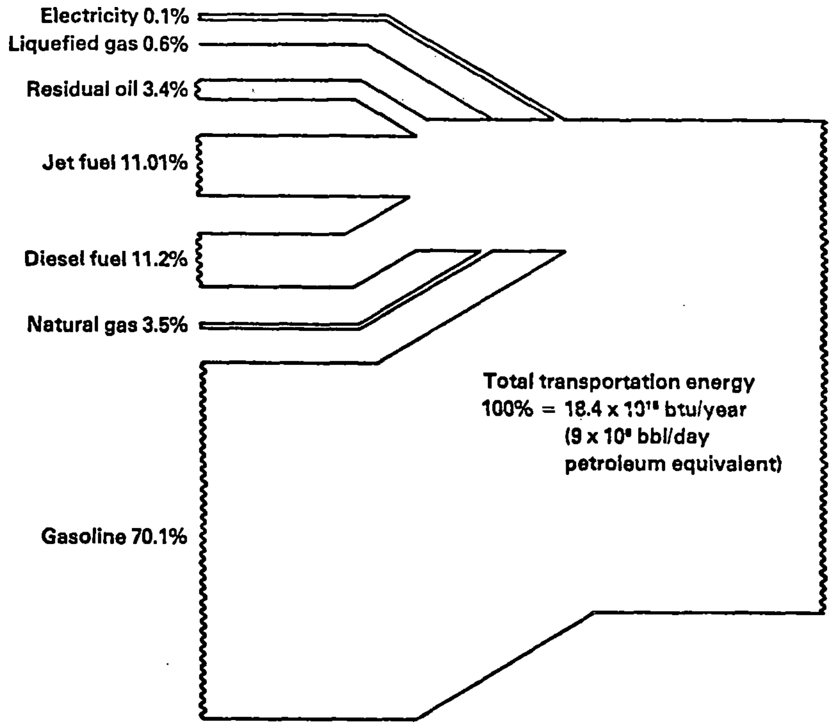
Electric utility connection costs will vary widely from one locale to the next, depending on the need for new transmission line extensions and reinforcement system. An estimated national average utility connection cost of $20,000 per rail route-mile has been computed for Networks #1 and #2 with most of this cost probably passed onto the railroad. However, since it is not clear how this cost would be amortized, it has been included in the net railroad facilities investment figure shown above.

C. Energy Effects of Railroad Electrification

1. Introduction:

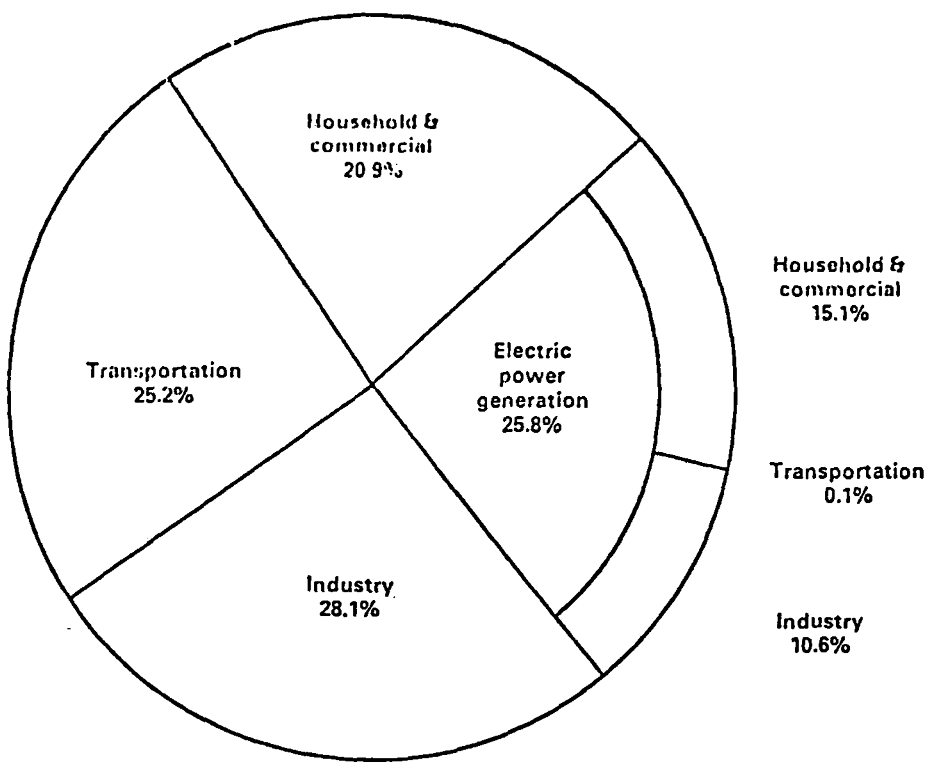
Petroleum use currently meets about 47 percent of our nation's energy needs, and dependence on petroleum imports, currently at a record high level, is still growing, reports the Wall Street Journal in an article dated March 15, 1977. In 1976, the nation imported roughly 41 percent of its oil at approximately $36 billion, up from $3.7 billion spent on imported oil in 1971. (Ref. 19) The fuel, almost entirely petroleum (figure 11), consumed for freight and passenger transportation amounts to approximately 25 percent of the total U.S. energy consumption (fig. 12), or roughly half of the petroleum used in the nation, according to Mitre Corporation (Ref. 5).

Figure 13 illustrates the end-use distribution of transportation energy. More than half the energy used in transportation goes to passenger travel by automobile, while the railroads account for only 3.4 percent of transportation energy consumption, or less than two percent of the nation's total use of petroleum. The nearly total reliance on petroleum by all transportation modes makes the supply of crude oil critical to a continuation of present transportation practices. Any short-term interruption in the supply could create disruptions; the long-term supply picture indicates that, eventually, changes will occur.



Data source: U.S. Dept. of the Interior

FIGURE 11. U.S. TRANSPORTATION ENERGY BY TYPE OF FUEL (1975 ESTIMATED)



Data Source: U.S. Dept. of Interior

FIGURE 12. U.S. TOTAL ENERGY BUDGET, 1976

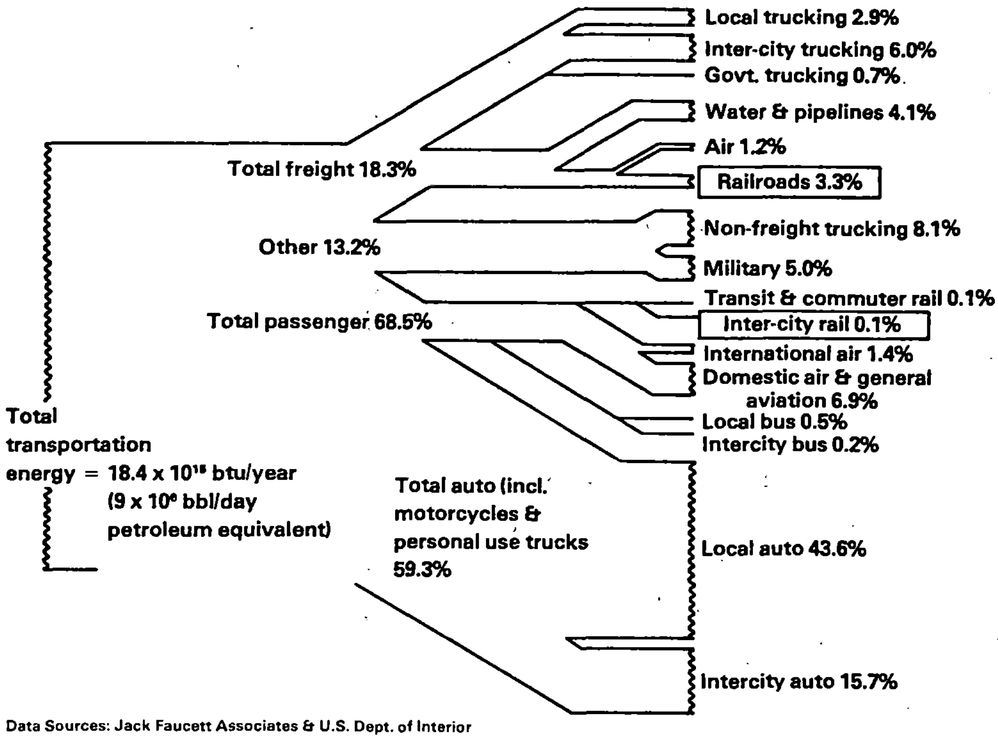


FIGURE 13: U.S. TRANSPORTATION ENERGY BY MODE (1975 ESTIMATED)

2. Energy Consumption:

The energy effects of railroad electrification can be measured by the amount of additional electricity that must be generated for electrified railroad operations and the corresponding savings in diesel fuel. To calculate these effects, Mitre Corporation developed a computer simulation program with energy consumption estimates made for the candidate routes (Ref. 5). Both potential diesel fuel savings and electrical energy consumptions were computed on a regional and nationwide basis, as was a comparison of electrical energy requirements with total existing and future projected electric utility power generation. Fuel sources for electricity generation are identified, and estimates of power company coal, oil, and natural gas requirements to support nationwide railroad electrification are presented.

a. Diesel Fuel Savings

The railroads currently consume about four billion gallons of diesel fuel annually with about 90 percent going into road freight service. (Ref. 20) Railroad yard switching and passenger service consume the remaining ten percent. In order to estimate the total potential amount of oil that could be saved through electrification, the fuel consumption predictions for traffic that could be converted to electrified operations on Networks #1 and #2 were estimated (tables 11 and 12) by Census Region (figure 14) and nationwide. The totals assume that the entire electrified networks are already in place for the years shown. The nationwide figures are summarized in figure 15. (The total railroad fuel consumption is based on four billion gallons consumed in 1975 with a constant growth factor of two percent.)

Any actual shift in railroad motive power energy consumption, from petroleum to a mix of fuels resulting from electrification, would occur only as fast as new electrification facilities and equipment could be installed. At a conversion rate of 1,000 route miles per year, electrification of a 26,000-mile network would take over 30 years to complete, assuming a period of roughly five years needed for planning, design, and construction prior to operating the first 1,000-mile segment. Obviously, the petroleum savings from such an electrification program would be relatively gradual, reflecting the pace of the conversion process.

Electrification of each 1,000 miles of high-traffic-density-railroad route would save roughly 80 to 90 million gallons of diesel fuel annually. Based on this rate (1,000 route miles per year), with the first segment going into service in 1983, the associated diesel fuel savings would be as indicated by the dotted line in figure 14.

b. Electrical Energy Consumption

The Mitre Corporation study (Ref. 5) estimated projected potential energy consumption for electrification on a route-by-route basis is similar to the diesel fuel calculations. The Network predictions, i.e., for traffic that could be handled by electronic locomotives on Networks #1 and #2, are shown in tables 13 and 14 by Census Region and nationwide. Again, these predictions assume that the respective electrified networks are in place for the years indicated. Actual consumption would be proportional to the rate of electrification conversion.

It should be noted that the electricity consumption figures developed here are based on railroad performance equal to the existing diesel operated system,

TABLE 11

NETWORK #1 DIESEL FUEL CONSUMPTION

Census Region	Route Miles	1975 Traffic (1000 MMGTM/year)	Estimated Diesel Consumption, Millions of gals./year			
			1975	1980	1985	1990
MA	1243.10	68.31	108.75	125.06	143.88	165.62
SA	1780.80	87.60	154.51	173.92	196.09	221.28
ENC	1649.30	86.24	175.93	195.91	218.23	243.05
ESC	1084.60	55.06	74.87	85.84	98.47	113.10
WNC	344.00	16.81	28.97	32.59	36.68	41.26
WSC	340.10	15.96	39.25	43.16	47.45	52.17
MTN	2665.20	138.44	294.66	321.38	350.89	383.27
PAC	709.60	34.03	72.69	78.25	84.30	90.76
USA	9816.70	502.47	949.64	1056.13	1175.98	1310.49

Data Source: Mitre Corporation

TABLE 12

NETWORK #2 DIESEL FUEL CONSUMPTION

Census Region	Route Miles	1975 Traffic (1000 MMGTM/year)	Estimated Diesel Consumption, Millions of gals./year 1975	1980	1985	1990
MA	1258.1	68.8	109.64	126.09	145.06	166.97
SA	3534.8	147.9	250.91	278.82	310.63	346.67
ENC	4555.3	167.9	326.16	356.18	390.65	428.75
ESC	3258.6	115.6	189.81	209.51	231.73	256.72
WNC	1534.6	44.8	75.67	83.69	92.65	102.59
WSC	3474.0	100.6	208.44	230.71	255.05	281.54
MTN	5474.0	200.2	406.32	443.75	484.80	529.58
PAC	3137.7	100.0	193.87	207.00	221.36	236.83
USA	26227.1	945.8	1759.82	1935.76	2131.92	2349.64

Data Source: Mitre Corporation

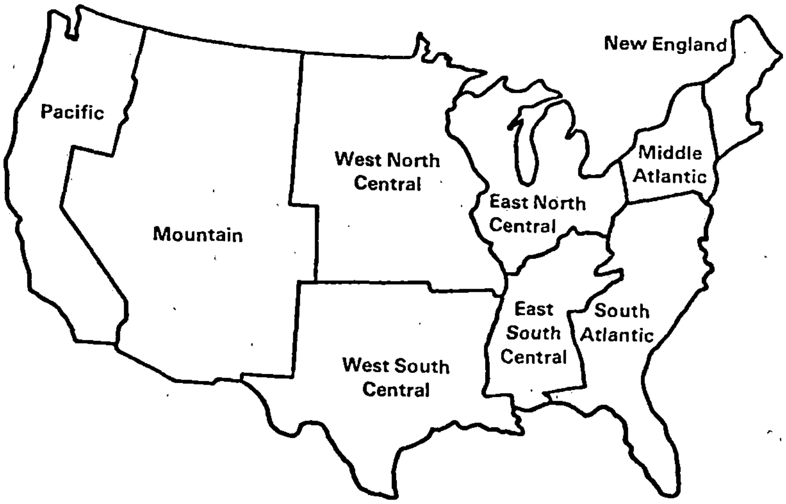


FIGURE 14. U.S. CENSUS REGIONS

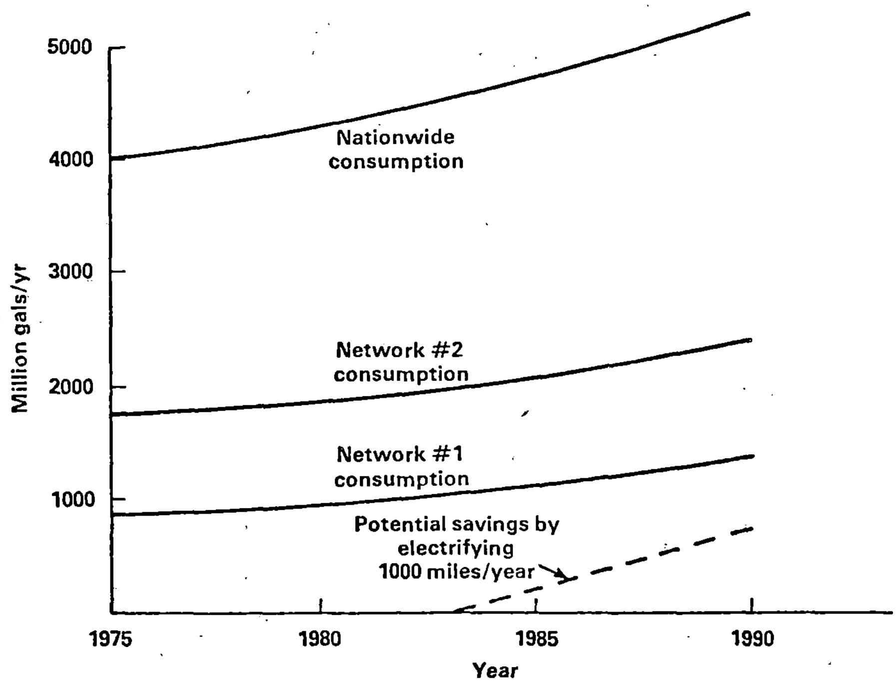


FIGURE 15. RAILROAD DIESEL FUEL CONSUMPTION

TABLE 13

NETWORK #1 ELECTRICAL ENERGY REQUIREMENTS

Census Region	Route Miles	1975 Traffic (1000 MMGTM/year)	Estimated Electrical Energy Requirements, GWH/year			
			1975	1980	1985	1990
MA	1243.10	68.31	1616.05	1858.45	2138.03	2461.04
SA	1780.80	87.60	2296.00	2584.48	2913.89	3288.17
ENC	1649.30	86.24	2614.39	2911.28	3242.84	3611.67
ESC	1084.60	55.06	1112.57	1275.58	1463.26	1680.67
WNC	344.00	16.81	430.53	484.35	545.06	613.08
WSC	340.10	15.96	583.31	641.30	705.08	775.22
MTN	2665.20	138.44	4378.65	4775.71	5214.23	5695.39
PAC	709.60	34.03	1080.16	1162.78	1252.65	1348.69
USA	9816.70	502.47	14111.65	15694.09	17475.06	19473.88

Data Source: Mitre Corporation

TABLE 14

NETWORK #2 ELECTRICAL ENERGY REQUIREMENTS

Census Region	Route Miles	1975 Traffic (1000 MMGTM/year)	Estimated Electrical Energy Requirements, GWH/year 1975	1980	1985	1990
MA	1258.1	68.8	1629.25	1873.70	2155.59	2481.17
SA	3534.8	147.9	3728.52	4143.27	4615.96	5151.52
ENC	4555.3	167.9	4831.88	5292.83	5805.06	6371.23
ESC	3258.6	115.6	2820.58	3113.32	3443.50	3814.86
WNC	1534.6	44.8	1124.46	1243.63	1376.78	1524.49
WSC	3474.0	100.6	3097.42	3428.35	3790.04	4183.68
MTN	5474.0	200.2	6037.92	6594.13	7204.13	7869.56
PAC	3137.7	100.0	2880.91	3076.02	3289.41	3519.29
USA	26227.1	945.8	26150.93	28765.39	31680.33	34915.65

Data Source: Mitre Corporation

and do not include any savings potentially available in an electrified system through regenerative braking. That is, the calculations assume that none of the energy required to accelerate trains is recaptured in decelerating them. Electrification could provide the means to capture a portion of a train's kinetic energy, which is normally dissipated as heat when braking a train.

The Soviets, who lead the world in railroad electrification, utilize extensive regenerative braking. (Ref. 21) In 1974, approximately 1 billion KWH, out of a total of 40 billion, or about 2.5 percent, were saved due to regenerative braking, on DC-powered locomotives only. Regenerative braking was introduced on a limited number of Soviet AC locomotives in 1975, but the results have not as yet been reported. Before introducing regenerative braking in the U.S., many regulatory and power management details would need to be worked out.

To assess the impact of the potential, new power requirements for electrification on existing and planned power generation capabilities, table 15 presents

TABLE 15

ESTIMATED ANNUAL NET GENERATION OF ELECTRIC UTILITIES

(1,000 gigawatt hours)

Census Region	1975*	1980**	1985**	1990**
NE	69.9	93.0	88.8 - 138.8	110
MA	238.8	364.6	461.7 - 585.7	660
SA	344.0	451.4	557.3 - 662.0	780
ENC	356.1	461.5	568.1 - 678.0	810
ESC	171.7	250.4	282.2 - 324.7	388
WNC	131.7	177.3	223.0 - 260.1	315
WSC	234.0	274.9	316.1 - 436.9	451
MTN	110.8	119.0	153.0 - 174.4	214
PAC	261.2	288.0	335.0 - 386.9	462
USA	1918.0	2480.0	2985.5 - 3647.5	4200

* Actual FPC data

** FRA National Energy Outlook projections the estimated annual generation of electricity by utilities. The estimates, in FEA's 1976 National Energy Outlook (Ref. 22), are taken from the Project Independence Evaluation System (PIES) model that balances supply and demand models for the future U.S. energy situation. FEA evaluated a number of scenarios using PIES; the range of values, presented for 1985 in table 15, represents the maximum and minimum predictions from these scenarios. The baseline scenario produces a five percent annual growth rate in electricity generation.

The overall potential impact of railroad electrification on power generation is indicated by tables 16 and 17, which show the estimated electrical energy requirements for Networks #1 and #2 as a percentage of net projected utility generation. Network #1 consumption would amount to only about one percent of the nationwide total. The percentage would decrease with time since the overall electricity consumption growth rate is greater than the rail traffic growth route (figure 16). The greatest regional impact would be expected to occur in the Mountain Region, illustrated in figure 17. Three very high-traffic density lines go through this area, and electrification of all three lines could increase regional electricity consumption by almost four percent. Utility generation growth in the Mountain Region is projected to grow slowly during the next five years. Therefore, extensive railroad electrification could have a forcing effect there. No other region's power supply requirements would be impacted significantly, even with extensive electrification.

TABLE 16

ESTIMATED NETWORK #1 ELECTRICAL ENERGY REQUIREMENTS

AS A PERCENTAGE OF NET UTILITY GENERATION

CENSUS REGION	1975	1980	1985	1990
MA	0.68	0.51	0.37-0.46	0.37
SA	0.67	0.57	0.44-0.52	0.42
ENC	0.73	0.63	0.48-0.57	0.45
ESC	0.63	0.49	0.44-0.50	0.42
WNC	0.33	0.27	0.21-0.24	0.19
WSC	0.25	0.23	0.16-0.22	0.17
MTN	3.96	4.02	2.99-3.41	2.66
PAC	0.41	0.40	0.32-0.37	0.29
USA	0.73	0.63	0.48-0.58	0.46

NOTE: Electrification of Network #1 is assumed to be in place for the above years.

Data Source: Mitre Corporation

TABLE 17

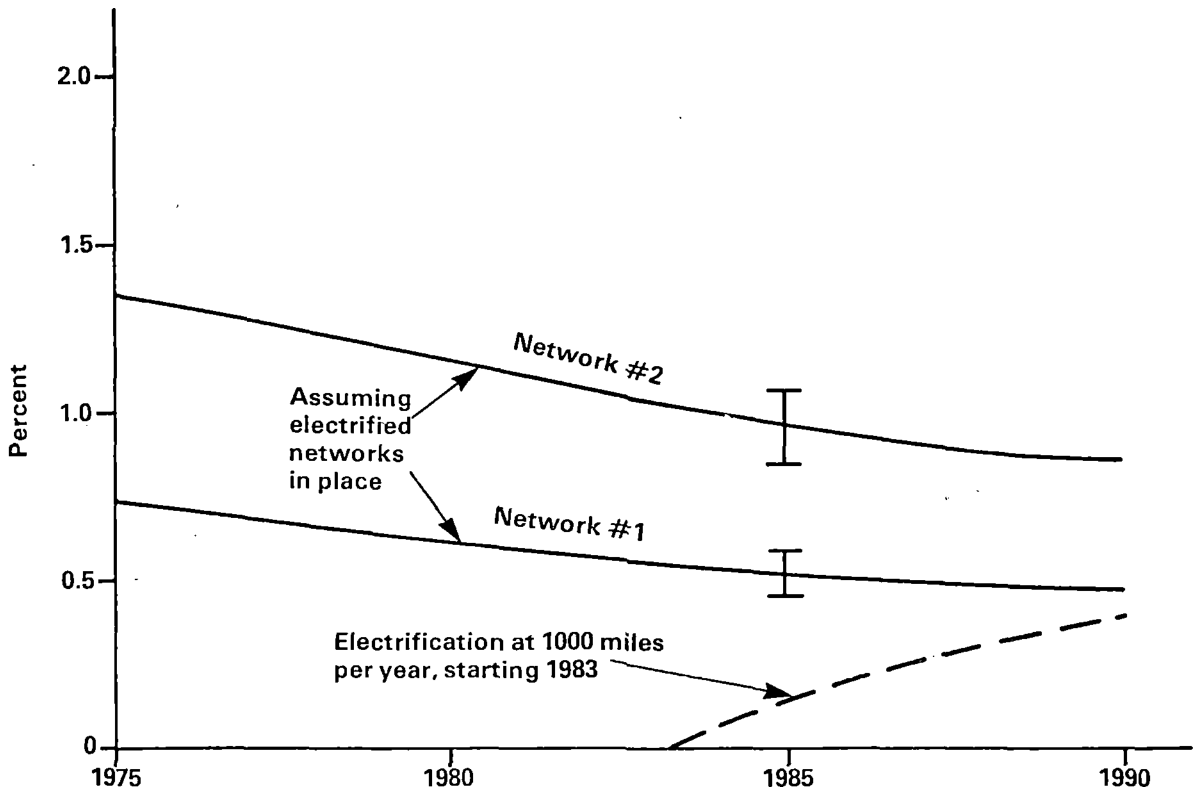
ESTIMATED NETWORK #2 ELECTRICAL ENERGY REQUIREMENTS

AS A PERCENTAGE OF NET UTILITY GENERATION

Census Region	1975	1980	1985	1990
MA	0.68	0.51	0.37 - 0.47	0.38
SA	1.08	0.92	0.70 - 0.83	0.66
ENC	1.36	1.15	0.86 - 1.02	0.79
ESC	1.64	1.24	1.06 - 1.22	0.98
WNC	0.85	0.70	0.53 - 0.62	0.48
WSC	1.32	1.25	0.87 - 1.20	0.93
MTN	5.45	5.54	4.13 - 4.71	3.67
PAC	1.10	1.07	0.85 - 0.98	0.76
USA	1.36	1.16	0.87 - 1.06	0.83

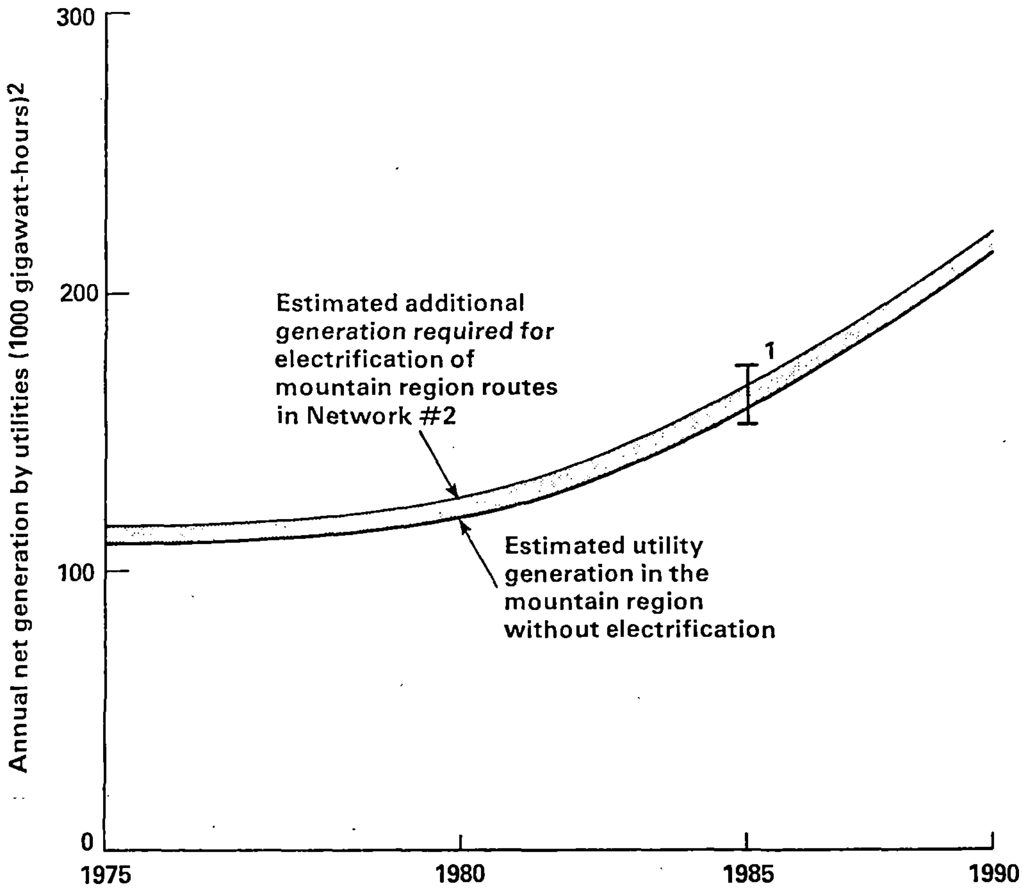
NOTE: Electrification of Network #2 is assumed to be in place for the above years.

Data Source: Mitre Corporation



Data Sources: FEA and MITRE Corp., Ref. 56

FIGURE 16: NATIONWIDE ESTIMATED ELECTRICAL ENERGY REQUIREMENTS FOR ELECTRIFICATION AS A PERCENTAGE OF NET UTILITY GENERATION



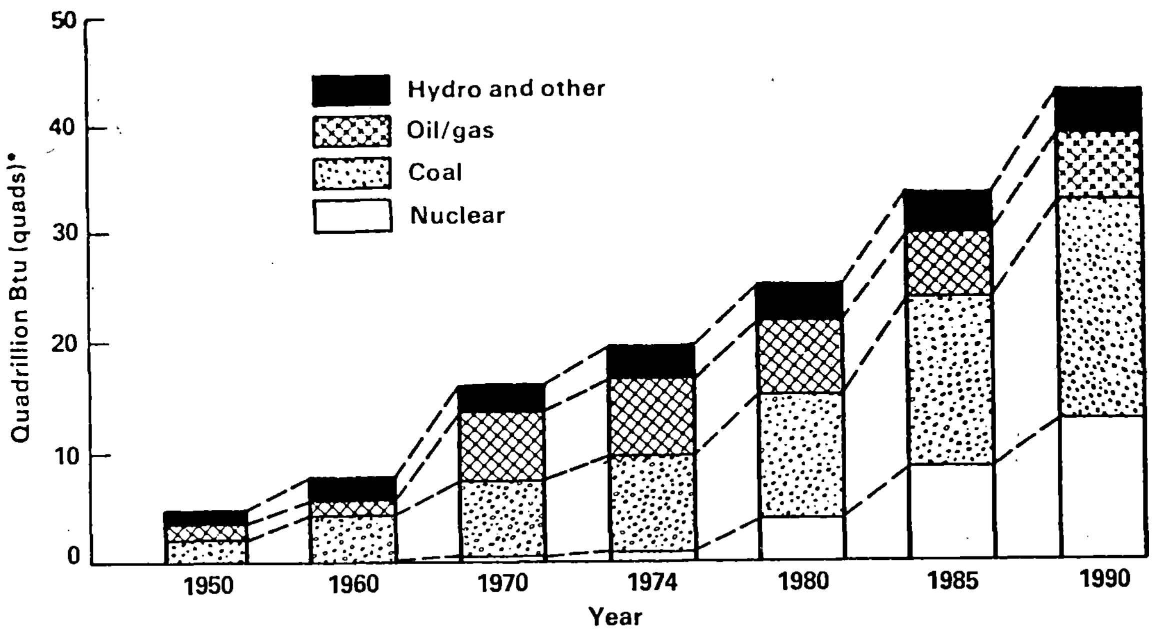
1Range of values for 1985.
2A gigawatt is a billion watts.

Data Sources: FEA and MITRE Corp., Ref. 56

FIGURE 17: ELECTRICITY FOR MOUNTAIN REGIONS

3. Fuel Sources:

The sources of fuel for electricity generation vary by region and also with the passage of time. Figure 18 is a graphical illustration of the nationwide sources of electricity, while table 18 presents a regional breakdown. Coal, traditionally the largest source, is expected to maintain its share of the fuel mix; while petroleum, currently the major source in the Northeast and Southwest Central Regions, is expected to decline considerably in the next 10 years. Hydro power is a major source in the Pacific Region, and nationwide, nuclear power, which now accounts for only about 10 percent, has been projected by FEA to grow to about 25 percent by 1985 (Ref. 22). Other sources will remain small on the current planning time frame, as indicated in figure 19.



*One quad equals 293,000 gigawatt-hours.

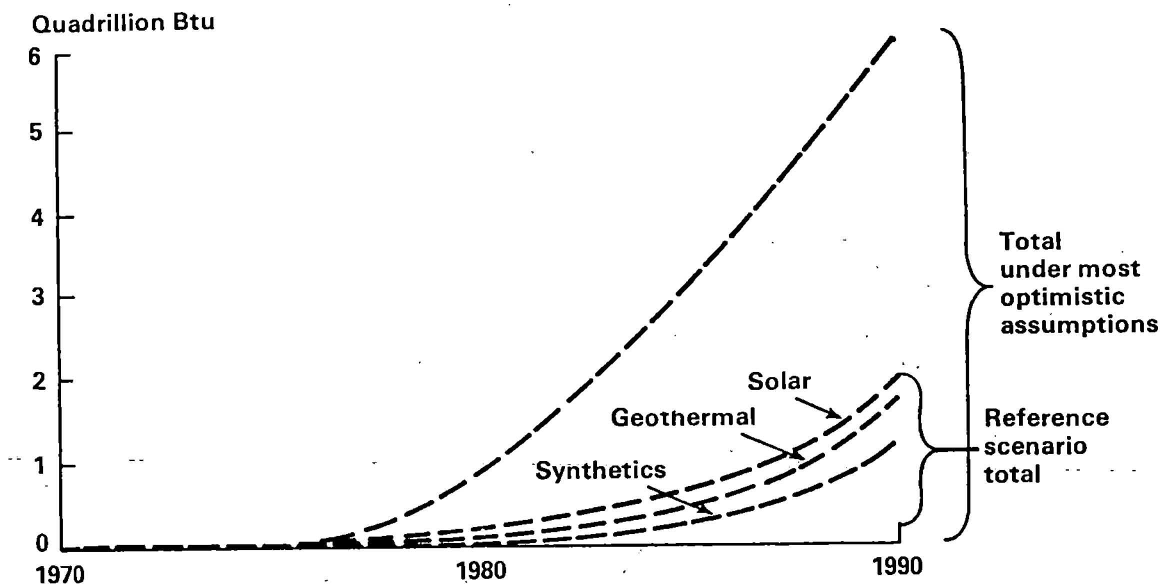
Source: FEA, National Energy Outlook, February, 1976

FIGURE 18: NATIONWIDE SOURCES OF ELECTRICITY

Region	Coal			Oil/Gas		
	1960	1974	1985*	1960	1974	1985*
New England	50.3	7.4	26.8	31.7	61.3	28.4
Middle Atlantic	69.3	42.7	47.9	18.5	36.2	13.6
East North Central	93.5	82.0	66.4	3.8	8.7	5.8
West North Central	40.3	54.4	70.1	46.9	27.2	4.9
South Atlantic	66.3	54.9	52.6	20.2	32.5	10.3
East South Central	74.5	76.5	50.8	5.5	5.4	4.5
West South Central	----	3.0	20.6	95.7	92.6	55.3
Mountain	11.8	46.3	48.7	36.6	23.2	16.9
Pacific	----	1.7	4.7	42.0	27.8	19.9
Nation	53.5	44.5	45.4	27.1	33.2	16.1

* 1985 #13 Reference Scenario

Nuclear			Hydro			Other		
1960	1974	1985*	1960	1974	1985*	1960	1974	1985*
0.1	24.4	41.0	17.9	6.9	3.9	----	----	----
0.2	8.5	29.9	12.0	12.6	7.3	----	----	1.2
0.2	8.3	26.3	2.5	1.0	0.6	----	----	1.0
---	7.7	17.2	12.6	10.7	7.7	0.2	----	----
---	7.4	32.0	13.5	5.2	7.3	----	----	1.2
---	3.6	37.3	20.0	14.5	7.4	----	----	----
---	0.2	22.8	4.3	4.2	1.4	----	----	----
---	---	14.9	51.6	30.5	15.2	----	----	3.7
---	2.8	10.2	58.0	66.7	62.2	----	1.0	2.5
0.1	6.0	26.1	19.3	16.1	11.5	----	0.1	1.0

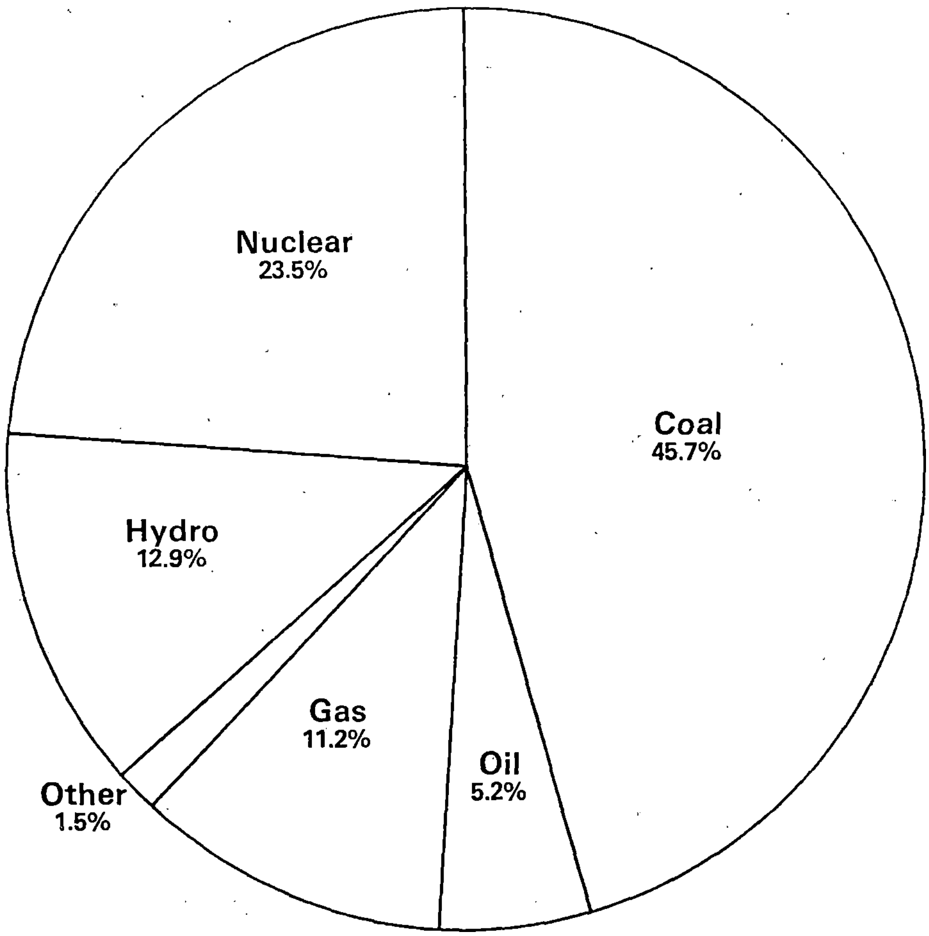


Source: FEA, National Energy Outlook, February, 1976

FIGURE 19: CONTRIBUTION OF NEW TECHNOLOGIES

To estimate the amount of fuel, by source, required to support electrification of the high-density railroad routes, each fuel type was allocated on the basis of the overall fuel mix for each region for each time frame considered. In some areas, a railroad traction power load might be handled primarily by the utilities' intermediate or peaking units, fueled by oil or natural gas. This would tend to negate the potential advantage of electrification by shifting the source of energy from petroleum to coal or nuclear. The Federal Energy Regulatory Commission advises that railroad electrification loads may be handled primarily by oil and gas fired units during utility peak hours. However, while this is certainly an important consideration, it is not expected to change the overall nationwide picture, in which coal and nuclear fuel would be expected to provide the bulk of the energy to power electrified railroads.

The following calculations are based on the regional sources of fuel for electricity generation, projected in FEA's 1976 National Energy Outlook. Where ranges of values are shown, they reflect the extremes of different FEA scenarios. Where a single value is shown, it is based on FEA's "$13 reference scenario", which assumes the price of imported oil remains at $13 per barrel. Figure 20 shows the 1985 nationwide mix of fuel sources for Network #2, weighted by the amount of railroad traction power projected to be consumed in each region, assuming the $13 reference scenario. The individual calculations of fossil fuel requirements shown in the following sections reflect an analysis made by Mitre Corporation of 18 out of 39 FEA scenarios. (Ref. 23)



Data Sources: Tables P-15 and P-19

FIGURE 20: NATIONWIDE MIX OF FUEL SOURCES FOR ELECTRIFIED NETWORK #2 (1985 FEA BASELINE SCENARIO)

a. Coal Requirements

The estimated amounts of coal required to generate electricity for railroad operations in Networks #1 and #2 (assuming the electrified networks are in place in the years shown) are given in tables 19 and 20. Network #2 data is plotted in figure 21. For these calculations, the 1975 traffic level requirement would be 6.23 million tons, annual growth rate of about 1.5 percent. At this rate of growth, the amount of coal required in 1990 would be 7.7 million tons. While the prediction of the amount of coal used for electricity generation is subject to a number of variables, the range of values from the FEA scenarios gives a spread of approximately 10 percent around the reference case values. Figure 21 also provides an estimate of nationwide coal requirements, assuming a railroad electrification conversion rate of 1,000 route miles per year (indicated by a dotted line). In the overall U.S. picture, utilities in 1975 consumed 406 million tons of coal, two-thirds of the total U.S. consumption. According to the Federal Energy Administration, the FEA National Energy Outlook for 1976 (Ref. 22) predicted the U.S. would produce and consume over one billion tons of coal (figure 22) by 1985 an estimated overall growth of about five percent per year. The largest increase in coal production is expected to come from underground mining in the East and surface mining in the West. This growth in coal production, however, will depend on a firm long-term utility demand and resolution of major environmental issues.

TABLE 19

ESTIMATED ANNUAL POWER PLANT COAL REQUIREMENTS FOR NETWORK #1 RAILROAD ELECTRIFICATION

(Million Tons/Year)

Census Region	1975	1980		1985		1990	
		High Sulfur	Low Sulfur	High Sulfur	Low Sulfur	High Sulfur	Low Sulfur
MA	0.305	0.17	0.16	0.1-0.3	0.2-0.4	0.28	0.26
SA	0.51	0.49	0.17	0.45	0.1-0.4	0.4	0.4
ENC	1.0	0.34	0.59	0.5	0.3-0.7	0.4	0.7
ESC	0.38	0.2	0.1	0.25	0.15	0.16	0.17
WNC	0.13	0.1	0.06	0.1	0.1	0.07	0.1
WSC	0.02	0.03	0.01	0.03	0.1	0.02	0.15
MTN	1.26	0.4	1.1	0.45	1.0	0.7	0.8
PAC	0.02	0.01	0	0.06	0.4	0.06	0.0
USA	3.63	1.74	2.19	1.94-2.14	2.35-3.25	2.09	2.58

NOTE: Electrification of Network #1 is assumed to be in place for the above years.

Data Source: Mitre Corporation

TABLE 20

ESTIMATED ANNUAL POWER PLANT COAL REQUIREMENTS FOR NETWORK #2 RAILROAD ELECTRIFICATION

(Million Tons/Year)

Census Region	1975	1980		1985		1990	
		High Sulfur	Low Sulfur	High Sulfur	Low Sulfur	High Sulfur	Low Sulfur
MA	0.3	0.16	0.16	0.13-0.30	0.17-0.36	0.28	0.26
SA	0.82	0.79	0.28	0.63-0.75	0.20-0.66	0.62	0.56
ENC	1.87	0.62	1.07	0.70-1.00	0.45-1.21	0.67	1.18
ESC	0.98	0.57	0.30	0.43-0.68	0.17-0.42	0.37	0.40
WNC	0.35	0.25	0.15	0.2 -0.25	0.14-0.28	0.17	0.30
WSC	0.12	0.16	0.03	0.14-0.17	0.10-0.55	0.12	0.67
MTN	1.74	0.53	1.44	0.55-0.68	1.00-1.60	0.94	1.04
PAC	0.05	0.02	0.0	0.02-0.17	0.00-0.10	0.14	0.0
USA	6.23	3.10	3.43	2.8 -4.00	2.23-5.18	3.31	4.41

NOTE: Electrification of Network #2 is assumed to be in place for the above years.

Data Source: Mitre Corporation

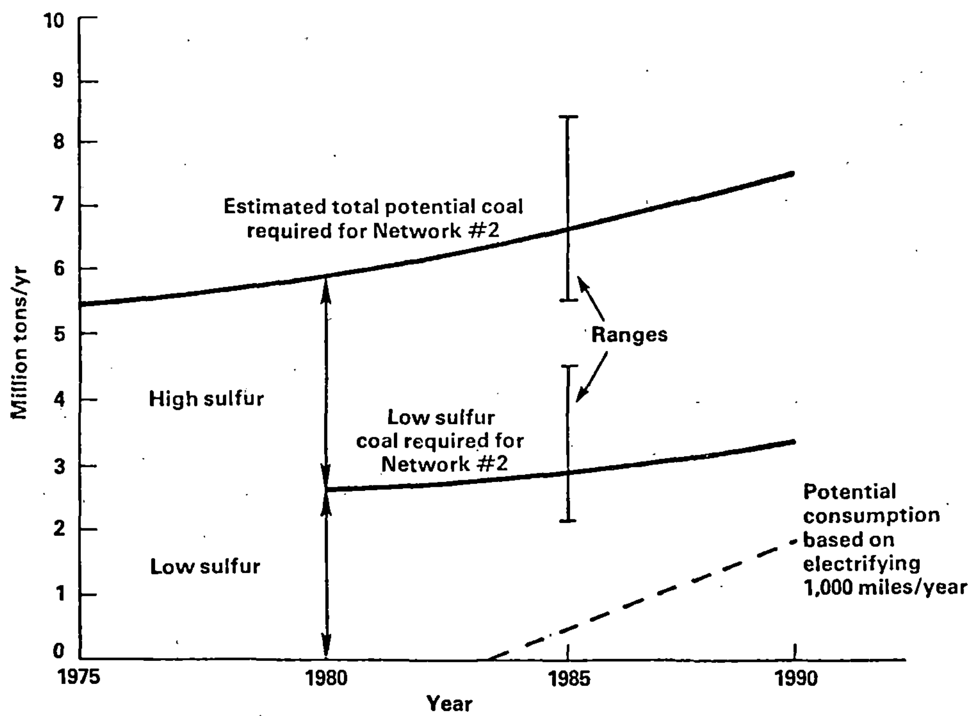


FIGURE 21. COAL REQUIREMENTS FOR RAILROAD ELECTRIFICATION

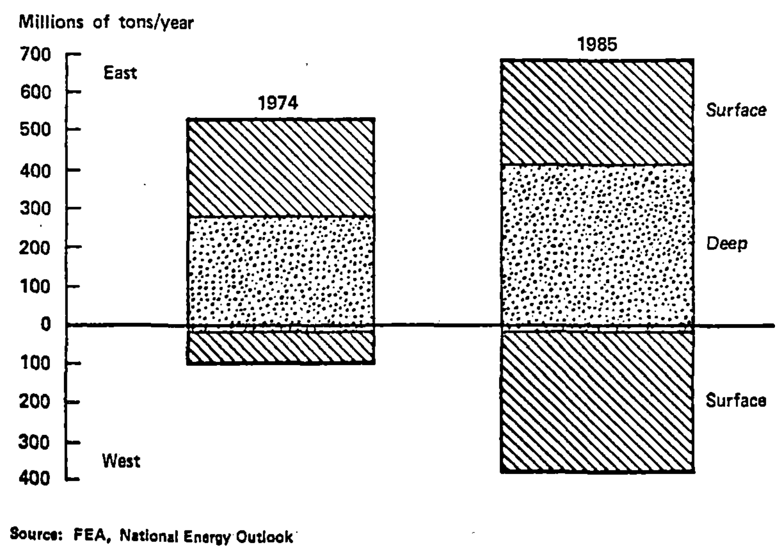


FIGURE 22. U.S. COAL PRODUCTION

b. Natural Gas Requirements

As with coal, the utility plant natural gas requirements were calculated by region and nationwide, using the FEA scenarios. The estimated natural gas requirements for Networks #1 and #2, assuming a mix of fuels are projected by FEA, weighted by the amount of railroad traction power needed in each region, are shown in tables 21 and 22. The wide ranges of estimates reflect the uncertainty of utility plant natural gas requirements in future years.

Nationwide electrified railroad requirements for natural gas would be expected to be on the order of 45 million cubic feet per year (for Network #2) through 1985, and then fall off to below 20 million cubic feet per year by 1990. The former figure represents about 1.5 percent of the current U.S. utility plant consumption of over 3 trillion cubic feet per year. Thus, according to the FEA Report, widespread electrification would have a negligible impact on total U.S. natural gas demand, which currently exceeds 20 trillion cubic feet per year.

c. Oil Requirements

A small portion of an electrified network's requirements for electricity would still depend on petroleum fuels. Using the same methods as for the preceding coal and natural gas consumptions, Network #1 and #2 oil requirements are shown in tables 23 and 24. Railroad diesel fuel consumption for Network #2 traffic without electrification is shown in figure 23 (upper line) along with the estimated amount required for power generation with electrification (lower line). Since railroad diesel fuel and utility oil are essentially equivalent on an energy (and thus volumetric) basis, the difference between the two curves equals the maximum potential petroleum savings available through electrification of the entire 26,000 mile network. Actual savings would be proportional to the rate of conversion from diesel to electric operations. Assuming a conversion rate of 1,000 miles per year, the overall petroleum savings would be on the order of 80 million gallons annually, about 90 percent of which would amount to net petroleum savings, after the utility oil requirements are subtracted.

Referring to figure 22, the potential oil savings would be about 1.5 billion gallons at 1975 traffic levels, rising to about 2.2 billion by 1990. The potential savings represent only about one percent of the petroleum currently used in transportation and about 0.5 percent of the total national petroleum demand.

TABLE 21

ESTIMATED ANNUAL POWER PLANT NATURAL GAS REQUIREMENTS
FOR NETWORK #1 RAILROAD ELECTRIFICATION
(Million Cu. Ft/Year)

Census Region	1975	1980	1985	1990
MA	158.6	1135.	927.-1142.	0.0-322.0
SA	1329.0	609.0	282.0-606.0	4.0-505.0
ENC	869.3	967.0	728.0-1083.0	96.0-220.0
ESC	236.8	542.0	586.0	0.0-445.0
WNC	865.6	293.0	199.0-314.0	0.0-45.0
WSC	5091.0	5031.0	2354.0-5167.0	107.0-1392.0
MTN	6516.5	6925.0	10916.	1885.0-7854.0
PAC	1216.4	2200.0	28.0-3598.0	0.0-24.0
USA	16283.2	17702.	16020.-23412.	2092.-10807

NOTE: Electrification of Network #1 is assumed to be in place for the above years.

Data Source: Mitre Corporation

TABLE 22

ESTIMATED ANNUAL POWER PLANT NATURAL GAS REQUIREMENTS
FOR NETWORK #2 RAILROAD ELECTRIFICATION

(Million Cu Ft/Year)

Census Region	1975	1980	1985	1990
MA	159.	1142.-1145.	935.-1152.	0.0-324.
SA	2158.	976.	446.-960.	6.0-791.
ENC	1606.	1756.-1760.	1304.-1939.	169.-388.
ESC	620.	1365.	1152.-1695.	0.0-1041.
WNC	2260.	752.	503.-794.	0.0-111.
WSC	27030.	26886.-26900.	12651.-27776.	575.-7512.
MTN	8974.	9542.-9554.	12497.-17631.	2602.-10838.
PAC	3243.	4707.-6786.	74.-9448.	0.0-63.
USA	46050.	47126.-49238.	29562.-61395.	3352.-21068.

NOTE: Electrification of Network #2 is assumed to be in place for the above years.

Data Source: Mitre Corporation

TABLE 23

ESTIMATED ANNUAL POWER PLANT OIL REQUIREMENTS FOR
NETWORK #1 RAILROAD ELECTRIFICATION

(Million Gals/Yr)

Census Region	1975	1980		1985		1990	
		Dist.	Res.	Dist.	Res.	Dist.	Res.
MA	37.2	14.7	22.4	0-32.3	0-21.1	2.3	17.5
SA	38.9	0.18	21.9	0-28.0	0-25.6	4.3	15.9
ENC	10.4	9.2	6.7	0.4-40.6	0-10.5	5.2	7.0
ESC	3.0	1.2	2.9	0.3-19.0	0-2.2	2.3	2.7
WNC	1.4	0.4	0.05	0-9.4	0-0.06	0.85	1.0
WSC	1.3	0.9	0.0	0.4-1.4	0	1.2	17.1
MTN	20.2	0.4	0.0	0-2.8	0	9.9	37.1
PAC	15.4	1.0	5.5	0-7.6	0.6-15.5	11.6	12.9
USA	127.8	27.98	59.45	1.1-141.1	0.6-74.96	37.65	111.2

Dist. = Distillate, i.e. high quality oil.
Res. = Residual, i.e. lower quality oil, with higher ash and sulfur content and higher velocity.

NOTE: Electrification of Network #1 is assumed to be in place for the above years.

Data Source: Mitre Corporation

TABLE 24

ESTIMATED ANNUAL POWER PLANT OIL REQUIREMENTS FOR
NETWORK #2 RAILROAD ELECTRIFICATION

(Million Gals/Yr)

Census Region	1975	1980		1985		1990	
		Dist.	Res.	Dist.	Res.	Dist.	Res.
MA	37.34	14.80	22.5	0.0-32.5	0.0-21.3	0.0-2.37	17.70
SA	62.87	0.14	35.00	0.0-44.4	0.0-40.6	2.35-6.75	24.80
ENC	19.17	16.7	12.20	0.6-72.8	0.0-18.7	7.70-10.56	12.50
ESC	7.92	3.07	7.36	0.7-46.1	0.0- 5.5	4.80-5.90	0.10-6.40
WNC	3.64	1.04	0.0-0.14	0.0-23.7	0.0-0.14	1.70-2.53	2.70
WSC	6.70	4.55	0.0	2.2-7.4	0.0	6.30	0.0-92.10
MTN	27.78	0.51	0.0	0.0-3.8	0.0	6.0-13.65	0.0-51.18
PAC	40.94	2.72	0.05-14.60	0.0-19.9	1.5-40.6	3.70-30.23	33.70
USA	206.36	43.53	77.11-91.8	3.5-250.6	1.5-126.84	32.55-78.29	91.54-244.08

Dist. = Distillate, i.e. high quality oil.
Res. = Residual, i.e. lower quality oil, with higher ash and sulfur content and higher velocity.

NOTE: Electrification of Network #2 is assumed to be in place for the above years.

Data Source: Mitre Corporation

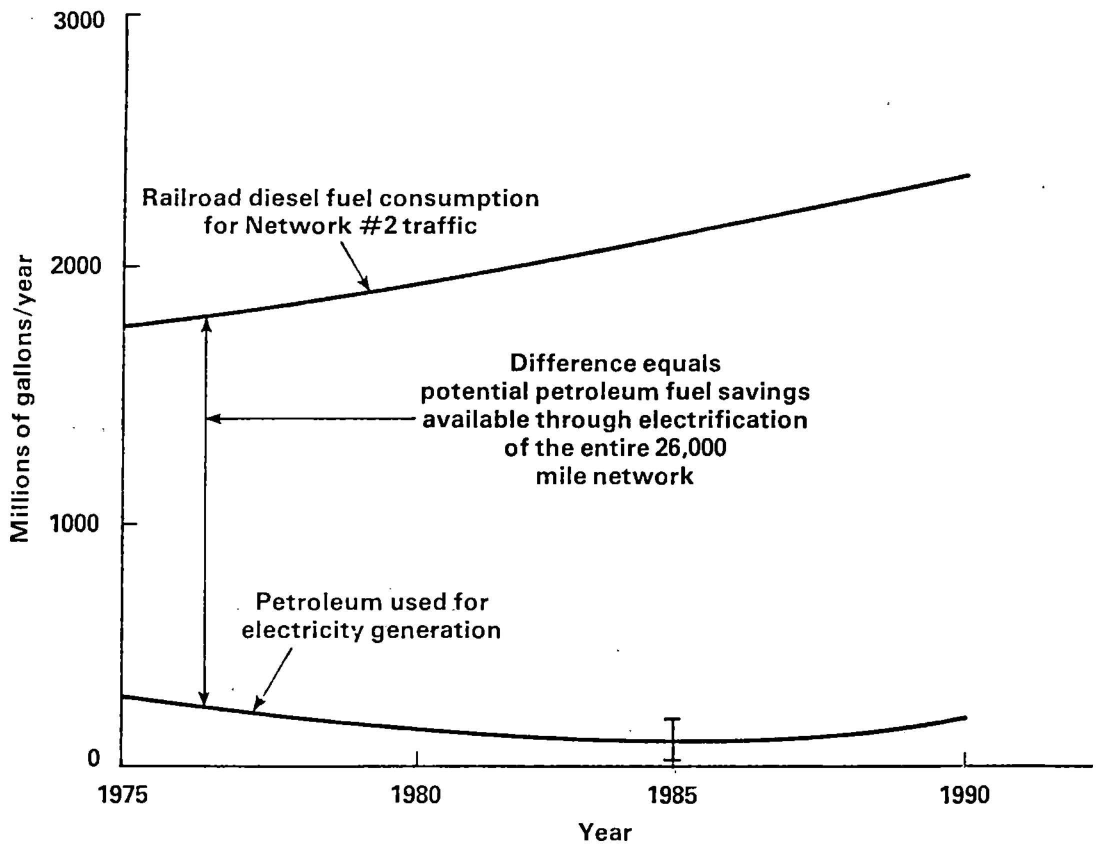


FIGURE 23: PETROLEUM REQUIREMENTS FOR RAILROADS

4. Energy Investment:

In order to evaluate all the energy implications of railroad electrification, it is necessary to include an estimate of the amount of energy required to construct new electrification facilities and equipment. This "energy investment" has not been studied in detail for railroad electrification, but an order-of-magnitude estimate has been computed. Based on a factor of 3.6 KWH/dollar of investment, electrification of 1,000 route-miles (at roughly $275,000 per route-mile, not including locomotives) would consume about 1 billion kilowatt-hours of energy for its construction. (Ref. 24) Since the total number of locomotives required with electrification would be the same or less than prior to electrification, this investment has not been included. Construction of new utility facilities to serve an electrified railroad could add up to, on an average, another 1 billion KWH per 1,000 miles of electrification.

Based on the above rough estimates, the energy investment for electrification would represent, typically, the equivalent of only about one or two year's operating energy consumption, which is small compared to the total energy consumed over the 30-50 year life of the system. However, in computing any net petroleum savings available with electrification, this energy investment must also be considered. It can be assumed that the energy needed to construct electrification facilities would come from a mix of fuel sources, such as was shown in table 18.

5. Effectiveness of Electrification in Saving Petroleum:

The above estimates show that the net savings in petroleum through widespread railroad electrification would be small when compared to current national consumption patterns. Considering the large dollar investment required, it might seem that electrification would represent a poor investment if strictly considered as a means of saving petroleum. However, to compare it with alternative "petroleum saving" investments, it may be useful to compute the net investment required per barrel of petroleum saved, over the life of an electrification project.

Assuming 1,000 miles of electrified railroad could be installed at a total cost of $350 million and would conserve on the order of 150 million barrels of petroleum over 50 years, the investment per barrel of petroleum saved would be on the order of $2.33. With the price of petroleum currently at $13 a barrel, it may not be cost effective to invest $2.33 per barrel saved. However, as the price of petroleum increases, the electrification option may become more attractive.

D. Environmental Effects of Railroad Electrification

1. Introduction:

This section examines the effects of railroad electrification on our environment. The three aspects of electrification having the most impact on the environment would be 1) railroad operations, 2) fuel sources and uses, and 3) equipment construction.

A convenient checklist for assessing environmental effects was developed as part of the Initial Assessment Study by the Northeast Corridor Improvement Project (NECIP). (Ref. 25) This checklist, shown in table 25 classifies factors as being

TABLE 25

ENVIRONMENTAL EFFECTS OF RAILROAD ELECTRIFICATION

	Construction	Operation	Fuel Supply
SOCIAL SYSTEMS			
Community Cohesion	○	○	◍
Displacement of People	○	○	◍
Community, Facilities, & Services	◍	○	◍
Employment, Income, Business Activity	◍	◍	●
Residential Activity	○	○	◍
Property Taxes & Land Value	○	○	●
Regional/Community Plans/Politics	○	○	●
Visual Features/Aesthetics	◍	●	●
Historical & Archeological	○	○	◍
NATURAL SYSTEMS			
Geological Systems	◍	○	●
Hydrology, Water Quality, Aquatic Biota	○	◍	●
Terrestrial Biota	○	◍	◍
Air Quality	◍	●	◍
Noise and Vibration	◍	●	◍
EMI	○	●	○
SAFETY			
Employees	◍	◍	●
Non-Employees	○	●	◍

○ Little or no effect ◍ Secondary or minor effect

● Primary or direct effect

social or natural systems and ranks each factor as having primary (direct) effect, secondary (minor) effect, or no effect at all on the environment.

2. Operations:

As shown in table 25, the operations of an electrified railroad would have primary impact on three natural factors: air quality, noise and vibration, and electromagnetic interference (EMI). Only one social factor, visual/aesthetic, would be affected as a result of operational changes should electrification become a reality. An additional factor to be discussed, but not included in the NECIP list, is that of safety.

a. Air Quality

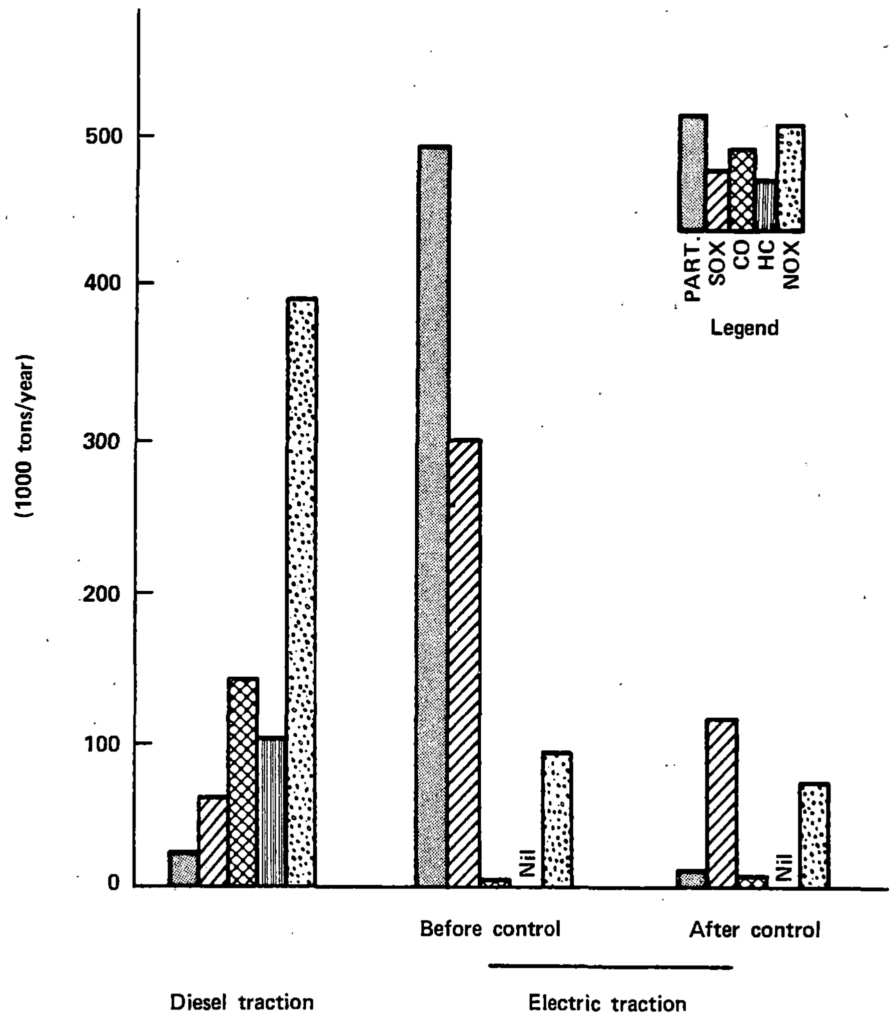
Table 26 shows how diesel locomotive operations are currently affecting air quality. The nitrogen oxides (NO_x), prevalent with diesel engine combustions, are the most significant pollutant, with railroads contributing about 3.3 percent of NO_x emissions; the contribution to all other pollutants, shown in table 26, is less than one percent.

TABLE 26

AIR POLLUTANTS FROM DIESEL RAILROADS

POLLUTANT	EMISSION FACTOR LB/1,000 GAL	EMISSIONS 10^3 TONS/YR	CONTRIBUTION TO U.S. ATMOSPHERIC POLLUTANTS BY WT.
Particles	25	50	.2%
SO_x	57	114	.3%
CO	130	260	.2%
HC	94	188	.5%
NO_x	370	740	3.3%

The total emissions generated by the traffic that could be converted to electric traction nationwide (Network #2) are illustrated in figure 24. Only a single nationwide case is presented because the pollutant levels are so small. Regional variations are pronounced, with the Central Regions having the highest levels of emissions, reflecting their relatively high reliance on coal. (Refs. 7 and 23)



Data Source:MITRE Corp.

FIGURE 24: NETWORK #2 ESTIMATED ANNUAL EMISSIONS 1985 PROJECTED TRAFFIC LEVEL

The difference between "diesel traction" and "electric traction" reflects a shift from petroleum fuel, in an internal combustion engine, to a mix of fuels, in which coal predominates (as shown in figure 19) in a continuous combustion process. Two values are given for the "electric traction" case: with and without control of the products of combustion. The "controls" for new power plants refer to national standards which have been established by the Environmental Protection Agency in "Standards of Performance for Fossil Fuel-Fired Steam Generators." (Ref. 26)

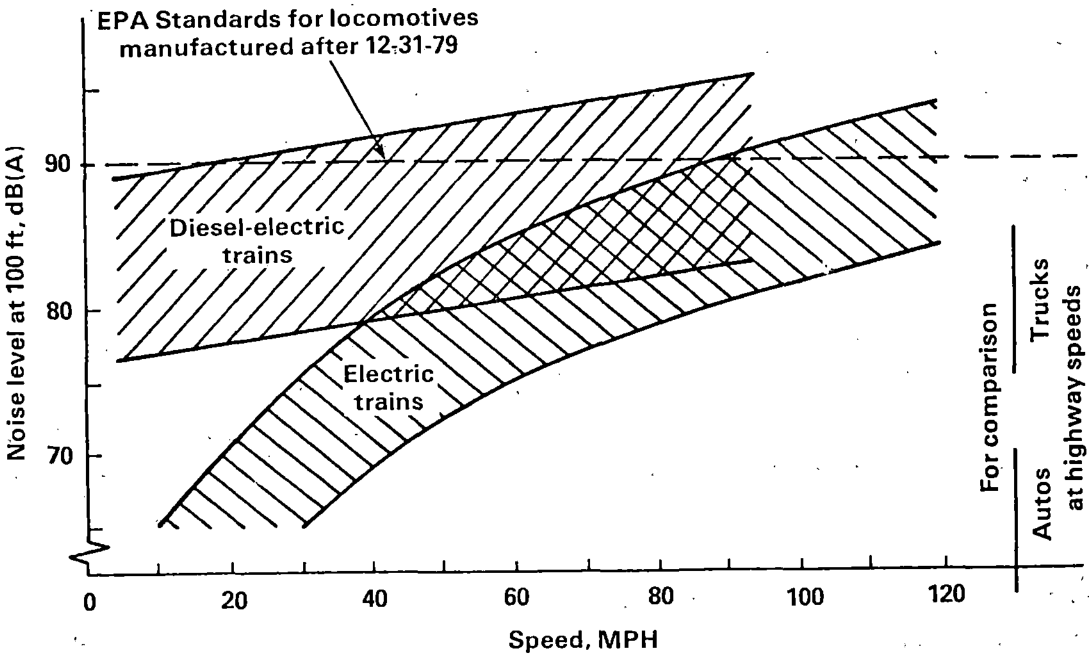
Assuming the desired control levels can be reached on stationary electric power plants, electrification would generally reduce the quantity of pollutants released to the atmosphere. Particulates are relatively easy to control and could be reduced to a level lower than with diesels. Sulfur oxides, however, are more difficult and costly to control. Even if control standards are met, the quantity of sulfur oxides (SO_x) would be approximately twice that of equivalent diesel operations. Electrification would practically eliminate carbon monoxide and unburned hydrocarbons emissions, and would reduce nitrogen oxides to about 20 percent of that occurring with diesels. If the desired control levels cannot be met, electrification would increase both particulates and oxides of sulfur.

One major difference concerning emissions with a conversion to electrified operations is the source. The emissions from diesel-electric locomotives are distributed along the route, whereas the emissions from generating stations are stationary. It is difficult to assign a preference to either case. The argument against wayside emissions is the inability to control them in urban areas, where they are obnoxious. The problem with centralized emissions is that they are much more concentrated and therefore, difficult to disburse. It is generally thought, however, that one advantage of electrification is that central power plant smoke stacks can be cleaned up more easily and at less cost per unit of power output than mobil power plants (diesel engines).

b. Noise and Vibration

The Environmental Protection Agency (EPA) has established limits on railroad noise sources and standards have been set for locomotive operation under stationary and moving conditions and for rail car operations. (Ref. 27) These regulations are primarily directed toward the diesel engine itself, as the major noise producer. The all-electric locomotive is quieter, since the diesel engine is eliminated. However, there are some noise producing components, such as equipment blowers that are still needed.

The relationship between the noise from diesel-electric operations and all-electric operations, as compared to the Federal regulations, is illustrated in figure 25. Conversion to electric locomotives would have a favorable impact, particularly in low-speed operations below about 40 mph. At higher speeds, wheel noise is a large part of the total, and the relative noise advantage of electrified railroad operations is diminished. At 60 mph, an electric locomotive-hauled train is just about as noisy as both a diesel-hauled train and a diesel highway truck.



Source: MITRE Corp.

FIGURE 25: NOISE LEVEL OF TRAINS

Locomotive vibration would be reduced with electrification by replacing diesel units with electrics. This would be a significant factor only at yards, shops, and terminals where locomotives stand idle for long periods, as engine vibration is a small part of train vibration when a train is moving.

c. EMI (Electromagnetic Interference)

Conversion of present railroads to electrified operation would result in electric field disturbances along the railroad rights-of-way and their immediate surroundings. Although technically the disturbances fall into at least four separate forms, they are commonly grouped under the term "Electromagnetic Interference" or "EMI."

The primary source of these effects is the single-phase catenary which supplies power to the train. The locomotive also produces disturbing electrical impulses or harmonics, which are radiated and conducted by the catenary. These and other electrical phenomena can disrupt communications by affecting nearby radio and television reception, telephones, other electronic operations and the railroads' own signals and communications, unless safeguards are provided. Such safeguards include the grounding and/or shielding of wires and cables paralleling the catenary and the standardized control of harmonics inside the locomotive.

d. Social Systems

Conversion to electrified railroads would, for the most part, have only minor effect on social factors. To be affected, but not significantly, are factors such as land value and employment. Acquisition of new land for fixed facilities would be minimal. The effect, however, of electrification operations on property taxes and land value would vary from location to location. Each jurisdiction would determine whether value of the fixed plant and adjacent land had been increased or decreased.

Minor changes in employment patterns can be expected as a result of electrification. At locomotive repair facilities, the jobs that are related to maintenance of diesel engines would be reduced proportionately to the number of diesel units displaced by electric units. However, there would be a small increase in the number of maintenance-of-way jobs to maintain and repair the catenary and substations.

The only social systems category that might be affected in a direct way is the visual/aesthetic impact. A primary, or direct, effect would be the result of new aerial transmission and distribution facilities. The desirability of such facilities would vary in relation to the surrounding environment. A potential benefit would result in those instances when existing open-wire pole lines would be removed and replaced by buried cables (as part of the electrification project). In other instances, there could be 'joint-use' corridors utilizing railroad rights-of-way as locations for new transmission facilities and minimizing the overall net impact of new electric power distribution facilities. In all situations, however, the net visual effect of electrification would be site-specific.

e. Safety

An overhead catenary, with its high voltage potential to ground, introduces a safety risk not present with non-electrified operations. Training and education programs on the awareness of special dangers and proper operating procedures would be essential. In general, if facilities are built and maintained with safety in mind, and if precautions are taken to train railroad personnel, electrification should not aggravate railroad safety experience.

The element of danger is also present to non-employees, particularly to juvenile trespassers who could climb on cars, under the catenary, and on the catenary support structure itself. To minimize injury to trespassers, it would be necessary to fence off danger areas and to post warning signs wherever there is access to electrified facilities.

3. Fuel Sources and Uses:

The environmental impacts of electrification are more numerous and more primary or direct in the Fuel Supply aspect than in Operations. (Table 25) There are seven categories in which the potential shift from diesel fuel to other sources, mainly coal and nuclear, would be reflected in substantial changes to the environment. However, these would vary in intensity, not only because of their nature, but because of the proximity of most of them to fuel producing and consuming facilities, i.e., mines, refineries, and power plants.

a. Social Systems

The change in fuel supply, brought about by the electrification of a rail network in the next 20 to 25 years, would be from the exclusive use of oil (diesel fuel) to a mix, including nearly 50 percent coal and 25 percent nuclear. Regarding social systems, coal mining would produce the most change in terms of employment, property taxes and land values, regional-community plans and politics, and visual, aesthetic features. The new coal boom towns of Wyoming, Montana, and Utah exemplify the effect which drastic and sudden changes in population have on a community's resources -- its land, housing, schools, hospitals, and retail trade. They also point out the attempts of such communities to establish stability in government, planning, and in preserving the beauty of the land in the face of widespread strip mining.

The shift to nuclear fuel would also have impact on communities and residential attitudes. Community opposition to the conversion of nuclear facilities, as in the 1977 protests at Seabrook, New Hampshire, can be expected. Offsetting such community effects and attitudes, to a large extent, is the increased employment generated by new or enlarged coal production and distribution.

b. Natural Systems

In the area of natural systems, fuel supply has a clear, unmistakable impact. It has been mentioned earlier that 26,000 miles of electrified railroad network in place would require, by 1990, an additional 7.7 million tons of coal and a reduced, though still present, quantity of fuel oil in the electricity generation mix. It has also been mentioned that this would represent a very small percentage increase in the total amount of those fuels required, and could in no way threaten or even hasten the depletion of our national resources. But in local areas, particularly in the coal-rich West, the impact would be significant. Land use, for example, would be increased to accommodate new mining, and power generation and spent fuel disposal facilities.

In hydrology (the quantity and availability of water and its quality) fuel supply would also have an impact of primary magnitude. Water is consumed at virtually all energy-producing operations for cooling, processing, and sanitary purposes. Nuclear-fired generating plants require the most water, followed by coal-fired plants and oil-fired plants in that order. The harmfulness of used or waste water is probably highest when discharged from nuclear power plants. In the Northwest, where water is now relatively scarce, environmentalists are deploring the discharge of warm nuclear waste water into the cool rivers claiming that river ecology is thereby damaged.

c. Safety

The safety element is of primary or direct importance in the fuel supply aspect of electrification. Coal mining, already an occupation with some hazards, would be intensified, as would its transportation. The possibility of accidents would be present, also, in the handling and use of nuclear fuel, although the safety record of nuclear generating stations is good.

4. Equipment Construction:

The construction activities required to build the catenary structure, substations, and transmission lines for electrified railroad operations should not seriously impact social systems, natural systems, or safety. The actual construction time would be relatively short. Construction crews might place temporary loads on the community and its facilities and services, but, at the same time, employment and business activity would be stimulated. The construction activity, being predominately above ground, would cause some adverse visual/aesthetic impact, and, while the construction of electrical transmission facilities involves hazards to the workers, the use of training, education and safety programs could be instrumental in keeping accidents at a low level.

5. Conclusions:

Using a list of factors developed by the Environmental Protection Agency (Ref. 28), the nature of pollutants and their estimated volume can be computed for various hypothetical levels of traffic density and route mileage, for railroads powered by electricity from coal and nuclear fuel; for dieselized railroads; and for diesel trucks. The application of these factors to diesel and electrified transportation results in large quantities of the air, water, and land contaminants (table 26). Amounts would vary with the density of traffic and the network mileage. However, diesel trucks, handling the same amounts of traffic over the same route mileages, discharge vastly more pollutants into the air than dieselized or electrified railroads. In the case of particulates, sulfur oxides, and hydrocarbons, the diesel truck/diesel railroad ratio is 3 to 1. In carbon monoxide, it is 4 to 1. In nitrogen oxides, it is 20 to 1. Except in the cases of sulfur and nitrogen oxides, coal-powered electric trains would improve on the diesel train performance.

Shown in table 27, the emissions and other environmental impacts of an electrified railroad can be calculated for trains powered either exclusively by coal or by nuclear fuel. These would not be real-life cases, but even under the extreme 100-percent coal-powered condition, the amounts of all air pollutants except sulfur and nitrogen oxides would be decreased through the use of electrification.

The localized effects of electrification would be substantial. National systems, social systems, and safety would all be affected. But from the national perspective, the environmental effects of railroad electrification, in comparison with other alternatives, would not be significant, as they would touch only a very small part of our total environment and its use.

TABLE 27

AN OVERVIEW OF RAILROAD ELECTRIFICATION IMPACT FACTORS

Impact category	Impact parameter	Units employed	Diesel train	Diesel truck	Electric train coal	Electric train nuclear
Air pollution	Particulate matter	Tons/10^6 GTM	0.0273	0.0660	0.0229	0.0
	Sulfur oxides	Tons/10^6 GTM	0.0498	0.1315	0.0617[2]	0.0
	Nitrogen oxides	Tons/10^6 GTM	0.0820	1.7125	0.1288	0.0
	Carbon monoxide	Tons/10^6 GTM	0.0767	1.0375	0.0071	0.0
	Hydrocarbons	Tons/10^6 GTM	0.0538	0.1710	0.0022	0.0
Water pollution	Water consumption	Ac-Ft/10^6 GTM	0.0064	0.0266	0.0662	0.0725
	Water discharges	Ac-Ft/10^6 GTM	0.0006	0.0023	0.0131	0.0082
Solid waste	Total generated (Complete fuel cycle)	Tons/10^6 GTM	0.1323	0.5500	9.4109	0.5775
Land use	Land requirement (Fuel production)	Acres/10^6 GTM-yr	0.0023	0.0094	0.0047	0.0030
Radiation release[1] (Atmospheric)	Noble gases	Curies/10^6 GTM	0.0	0.0	0.0	54.8232
	Halogen & particulates	Curies/10^6 GTM	0.0	0.0	0.0002	0.0059
(Waterborne)	Tritium components	Curies/10^6 GTM	0.0	0.0	0.0	18.5302
	Mixed products	Curies/10^6 GTM	0.0	0.0	0.0	0.1768

NOTES:

[1]Pressurized water reactor (reactor only).

[2]Emission with 90% SO_2 control is 0.0617 while emission without controls is: 0.6170.

Data source: EPA. Table P-28 comes from the Unified Industries, Inc. report, Ref. 7, page 175.

E. Impact on the Electrical Power Supply Industry

1. Railroad Load Characteristics:

Railroad electrical loads pose some unique requirements on electric utility systems. The demand for electricity for locomotives can vary rapidly over its full operating range. One moment, the locomotive may be fully loaded (heavy grade or acceleration), and the next moment it may be fully unloaded (idling or braking).

Electric locomotives can draw very high levels of power which must be made available by the utility at the moment of demand. The utility transmission system has to be sized to provide the peak demand at each railroad substation. No savings are available in the transmission system as a result of utilizing peak demand only occasionally. The possibility of train scheduling and train power control to minimize utility demand during the peak power demand periods is of considerable interest to the power utilities.

a. Factors Affecting Power Rates

In alternating current (AC) systems, the peak voltage and the peak current may not occur simultaneously. If the peaks are not simultaneous, the power factor is said to be less than one. If the power factor is less than one, the electric current required to provide a given power level exceeds that for unity power factor. The transmission system must be sized to handle the maximum current. Normally, the power utilities will charge extra for a power factor lower than 0.90. (For low power factors, a surcharge on the entire bill in the range of 0.3 percent penalty per percent of power factor below 90 percent appears reasonable.) (Ref. 4, p. 3) Power factor correction can be made on board the locomotive and at the wayside. A study would be needed in most cases to determine the most economical way of achieving the necessary power factor correction.

The modern electric locomotive, using silicon controlled rectifier (SCR) control, generates frequency harmonics which may be fed back into the utility supply system. These harmonics may cause problems for other customers. Power factor control can help minimize harmonics.

Utilities are very concerned about system load factor since it directly affects the cost of providing enough capacity to meet the peak load condition. Load factor is the ratio of actual electrical energy produced to that energy that would have been generated if production was at the peak power level achieved over a defined period of time. The industry's average load factor is currently just over 60 percent. Customers who have a poor monthly load factor, generally below 60 percent, pay a penalty. (Multipliers of 0.91 for 90 percent, 1.06 for 50 percent, 1.14 for 40 percent, and rising rapidly below that, are national averages.) (Ref. 4, p. 3)

The railroad load, in a modern AC system, is a single-phase load. Unless special steps are taken, connection of a single-phase load to a three-phase system can create an imbalance, which can cause damage to the utilities' generators. Generally, the three phases would be split so that adjacent sections of tracks would be fed by different phases. Phase breaks in the catenary would keep the different phases separated. The maximum current imbalance allowed by utilities, as measured at the generators, is generally five percent. Small utilities, which feed only one substation, are the ones that may have problems. In some cases, it may be necessary to supply these isolated substations from a transmission line supplied by a larger adjacent bulk power source or use rotary converters, to convert single phase to three phase loads, at the utility connection.

Opinions as to the seriousness of the single phase problem vary widely among United States utilities. A large western utility which has examined the problems feels that imbalance will not present a problem as long as reasonable design and dispatching control is used. On the other hand, a state-operated utility system with a peak demand approaching 2000 megawatts (MW) felt that it could not tolerate an imbalance exceeding one train of about 15 MW or less than one percent of its peak load. Other larger utilities subscribe to the opinion that there will be no serious problem provided a reasonable effort is made to design and operate so as to maintain reasonable phase balance. Nonetheless, a modest surcharge multiplier, in the range of 1.5 can be expected to be applied. (Ref. 4, p. 4)

The magnitude of the railroad electrical load will vary depending on the size and number of trains, the terrain and speed limits. A typical double-track substation at 25 KV would probably have two transformers rated 20 MVA. Since the short-time (one-half hour) overload capacity of traction power transformers is generally three times the continuous rated load, each transformer could carry up to 60 MVA, for a peak substation capability of 120 MVA. Of course, the total substation capacity would be utilized only under extremely unusual circumstances, such as loss of an adjacent substation.

In addition, the use of regenerative braking by electric locomotives could help reduce the peak load. However, there are numerous power management and safety problems to be resolved before locomotive-generated power could be fed back into the utility system.

2. Adequacy of the Transmission System:

On a heavily-traveled railroad route, a typical substation might be required to furnish a peak load of up to 90 megawatts (MW). Although it might be feasible to connect such a high momentary load to a 230 KV transmission line, it would probably be unacceptable to connect it directly with a 115 KV line, unless a means of phase-balancing, such as the use of a rotary converter, were used. It would probably not be desirable to tie the railroad loads directly into transmission lines rated less than 115 KV.

It has been estimated that, nationwide, no more than one out of three 115 KV-138 KV transmission lines would need reinforcement, either in utility substation or in the line itself, to handle a typical railroad load. (The DOT Transportation Systems Center estimates are based on analysis of transmission line facilities in the Northeast Corridor.) Transmission lines rated 230 KV and higher should not require reinforcement to handle the railroad load. Roughly two-thirds of the railroad substations in Network #2 would probably be served by 115 KV-138 KV transmission lines. An analysis was made by OR&D overlaying the 26,000-mile network on FPC Bureau of Power maps. The voltage levels of transmission lines adjacent to the candidate rail routes were grouped and tallied to arrive at this estimate. On this basis, only about one-fifth of the utility transmission line system, nationwide, would have to be reinforced.

3. Availability of Generation:

Historically, the electric utility industry has maintained high reliability standards in the generation of adequate power to meet demands. These standards have been maintained to a large degree as a result of availability of adequate reserve generation capacity. Reserve margins have generally averaged 10 to 25 percent of the annual peak load for most utilities. (Reserve Margin is defined here as the amount of serviceable generating capacity installed in excess of the peak load.) The average reserve margin for the United States ranged from 16.6 to 23.7 percent until 1974 when it rose to 27.7 percent, and further rose to 33.5 percent in 1975, as a result of conservation efforts and an economic slowdown. Several sources predict (Ref. 4, p. 3) that reserve margins will be in the range of 23 to 29 percent by 1985, a level which maintains electric service at our historically acceptable level of reliability. The Federal Energy Regulatory Commission has advised that the national electric utility reserve margin will be between 20 and 25 percent in 1985.

The industry's long-term planning has been on the basis of load exceeding available generating capacity once in 10 years. Prediction of this performance involves primarily the interrelation of projected load growth, load factor, reliability of major generation units, and the ability to bring new units into service to meet the growth, with plant construction schedules currently ranging from four to 12 years.

The required generation capacity is, of course, directly related to actual electrical energy consumption. Historically, the growth rate has been such as to double consumption every 10 years. However, a combination of the oil embargo, a Presidential call for energy conservation, and a downturn in economic activity resulted in essentially zero growth in 1974 and 2 percent in 1975. For the purposes of this study, an average rate of growth of 5 percent per year has been projected through 1980.

Essentially, the impact of railroad electrification on utility generation should be very small and would decline with time even in the area of greatest impact, the Mountain Region, through which three very high density rail lines run. Immediate electrification of all three of these routes would require a net increase of roughly only four percent of net regional utility generation. All other regions would be affected substantially less. Extensive railroad electrification nationwide would represent a peak load of between 6,000 to 8,000 megawatts, which represents less than one percent of the projected installed generation capacity in 1985. (Ref. 4)

4. Utility System Capital Requirements:

In recent years, many utilities have encountered difficulties in attracting sufficient capital, principally because of the widespread shortage of investment capital, the reduced earnings resulting from large incremental increases in fuel costs and a much higher than previous inflation rate. These conditions are being corrected, and sufficient capital should be available to meet the utility industry requirements in the future. (Ref. 4)

In the 1976 study, entitled "Capital Resources for Energy through the Year 1990," Bankers Trust Company projected that the energy industries would require up to 22 percent of the Nation's total capital supply between 1975 and 1990. The study estimated that the investor-owned utilities, which represent 80 percent of the utility companies, would have to finance 65 percent of their capital needs externally, and concluded that the total capital requirements for the electric power industry would be $415 billion by 1990. (Ref. 29) Assuming a possible total requirement of 6,000-8,000 megawatts of additional generation capacity with extensive electrification and a cost of about $1 million per megawatt (Ref. 7), electrification of Network #2 would require approximately $6 to $8 billion of utility capital, of which roughly $3-$5 billion would have to be generated externally. (Ref. 29) While a formidable sum of money, it represents only on the order of two percent of the total capital requirements of the electric power industry during the time frame in which railroads would be electrifying.

Historically, the cost of adding generation has not been charged directly to a new customer. Presently, the imbedded cost of generation (the average value of equipment, when taken as a whole) is heavily weighted by the costs of equipment installed prior to the rapid rise in construction and electrical equipment costs. New generation equipment now costs in the range of three times that of the imbedded cost of many utilities. Because a large, new industrial customer may require a substantial amount of generation capacity, there is a strong trend toward utilities charging on the basis of costs of new generation. This practice, called Loop-Range Incremental Costing (LRIC), will cause a new customer to pay a higher charge than present customers. The form which this aproach appears to be taking, is one in which the new customer's initial demand and energy charges will be based upon the investment required for new generation equipment. The rate would then remain constant, except for fuel cost variations, until the average rate "caught up" with this higher rate. At such time, it would be equal to the older customers', and would be subject to the same increases which are projected to continue as a result of inflation. Most utilities would probably place railroad traction loads on an LRIC basis.

5. Connection and Reinforcement Costs:

It has been customary for an electric utility to provide all necessary equipment and transmission and distribution lines required to supply the customer at the contracted voltage. This situation is changing rapidly as utilities feel the dual pressures of difficult capital formation and reduced return on investment, caused primarily by increased energy costs and inflation. Discussions with ten major utilities revealed a uniform approach toward developing a policy requiring the customer to pay in advance for such additions as transmission and distribution line extensions and high-voltage utility-owned circuit breakers. (Ref. 4) Some utilities have attempted to charge a lump sum for reinforcing their existing transmission system when it is inadequate to serve the new load. This type of reinforcement charge has been unpopular and, therefore, not widely applied.

Transmission line extension costs could be one of the major connection cost increments for railroad electrification. It is variable with geographic area, population density, and terrain conditions. Estimates for these types of lines have been made, and recently many have been constructed. Table 28 gives an estimate of the cost of single circuit transmission system extensions of capacity, suitable for traction substation feeds essentially in the range of 100 MW peak load per substation. All three phases would be brought to each substation so that the load could be split between two phases, if desired.

TABLE 28

TRANSMISSION LINE EXTENSION COSTS

(1976 $1000's per mile)

	115 kV Wood Poles	230 kV Wood Poles	345 kV Wood Poles	345 kV Steel Poles
Pacific Northwest	55	70	100	225
Southwest	50	70	100	225
Midwest	60	75	100	260
Southeast	75	100	135	275
North Atlantic	100	165	150	375
New England	75	100	250	275

NOTE: Above costs do not include right-of-way costs (if any) which can add up to 30% to the above figures.

SOURCE: A. D. Little, Inc. estimates.

When it has been established that a substantial connection charge is to be made, there are several commonly used methods for payment.

- o Lump sum payment in one or several increments over a few years.
- o Payment as part of the energy usage on a discounted cash flow basis to provide amortization and ROI over a firm, long-term contract.
- o Payment of a carrying charge as part of the monthly bill throughout the life of the equipment. This charge is in the range of 14-18 percent per year.

Some utilities require a carrying charge to be paid only until such time as the line extension charge can be carried by the energy usage of two or more customers. Some utilities charge only a percentage of the connection cost to the customer, typically 50 percent, and absorb the balance in their internal capital cost structure.

In examining the prospective railroad electrification network of slightly less than 26,000 route miles (Network #2), it is estimated that approximately 3,100 miles of new transmission line would have to be constructed at a total cost of $215 million (exclusive of right-of-way). While this averages $8,300/route-mile, several large increments of required extensions are concentrated in a few railroad sections, primarily in the West. Most of the routes being considered east of the Mississippi River have many transmission lines crossing or paralleling them. These routes would require very little additional transmission line construction. Even when considered all together, new transmission line costs would represent only on the order of two to three percent of the total electrification cost, exclusive of locomotives. Individual rail segments could, of course, vary widely from these rough estimates. Convenient connection points would not always coincide exactly with substation locations. If one considers that there would be approximately 680 substations in the entire Network #2, and allowing one mile of additional transmission line for each substation connection, the connection cost for the entire network on an average basis would be in the range of $47 million, or about $1,800 per route mile. (While the cost of high-voltage switchgear is sometimes considered part of the utility connection cost, in this study, it was included in the basic substation cost figures.)

Averaging the costs of new transmission lines and utility connections for the 26,000-mile network would total $262 million, or about $10,000 per rail route-mile. A similar detailed analysis of these costs was not made for Network #1 and #3; however, the average costs for these networks should not be significantly different.

6. Conclusion:

The 4R Act calls for an evaluation of "the ability of existing power facilities to supply the additional power required..." Strictly in terms of electric utility facilities that are "in place" today, widespread electrification would require a major increase in electric power facilities, particularly in the less industrialized Western regions of the country. However, even if the decision were made now to start electrifying, it would probably take close to 30 years before a network of 26,000 miles could be powered by electricity. Utilities would have sufficient time to plan for and construct any new facilities that might be required to serve the new railroad load. Therefore, it can be concluded that widespread railroad electrification could be accommodated by the U.S. electric utility system without any severe consequences.

F. Railroad Risks and Return on Investment

1. Railroad Perspective:

Since no U.S. Class I railroad has electrified in the last 40 years, there is little recent experience in this country on which to base a decision to electrify. Electrification is generally perceived by railroad management as a highly inflexible, high-risk investment. The risks can be grouped into the general categories of unresolved technical issues, other quasi-technical and/or institutional problems, and financial and business uncertainties.

a. Unresolved Technical Issues

Despite the worldwide use of electric traction and the existence of that technology base, there are still some unresolved technical issues. Most of the components (catenary, locomotives, etc.) exist; however, drawing them together in a new environment raises questions of both system reliability and costs. These uncertainties mean that an extensive "debugging" process may be required for the initial systems.

First, electromagnetic interference of a high-voltage AC catenary system will require changes in, or shielding of, the signal and communications systems to prevent interference with television and radio transmission. The extent and cost of these necessary precautionary measures, however, are uncertain. Second, designing the railroad/utility interface may raise some unknown technical difficulties. Railroads must understand how their train operations would affect utility load peaks, and what the cost penalties would be. Unknowns in the area could negatively affect costs and/or operations. Third, the merits of regenerative braking need to be further investigated. The effects of catenary phase-breaks must be determined and treated appropriately by on-board equipment design to minimize any adverse effects. Lastly, accurate technical information on reliability and maintenance of electric railroad equipment must be developed. Thus, while unresolved technical questions should not prevent a railroad from electrifying, they must all be addressed before an electrified line could be a complete success.

b. Quasi-Technical/Institutional Problems

The report pinpointed several other problems, including the following:

- o Many railroads have expressed concern that construction of the system could be delayed or even stopped by environmentalist objections to the "visual pollution" of the catenary structure. One successful suit in one location could stop the entire project.
- o Electrification is a highly flexible investment. While locomotives, cars, and track can all be moved with reasonable ease, such is not the case with the catenary and substations. This inflexibility becomes significant, given the long-life of the system. Thus, the railroad route to be electrified would have to be economically secure.
- o Electrification would bring together the railroad and utility industries, both of which are already highly regulated, albeit in different ways. This could produce additional regulations concerning ownership, operation, rates, and profitability, especially if there were a railroad -- utility consortium or third-party investment in power delivery systems. The regulatory situation could be complicated by various additional State and local regulations that may be applied to an electrified line.
- o An uncertain future freight rate structure is a major concern of the railroad industry. If the cost of operations were to be used as the primary basis for setting rail freight rates, there would be little incentive for railroads to make large capital investments, such as for electrification. Operating cost savings are essential to achieve an adequate return on investment. Therefore, if these savings are passed on to the user in the form of lower freight rates, the return on investment could be seriously diminished according to the AAR and certain railroads.
- o Railroads are concerned about losing control over their energy supply. Possible brown-outs or black-outs could have grave operational implications to electrified railroads. While the extent and sophistication of the commercial power grid would generally assure reliable service and quick restoration of power in emergencies, recent experience indicates that black-outs can, and do, occur.

c. Financial and Business Uncertainties

The greatest concerns railroads have in regard to electrification are in the areas of financial and business uncertainties. These concerns, which may have little to do with whether an electrified railroad could operate soundly, technically, or operationally, are generally beyond direct control of railroads themselves, and include many outside factors such as national economic growth, demand for rail freight service, and competition from other modes.

Electrification's success depends on a strong, growing market for rail transportation services over the project life (30-50 years). At present, there are many uncertainties about future railroad route structure, freight volume growth and market strengths. The risk of electrifying a "marginal" route is that, if traffic declines, the incremental savings in operating costs with electrification might not be sufficient to recover the investment. Furthermore, benefits of electrification could not accrue until a complete system were installed and put in service, which could take three to five years from the date of the decision to electrify. Railroad cash flow could be adversely affected if there were start-up problems or other delays in converting from diesel operations. Once in service, an electrified railroad would typically take up to ten years or more to recover the initial investment and another 15-20 years might be needed to earn an attractive overall return on investment. The financial commitment required, particularly in the face of high interest rates, would necessitate a detailed and critical examination of all investment and operational cost factors prior to a decision to electrify.

On the positive side, however, electrification could provide railroads a hedge against the effects of inflation, by substituting a near-term, fixed cost for constantly rising variable costs. By reducing motive power maintenance, railroads would have better control over rising, labor-dependent costs. Cost escalation of the initial capital investment, however, might nullify some or all of this potential benefit.

2. Return on Investment:

a. Methodology

Electrification is only one long-range alternative for improving railroad performance. As such, it should be evaluated by comparing it to other possible investments. The method of comparison generally used is an economic analysis which estimates cash flows, resulting from the decision to electrify. To account for the time value of money, these cash flows are discounted, and a discounted cash flow rate of Return on Investment (ROI) is computed. ROI, along with a number of other related factors, such as payback period, net present value and risk, would then be used to compare electrification with other investment alternatives.

There are several methods for computing ROI and numerous variations of assumptions that can be made. Generally, the preferred method is to calculate ROI using constant dollars, without inflation. From a railroad's perspective, it may also be useful to calculate ROI using current dollars, including the effects of inflation. Either way, it is important to account for any differential rates of cost escalation which may exist between alternatives.

In the following section, both methods of calculating ROI (with and without general inflation) have been used. Another consideration is the effect of taxes on ROI, which is discussed later in this section.

While it is not an objective of this report to provide economic feasibility analyses for electrification of specific routes, it is appropriate to include several examples of national routes which have been studied. Three scenarios were analyzed by A.D. Little, Inc. and their calculations are presented below.

b. Electrification Scenarios

The three scenarios developed by A.D. Little, Inc., in their "Energy Costs for Railroad Electrification" study (Ref. 3, pp. 115-121) are labeled as follows:

(1) Mixed freight over difficult terrain
(2) High-speed freight over moderate terrain
(3) Unit coal trains over flat terrain

In each of the cases, passenger traffic is a small portion of the total, and it does not have a significant impact on investment required or the internal return on investment generated.

Because traffic densities and growth projections are a subject of proprietary nature, the densities shown are reasonable but are not the actual values for the routes studied. An arbitrary growth rate of 3.2 percent/year, compounded, was used in the "Best Estimate" of each scenario. All dollar values are expressed in current dollars, and an inflation rate of five percent/year was assumed for the "Best Estimate." The capital investment figures shown in A.D. Little's estimates are expressed in 1975 dollars, which are about 12 percent lower than they would be if expressed in 1977 dollars.

To simplify the calculations of ROI in the following scenarios, it was assumed that all investment would be made in a lump sum in the zero year of the project's 30-year operating life. Calculating ROI using this simplified schedule results in a slightly higher value because cash flow is generated in year one after investment, but for this application it did not exceed one ROI percentage point, and was usually less. As the diesel locomotive fleets already exist, 5.6 percent of each fleet was assumed to be replaced each year (reflecting an 18-year locomotive economic life) and entered as a cost credit line as Diesel Unit Replacements. (Ref. 3, p. 116)

(1) Mixed Freight Over Difficult Terrain

This route's terrain ranges from gently rolling to mountainous with many curves and a number of vertical obstructions. The civil reconstruction costs are based upon average conditions and could be substantially higher when estimated on the basis of actual work which will be required. The investment costs are estimated for electrification at 25 KV.

Sensitivity tests were made to estimate the effect of variations in the "Best Estimate" parameters, and the following ROI's were computed:

Parameter	Variations	ROI
Traffic growth	No growth	17%
Inflation rate	No inflation	15%
Growth & inflation	Both = 0	12%
Power delivery system	+20%	18%
Diesel fuel cost	+40%	27%
Electric energy cost	+40%	14%
Electric unit maintenance	+40%	19%

(2) High-Speed Freight over Moderate Terrain

The route in this scenario ranges from flat, long runs with only slight grades to other areas with grades approaching two percent, but with few curves. Civil reconstruction is not extensive, and has been accurately estimated; construction costs have been estimated on the basis of field examination. The great majority of the route is accessible for off-track construction; much of it has a parallel access road. Traffic is principally high-speed manifest freight with a few unit coal trains intermixed, and one passenger train each way per day maximum. This example assumes electrification at 50 KV.

(3) High Speed Freight Scenario

Sensitivity tests for the scenario resulted in the following ROI's:

Parameter	Variations	ROI
Traffic growth	No growth	15%
Inflation rate	No inflation	14%
Growth & inflation	Both = 0	10%
Power delivery system	+20%	17%
Diesel fuel cost	+40%	27%
Electric energy cost	+40%	6%
Electric unit maintenance	+40%	17%

(4) Unit Coal Trains over Flat Terrain Scenario

This route is very level terrain with only an occasional, gentle curve. Civil reconstruction requirements are minimal. Access is such as to permit nearly all construction to be done off-track. The traffic is nearly all unit, large size coal trains. Several manifest freight trains per day operate intermixed with the coal trains, and there is no significant passenger traffic projected. This example assumes electrification at 50 KV.

(5) Unit Coal Train Scenario

Sensitivity tests yielded the following ROI's:

Parameter	Variations	ROI
Traffic growth	No growth	17%
Inflation rate	No inflation	15%
Growth & inflation	Both = 0	13%
Power delivery system	+20%	18%
Diesel fuel cost	+40%	27%
Electric energy cost	+40%	13%
Electric unit maintenance	+40%	19%

c. Analysis of Results

Examination of the three scenarios provides an ROI greater than the cost of capital. However, because such factors as the availability of capital funds, economic risk, and alternative investment opportunities, must also be considered, no definitive statement can be made regarding the financial viability of any of these scenarios. Electrification project ROI is sensitive primarily to traffic density, inflation, and energy costs.

Another method of calculating ROI, eliminates the effects of general inflation by expressing all dollar values in "constant" terms. (Ref. 30) This method is employed in the following section to analyze a variation of the Mixed Freight Scenario, and to investigate the effects of a number of other changes to A.D. Little's basic assumptions.

d. Variation of the Mixed Freight Scenario

In the following scenario, capital and operating costs have been adjusted to reflect estimated actual cost escalation from 1975 to 1977. The initial diesel fuel cost was lowered from 49¢/gallon to 40¢/gallon. (A five percent factor for diesel engine lube oil was applied, thus raising it to 42¢/gallon.) The cost of electric energy was kept at 3.0¢/KWH. An energy cost differential factor, which reflects the projected relative variation of diesel fuel and electric energy with time, was applied to these initial energy figures. (Figure 8) The inflation factor was eliminated and a two percent annual traffic growth rate was adopted as a base assumption.

e. Freight Scenario Variation

RESULTS	ROI
Estimate with fuel differential and +2% annual growth:	
Before taxes	23%
After 48% tax on savings	15%
Estimate with fuel differential and 0% annual growth:	
Before taxes	21%
After 48% tax on savings	13%
Estimate with fuel differential and -2% growth:	
Before taxes	19%
After 48% tax on savings	11%

SENSITIVITY OF ROI
TO SELECTED COST CHANGES

Item Varied	Price Increase	ROI
Catenary Costs	20%	21%
Catenary Costs	-20%	25%
Transfer of Diesels	-40%	21%
Diesel Fuel	40%	27%
Diesel Locomotive Maintenance	40%	25%
Electric Energy	40%	20%
Electric Locomotive Maintenance	40%	22%
Remove Fuel Differential	-	12%
Total Initial Investment	20%	20%
Total Annual Savings	20%	30%

Unless specified, the values assume an annual rate of growth of +2 percent and a fuel differential factor shown in figure 8. With no growth, and before taxes, the payback period is 9.7 years. After taxes of 48 percent, the payback period is 18.7 years. The net present project value over a 30-year operating life and assuming a discount rate of ten percent is $3 billion. The "after tax" value of ROI assumes the railroad would pay a tax of 48 percent on net savings with electrification and does not include the effects of possible tax reductions due to depreciation or investment tax credits. Including these effects would tend to improve ROI.

3. Railroad Operational Considerations:

In addition to the economic effects, electrification could have a major impact on railroad operations. There are various differences between diesel and electric motive power that would either require, or make it advantageous, for railroads that electrify to change their dispatching and train handling methods. A.D. Little, Inc. identifies (Ref. 3, p. 13) the following improvements and restraints attributable to operation of electric locomotives versus diesel-electric units.

MOTIVE POWER IMPROVEMENTS

- Higher rail horsepower per motive power unit
- Increased availability and reliability
- Lower per unit-mile maintenance cost
- Faster turn around time, no refueling
- Higher acceleration capability
- Higher, built-in overload capability

MOTIVE POWER RESTRAINTS

- Less flexibility
- Uniform train spacing to keep peak power demand down
- Damaged catenary due to derailments and repairs before service restoration
- Locomotive changes required at the end of electrified segments

A significant number of the above items in both lists are quantitative and can (and have been) directly incorporated in the economic analyses. However, economic and other comparisons usually assume equal performance of electrified versus non-electrified systems. To the extent that the two types perform differently, the economic analyses may be misleading.

A major factor in deciding to electrify is whether the system, when electrified, would operate as well or better than the present diesel system. In order to minimize the impact of the conversion, it may be desirable to limit the amount of change in operations during the initial stages. In the long run, however, it is expected that operations would be adapted to maximize the advantages of the operating characteristics of the electric locomotive.

4. Railroad Passenger Service Implications:

The foregoing discussion has been centered around the benefits and impacts of electrifying only railroad freight operations. Railroad passenger service could benefit from electrification for many of the same reasons as freight service. Electrified operations could improve the performance of passenger trains and allow flexibility in using either separately powered (multiple unit) vehicles or locomotive-hauled trains. A comparison of Networks #1 and #2 with intercity rail passenger routes shows many similarities in existing Amtrak intercity rail passenger routes with the candidate freight routes for railroad electrification. Roughly 50 percent of the routes are identical, and others traverse similar corridors. A secondary benefit to main line freight railroad electrification, would be the spin-off effect of reducing passenger train operating costs on routes where freight and passenger service coincide.

G. Financing Railroad Electrification

1. Summary Review of Electrification Cost:

The average estimates of the cost of electrifying U.S. railroads, at present dollar values, are about $217,500 per single-track and $371,000 per double-track per route-mile. Considering the mix of single and double track in the three networks studied, the heaviest-density network of 10,000 miles would cost approximately $3 billion, a more widespread network of 26,000 miles would cost approximately $7 billion, and the largest network of 40,000 miles would cost about $10.5 billion. These aggregates cover only track-side costs -- civil reconstruction, signal and communication system modifications, catenary, and substations. Additional generating capacity, transmission lines, and connections to the railroads' power system would cost an additional $4 to $12 billion, depending on the size of the network.

In sum, the total cost of a national program of electrification would be several billion dollars initially, with potentially greater sums required if electrification becomes economical for widespread implementation. Electrification would be the largest investment in roadway and structures that the railroads would have made since laying the original track in the 19th century.

2. Alternative Ownership Arrangements:

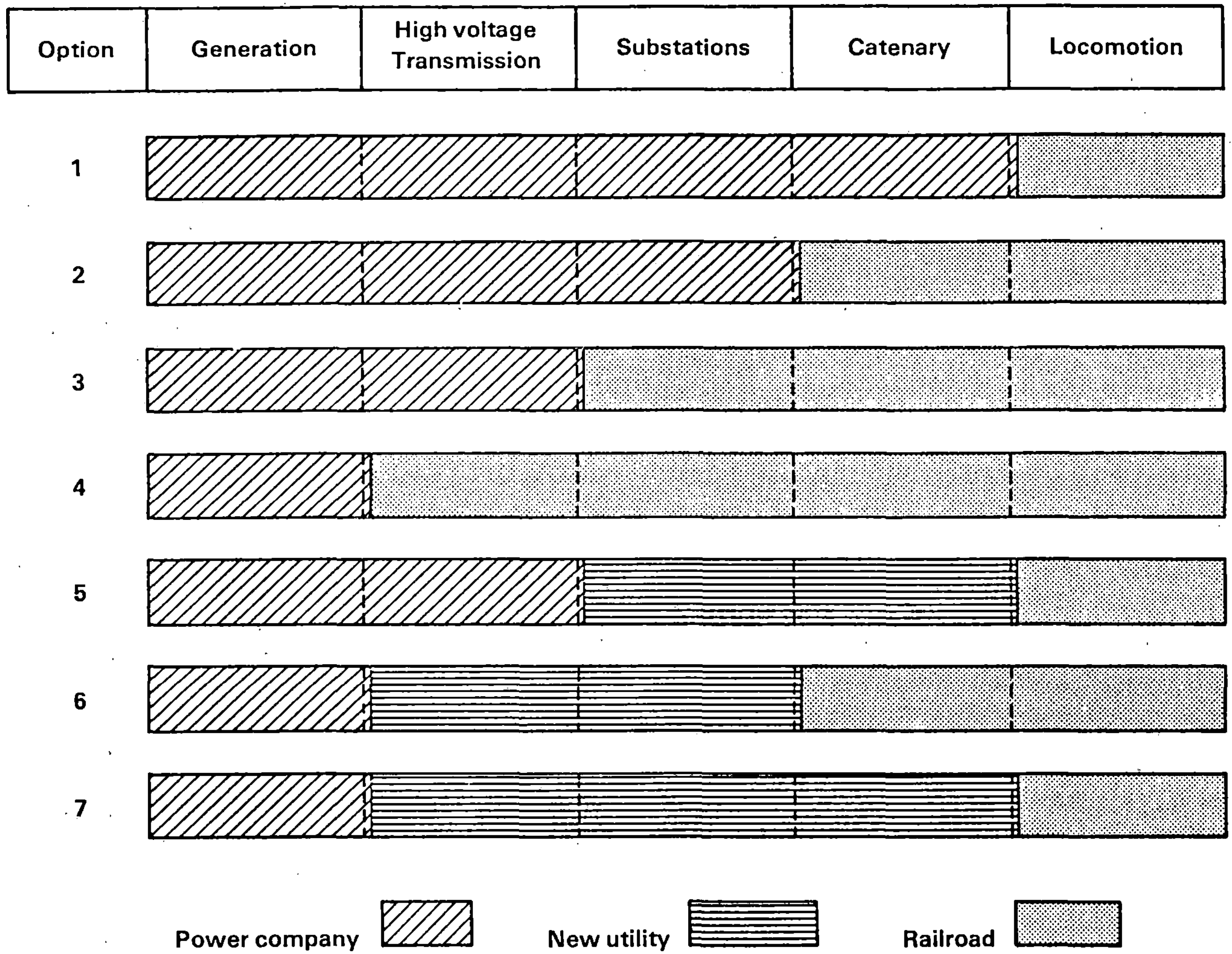
Two key electrification issues are ownership and operational control. Figure 26 shows possible options for both ownership and financing. However, only two factors are common to all seven options; in every case, power generation would be the responsibility of the power company, and motive power the responsibility of the railroad. For those elements of the system between the generation of power and its use, there are various options for responsibility, including the unique new entity termed, on the chart, "new utility." Formation of such a new entity, an electrification company or consortium, may be the fastest and least divisive way to achieve electrification on a large scale. Being jointly owned, it would spread the capital requirements and risks of ownership among several parties. (Ref. 31)

Under the traditional ownership arrangement (Option 3), the railroads would own the substations, catenary, and motive power; the power company would own the transmission lines and the generating facilities. Neither the railroads nor the utilities would face a physical problem in railroad electrification, but the financial problem, that of raising the huge sums of money required for railroad electrification, is a greater problem.

3. Ability of Utilities to Finance Their Share:

Given the recent shift in utility marketing programs from promoting all-electric homes to providing energy-conservation tips, the major utilities were not interested in total electrification project funding. However, there would be significant advantages if the utility industry took the principal role in electrification, if viewed from a national network perspective, and if private capital were to be used. If the initiative for financing were through the utilities, the overall risk to holders of electrification project debt could be diluted if other, financially stronger railroads also had electrified segments in the same utility's territory. Moreover, the private sources of capital perceive the utilities, as an industry, to be a stronger and more stable borrower than the railroads.

Bankers Trust Company of New York projected total capital needs of the electric utility industry through the year 1990 (Ref. 29), at $415 billion. If railroad electrification over the same time frame added another $4 to $12 billion, depending on network size, that sum would represent only one to three percent of the industry's total capital requirements. Thus, there seems to be little doubt that the utility industry could probably finance its share of railroad electrification.



Source: Canadian Institute of Guided Ground Transport

FIGURE 26: ALTERNATIVE OWNERSHIP ARRANGEMENTS

4. Ability of Railroads to Finance Their Share:

The United States railroads cannot, with their own resources, finance the billions of dollars necessary for a national program of railroad electrification. By every major financial indicator, the railroads, as a whole, have deteriorated to the point where, not only are they unable to generate internally the funds necessary for their ordinary capital needs, but they find external financing from conventional sources difficult and sometimes even impossible.

This is the United States railroad picture as a whole. Individually, there are several financially strong railroads which would be able, presumably, to finance their own electrification. However, this would require the postponement or even abandonment of other capital projects of more immediate importance or more certain (or satisfactory) return on investment. This accounts for the fact that, although 17 U.S. railroads have studied electrification recently, not one has made a commitment to electrify. (Ref. 7, p. 10) And, even if such railroads were to go into electrification on their own, the result would be disconnected, electrified railroad segments, not offering through-train operating capability.

a. Criteria for a Financially Healthy Railroad

The basic financial performance measurements for a healthy railroad were annunciated not long ago as follows (Ref. 32):

> "In determining the rail industry's credit-worthiness, financial analysis will focus on the long-term safety of interest payments in the case of debt, and long-term return on their investment, and the certainty of that return, in the case of common stock. This includes an ability to pay a cash dividend.
>
> "To assess the quality of the debt instruments, investors will begin by measuring the amount of debt carried by the industry and the ability to support the fixed charges related to that debt. Investors will expect leverage ratios (debt to total capitalization) to be in the 35- to 45-percent range. To determine the ability of the industry's earning power to support forecast leverage levels, investors will measure the extent to which pre-tax earnings cover fixed charges (interest plus one-third of non-cancellable leases). A coverage level which would inspire confidence by most investors falls in the range of 2.5 to 3.0 times. The margin of safety or the percentage that revenue may drop and still cover fixed charges is perhaps a better indication of adequate coverage as it indicates how far operating revenue could decline before fixed charges would

not be covered. Investors can be expected to require this martin to be between 10 and 15 percent. Finally, adequacy of daily cash needs will be measured by investors' review of expected working capital levels. These factors will be weighed by potential investors of railroad debt in order to compare the value of these securities with others they would consider in the capital markets. Expected performance below these ranges may allow access to the debt market but only at high interest cost.

"A similar analysis will be performed by potential equity investors in the industry. Although these investors will show interest in expected return on equity, they will measure the return on common stock in terms of funds (rather than earnings) that are available to be paid to owners as dividends or, in financial terms, net cash flow. Due to the low rate of return of the industry in recent years, railroad stock has been selling on the basis of its dividend yield. In my opinion, railroad stock which does not pay a cash dividend will have very little value in the marketplace.

"Fulfilling these criteria is a minimum requirement for access to the capital markets."

These criteria, along with others are succinctly displayed in tables 29A-29E.

b. Financial Conditions of the Railroad Industry

Only a handful of the Nation's railroads can meet or exceed these criteria. The shortfall in adequate funds is apparent when the performance of the aggregate of all U.S. Class I railroads is matched against them.

(1) Coverage of Fixed Charges

As shown in Table 30, in the 10-year period 1946-1955, the railroads were able to generate only enough income to cover their fixed charges an average of 2.45 times. In the 10-year period 1956-1965, the comparable average was 2.79 times. In the decade 1966-1975, the figure had dropped to 1.88 times. At no time since 1966 has the ratio exceeded the desired minimum level of 2.5. (Ref. 33)

(2) Debt/Capitalization Ratio

Total long-term debt has been increasing steadily in recent years, while shareholders' equity has been steadily decreasing. (Table 31) The result is

TABLE 29A

CRITERIA FOR FINANCIALLY VIABLE RAILROADS

		Target
Coverage	Fixed charge coverage multiplier	2.5 - 3.0
	Margin of Safety	10.0 - 15.0 percent
Leverage	Debt/total capitalization	35.0 - 45.9 percent
Liquidity	Days of working capital	21 (Minimum)
	Current ratio (times)	1.8
Return	Return on equity	10 percent
	Dividend yield on common stock	5.0 - 6.0 percent
Acceptable startup period		4 - 6 Years
Quality of earnings		Positive cash flow Private control Access to private Capital markets

SOURCE: TRB, Ref. 109.

TABLE 29B

MIXED FREIGHT SCENARIO

Route Miles: 260 plus 92 alternate
Track Miles: 1078
Traffic Density: 97 million TGT/yr (Trailing Gross Tons)

Investment Schedule	$ - 1,000's
Catenary, 1015 main line miles @ $86,000/track-mile	87,290
63 Siding and yard miles @ $65,000/track-mile	4,095
Substations, 19 @ $560,000 each	10,640
Switching Stations, 19 @ $94,000 each	1,786
Signaling and Communications Modifications, 369 signaled route miles @ $62,000/route-mile	22,878
Civil Reconstruction, additional increment for catenary clearance only	10,380
Electric Locomotives, 70 @ $880,000 each	61,600
Diesel Locomotives transferred, 157 @ $340,000 each	(53,380)
Net Investment	$145,289
Annual Costs and Credits	$ - 1,000's/yr
Diesel Locomotive Replacement, 8.7 avg. @ $500,000 each	(4,350)
Diesel Fuel, 47 million gals. @ 49¢/gal.	(23,030)
Diesel Locomotive Maintenance, 18.18-million miles @ 58¢/mile	(10,544)
Electrical Energy, 531 million kWh @ 3.0¢/kWh	15,930
Electric Locomotive Maintenance, 10.89-million miles @ 28¢/mile	3,049
Catenary Maintenance, 1078 miles @ $1,400/mile	1,509
Net Annual Savings	$ 17,436
Best Estimate ROI (before taxes)	19.5%

TABLE 29C

HIGH SPEED FREIGHT SCENARIO

Route Miles:	750-Double and 215-Single Track
Track Miles:	2227
Traffic Density:	70-million TGT/yr on Double and 26 Million TGT/yr on Single Track Sectors

Investment Schedule	$ - 1,000's
Catenary, 2227 miles @ $83,000/track-mile	184,800
Substations (owned by utility)	
Signaling and Communications Modifications, 965 Route Miles at $64,900/route-mile	62,600
Civil Construction	18,300
Electric Locomotives, 198 @ $1,054,000 ea. avg.	208,700
Diesel Locomotives Transferred, 397 @ $430,000 each	(170,700)
Net Investment	$303,700

Annual Costs and Credits	$ - 1,000's/yr
Diesel Unit Replacement, 21.6 @ $500,000 each	(10,800)
Diesel Fuel, 124 million gals. @ 48.8¢/gal.	(60,500)
Diesel Unit Maintenance, 63.4-million miles @ 60¢/mile	(38,000)
Electrical Energy 1.56-billion kWh @ 4.04¢/kWh	63,000
Electric Unit Maintenance, 36.9-million miles @ 28¢/mile	10,300
Catenary Maintenance, 2227 miles @ $1200/mile*	2,700
Net Annual Savings	$ 33,300

*Substation maintenance by utility.

Best Estimate ROI (before taxes) 18.4%

TABLE 29D

UNIT COAL TRAIN SCENARIO

Route Miles: 365
Track Miles: 629
Traffic Density: 70-million TGT/yr

Investment Schedule	$ - 1,000's
Catenary, 595 miles main line @ $64,000/track-mile	38,100
34 miles yard wiring @ $55,000/track-mile	1,900
Substations, 3 single track @ $506,000 each	1,500
6 double track @ $905,600 each	5,400
Switching Stations, 3 single track @ $72,200 each	200
6 double track @ $94,000 each	600
Signal Modifications (Microwave now installed) 365 route miles @ $30,000/route-mile	11,000
Civil Reconstruction	2,300
Electric Locomotives, 30 @ $940,000 each	28,200
Diesel Locomotives Transferred, 79 @ $416,000 each	(32,900)
Net Investment	$ 56,300

Annual Costs and Credits	$ - 1,000's/yr
Diesel Unit Replacements, 4.6 @ $500,000 each	(2,300)
Diesel Fuel, 22.3-million gals. @ 42.6¢/gal.	(9,500)
Diesel Unit Maintenance, 11.7-million miles @ 60¢/mile	(7,000)
Electrical Energy, 314-million kWh @ 2.87¢/kWh	9,000
Electric Unit Maintenance, 5.9-million miles @ 28¢/mile	1,700
Catenary Maintenance, 628 miles @ $1400/mile	900
Net Annual Savings	$ 7,200

Best Estimate ROI (before taxes) 20.5%

TABLE 29E

MIXED FREIGHT SCENARIO VARIATION

Route Miles: 260 plus 92 alternate
Track Miles: 1,078
Traffic Density: 97 million TGT/yr

Investment Schedule	**\$ - 1,000's**
Catenary: 1,015 miles of double track @ \$94,600/track-mile	96,019
63 miles of single track @ \$65,000/track-mile	4,095
Substations: 19 @ \$616,000 each	11,704
Switching Stations: 19 @ \$103,400 each	1,965
Signalling & Communications Modifications: 369 route miles @ \$68,200/route mile	25,166
Civil Reconstruction for Catenary Clearance:	11,418
Electric Locomotives: 70 @ \$940,000 each	65,800
Diesel Locomotives Transferred: 157 @ \$375,000 each	-58,875

Net Investment	157,291
Annual Costs & Credits	**\$ - 1,000's/yr**
Diesel Locomotive Replacement: 8.7 avg. @ \$550,000	-4,785
Diesel Energy: 47 million gal. @ 42.0 cents/gal.	-19,740
Diesel Locomotive Maintenance: 18.18 million miles @ 68.0 cents/mile	-12,362
Electric Energy: 531 million kWh @ 3.0 cents/kWh	15,930
Electric Locomotive Maintenance: 10.89 million miles @ 29 cents/mile	3,158
Catenary Maintenance: 1,078 miles @ \$1,500/mile	1,617

Net Annual Savings	16,182

TABLE 30

COVERAGE RATIOS FOR CLASS I RAILROADS 1946-1975

($ in millions)

Years	Income Available To Cover Fixed Charges	Fixed Charges	Coverage Ratio
1946-1955 Avg.	$5,014	$2,047	2.45
1956-1965 Avg.	4,814	1,727	2.79
1966	6,420	2,178	2.95
1967	4,933	2,164	2.28
1968	5,189	2,280	2.28
1969	5,052	2,192	2.30
1970	3,548	2,480	1.43
1971	3,707	2,525	1.47
1972	4,145	2,280	1.82
1973	4,498	2,448	1.84
1974	4,967	2,643	1.88
1975	3,539	3,230	1.10
1966-1975 Avg.	4,600	2,442	1.88

Data Source: Moody's Investor Service, Moody's Transportation Manual, 1977.

TABLE 31

DEBT/EQUITY AND DEBT/TOTAL CAPITALIZATION RATIOS FOR CLASS I RAILROADS

($ in millions)

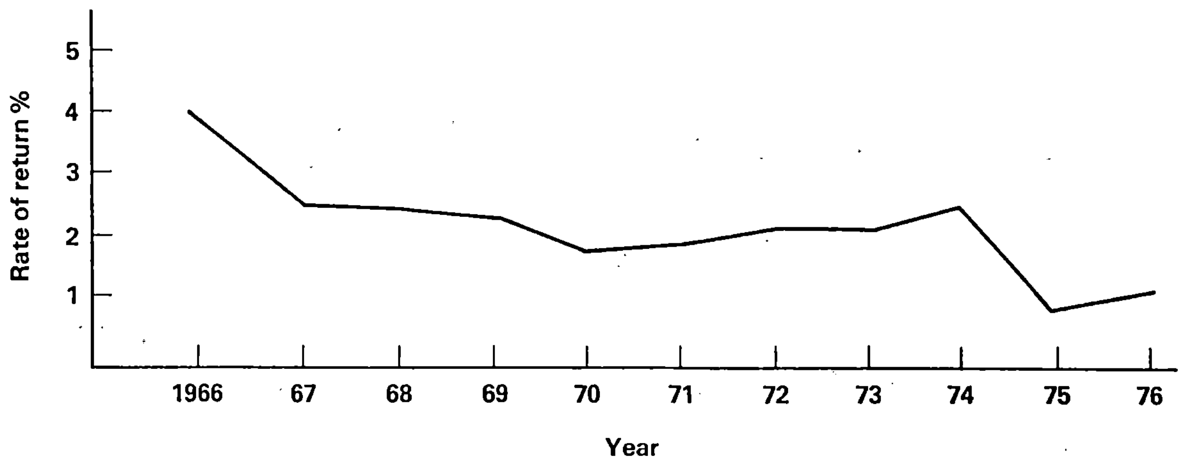
Year	Total Long Term Debt	Total Shareholders Equity	Debt to Equity Ratio	Debt to Total Capitalization Ratio
1968	$10,110	$17,960	0.56	.36
1969	10,430	17,770	0.59	.37
1970	10,850	17,320	0.63	.39
1971	10,950	16,720	0.65	.40
1972	10,590	15,530	0.68	.41
1973	11,010	16,420	0.67	.40
1974	11,060	14,950	0.74	.43
1975	11,834	14,088	0.84	.46

Data Source: Moody's Investor Service, Moody's Transportation Manual, 1977.

that by 1975 the ratio exceeded the upper 45 percent limit of investor tolerance. (Ref. 33)

(3) Rate of Return

The average rate of return on net investment for all Class I railroads has not exceeded four percent in 20 years. Figure 27 shows the steady decline of this rate of return over the last 10 years. The relative financial weakness of the railroad industry is also reflected in a comparison of its return on net worth with that of another situation, in which Conrail succeeded six bankrupt railroads. In addition, national averages can be misleading, particularly since some railroads are incurring heavy net losses. However, while there are a number of healthy, financially strong railroads, their earnings are only marginally sufficient to finance very large capital expenditures, such as electrification, no matter how attractive the rate of return.



Source: AAR

FIGURE 27: RATE OF NET INVESTMENT
CLASS I RAILROADS

(4) Other Financial Indicators

Another reflection of the inadequacy of internally generated funds is the discrepancy between capital expenditures cash flow. (Figure 28 Since 1962 there has been a shortfall of cash flow to meet capital expenditures amounting cumulatively to over $6 billion; since 1951, the cumulative deficit is $7.7 billion.

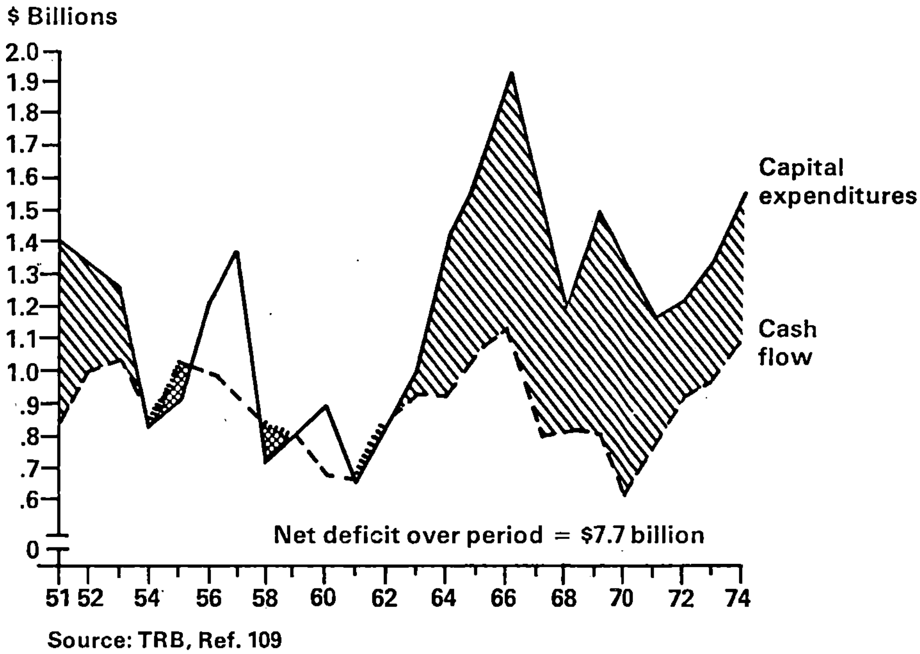


FIGURE 28: CAPITAL EXPENDITURES AND CASH FLOW, 1951-1974
CLASS I RAILROADS

In addition, roadway and structure expenditures, usually financed with external funds, have dropped markedly as a percentage of total capital expenditures, but equipment purchases have correspondingly increased. This is largely because equipment trust certificates, by which most of the equipment acquisitions are accomplished, provide special security for the investor.

5. Funding Mechanism:

a. Railroad Capital Sources

Current conditions and trends within the railroad industry indicate that there is a general problem of obtaining internally generated funds for new capital projects, especially for capital-intensive projects, like electrification. The situation today differs drastically from that of almost 50 years ago when the Pennsylvania Railroad announced its decision to electrify its main line from New York to Wilmington, at a cost of $100 million, financed entirely by internal funds. (Ref. 34) Because of the shortage of funds, today's railroads have gone more and more heavily into debt in recent years. The availability of external financing in the traditional capital markets also does not appear encouraging as a look at the various types of debt instruments indicates. The following discussion of mortgage bonds, common stock and leasing is taken from a paper by Richard Fishbeim "Financial Considerations of Railroad Electrification" presented at the TRB Conference on Railroad Electrification, June 1977.

(1) Mortgage Bonds

As a first option in raising money, a railroad can consider the sale of mortgage bonds. In recent years, the amount of railroad bonds sold has been limited. Costs have been significantly greater and maturities sometimes materially shorter than those of comparable industrial issues. In general, institutional investors have been wary of railroad obligations except for equipment trust certificates. Insurance companies, in particular, which historically have been the largest buyers of railroad mortgage bonds, have been reducing their investment in the industry over a long period of time.

(2) Common Stock

A second option is the issuance of common stock although there have been no railroad common stock offerings in recent years. The absence of railroad equity offerings is due partly to the low price-earnings ratio at which most common stocks sell, and also to the limited appeal that such issues have in the marketplace.

(3) Leasing

A third option a railroad can consider is leasing. Because of the typical railroad's debt structure, leasing arrangements are becoming a favored way for carriers to expand plant without being required to raise the necessary capital or assume additional debt. But as a practical matter, long-term, non-cancellable leases are viewed by lenders as synonymous with debt, and the rental payments due are comparable to interest. The advantage of leasing, however, would be to permit the electrification system to be financed by itself, apart from existing railroad mortgages. The disadvantage of leasing is that it tends to be more expensive. There are also tax, title, and accounting problems involved. A Railway Management Review article, "Financing Railroad Electrification," assesses the railroad prospects for funding electrification considering these funding sources. (Ref. 35)

b. Project Financing

The possibility of establishing a new utility or new electrification company to assume corporate ownership and management of an electrification project was mentioned earlier. The advantages of spreading the risk among several groups of investors -- railroads, utilities, suppliers, users, bankers, and insurance companies -- might facilitate the acquisition of the necessary capital. However, since the financial viability of this company would be entirely dependent upon the railroad, this new firm might not have any easier time raising capital than either the railroad or the utility. But many tax, regulatory and jurisdictional considerations would have to be resolved before such an innovation could be established effectively. As a matter of fact, the regulatory issues raised by several of the various ownership arrangements are complex. Railroads feel that they have a great deal at stake in the areas of ownership and control of operations, and are not likely to enter voluntarily into any agreement which would allow anyone outside the railroad organization to assume greater control. Therefore, this form of financing is not a likely prospect.

c. Government Assistance

In any of these ownership arrangements federal assistance is available to the railroads for electrification projects under Title V of the 4R Act through either the purchase of preference shares or the guarantee of low interest loans by the Government.

6. Summary:

Nationwide railroad electrification is estimated to cost between $3 billion and $10.5 billion, depending on the size of the network. Another $4 to $12 billion might be required to provide and deliver the electrification power. If the responsibility and expense of electrification were to be shouldered only by railroads and electric utilities, the utilities would be able to finance their share but, with very few exceptions, the railroads would not. If widespread railroad electrification is to take place in the United States, it seems certain that it will be with the assistance of the Federal Government.

H. Research and Development Needs

1. Introduction:

It should be made clear that no technological breakthroughs are needed to implement railroad electrification in this country. Likewise, no breakthroughs are on the horizon which would make obsolete a system using present technology. Therefore, if feasibility studies or policy decisions indicate that electrification of a particular route or routes is justified with present technology, it should be implemented. However, electrification requires a significant capital investment, which can only be recovered through savings in operating costs and/or additional traffic revenue, attracted through long-term cost or service improvements. Because of the magnitude of the commitment required, the risk of failure must be virtually eliminated. Research and development projects have the potential to reduce risk and possibly improve electrification system rates of return on investment. Studies need to be carried out in order to (1) define the reliability, safety, and maintainability requirements of the system, (2) establish common technical requirements (standards) for optimum interchangeability of equipment, (3) develop a data base to increase the credibility of railroad electrification feasibility studies, (4) improve the railroad/utility interface, (5) improve the cost and performance of the equipment, and (6) innovate with long-range R&D. The following narrative discusses the above research and development needs.

2. Systems Analysis and Engineering:

Prior to and early in a U.S. electrification program, systems analysis and engineering should be carried out on a number of problems, common to all railroad properties, which have reduced the credibility of conventional feasibility studies. Among the areas that would require such work are the following:

a. Comparison of Electric with Present Diesel-Electric Operation

Economic feasibility studies typically compare the electric and diesel electric alternatives under conditions of equal service and reliability. Further quantitative study should be made of the gains and losses of service speed and reliability in conversion to electric operation. Operational changes to optimize the benefits of electrification should be evaluated. Complications, such as the management and maintenance of a dual fleet (presuming partial electrification of any one railroad), the limitation of the electric fleet to main lines which are wired, the extra change requirements and the reduced diesel utilization, should be evaluated. Reliability of the two alternatives as it affects service to the shipper should be quantified, as well as railroad and utility equipment reliability.

b. Interfacing between Railroads and Electric Utilities

The supply of potentially thousands of miles of electrified railroads from adjacent electric utilities raises many problems which require study and resolution at an early stage. These problems include whether or not to build dedicated transmission lines paralleling the railroad, whether to reinforce weak utility systems or employ artificial phase balancing methods, and how to handle these phase breaks between adjacent utility companies.

c. Review, Adaptation, and Application of Foreign Technology

Because railroad electrification has progressed so far in Europe and Japan, as compared to the United States, studies should be carried out of foreign technology to determine the applicability to railroad operations of the United States. At the analysis level, this should include delineation of the similarities and differences of equipment, construction, and operation and assessment of alternatives including adaptation of foreign technology to meet present United States railroad operational requirements. At the equipment level, this could include test and evaluation of foreign locomotives and fixed plant equipment on United States properties and test facilities and evaluation of locomotives designed to United States requirements on foreign properties.

3. Electrification Standards:

Standards should be prepared for electrification facilities to insure safety, compatibility with other services, and the utilization of reasonably uniform equipment. Standards committees should be formed to assume responsibility for evolving the recommended practices into sets of standards as use and review establishes their validity. A start must be made in the preparation of standards long before designs for equipment are frozen for major production, because time is required for standards to be reviewed by public agencies and by industry groups before their acceptance.

4. Feasibility Studies:

An engineering economic analysis is an important element of the decision-making process through which railroads go when considering electrification. The accuracy of the cost assumptions which go into the analysis need to be better defined since the uncertainties associated with the cost estimates, coupled with the unfamiliarity of the U.S. railroads with modern electrified rail operations, has led to a "let's not be first" attitude toward electrification. This work would lead to development of a more believable base of data for such parameters as the maintenance cost of the electric locomotive versus the diesel-electric, the first cost of the electrified installation, and the cost projections of petroleum versus electrical energy.

Most of the railroads contacted in the course of this study expressed an interest in a Government-sponsored demonstration. The issues giving rise to a demonstration are the uncertainties in electrifying which can be evaluated only during the actual implementation of the project. The uncertainties include changes in locomotive dispatching procedures and operations, the effect of inducing stray currents into both railroad and non-railroad communication and other systems, the problems (cost and delays) which could be encountered from environmental issues, the actual cost of constructing the system, the interface with the utility systems, the interruptions which would occur in implementing electrification into an operating railroad, etc. The ramifications of a Government-sponsored demonstration should be evaluated in the context of such questions as: Is a demonstration needed or desirable? Where, when and how comprehensive should the demonstration be? Who underwrites the cost? How extensive is the railroad involvement? An assessment of these issues would assist in the overall understanding of electrification as an investment alternative for the railroads.

5. Railroad/Utility Interface Improvements:

The nature of the railroad electric load is unique, requiring connection to the electric utility system which would need to provide larger than normal reserves of generation and transmission capacity. Since the capital cost of investment in this and in the transmission line extensions would probably be passed on to the railroad, research and development should be initiated to reduce the impact of utility capital cost on the energy costs of the railroads. Study efforts should also be undertaken in the areas of peak demand reduction, phase balance improvements, reactive power reduction, and regenerative power management.

6. Equipment Improvements:

The amount of catenary installed in the United States in the last 40 years has not been sufficient to preserve and update the installation techniques and skills developed in the first quarter of the century. In addition, the procedures used in recent projects in this country have not been concerned with track blockage, because installation was not over main line tracks where interface with revenue operation is critical. The experience of recent, foreign, catenary installation techniques should be studied to determine their applicability to U.S. rail operations. In the area of economical catenary design, one can also look to the wealth of experience accrued in Europe which could offer proven catenary designs for possible use in this country. The large capital investment required for catenary and installation labor make it prudent to examine alternative designs that can provide satisfactory performance at reduced expense. Research and development should be undertaken to identify and evaluate new catenary designs which could provide significant reductions in equipment and labor costs.

In the area of locomotive and multiple-unit motive power, research and development should be undertaken to develop techniques and equipment for use on locomotives to raise the tractive and braking efforts under all conditions. The payoff will be greater productivity by each locomotive because of increased acceleration, deceleration, and drag power on grades. Research and development of advanced propulsion systems should continue in order to achieve increased horsepower and productivity of the locomotive without increasing its weight, improved truck dynamics by reduced motor weight for a given horsepower unit, and reduced motor maintenance and reduced levels of harmonics and electromagnetic interference through the use of brushless AC traction motors.

7. Long-Range Research and Development:

The development of second-generation railroad electrification equipment should be encouraged by investing seed money in universities and equipment manufacturers for research into innovative design techniques. Investigation into linear motor technology for brake systems falls in this category, as does direct current traction systems. Also, the use of high-voltage DC catenary could offer cost savings from increased substation spacing because of a lower voltage drop associated with DC systems. The state-of-the-art does not permit implementation of a high-voltage catenary at this time at a power level required for main line freight-hauling applications.

8. Conclusion:

The know-how required to implement electrified rail operations is available within the United States, as attested by the recently constructed facilities of the Black Mesa & Lake Powell, Muskingum Electric, and the Texas Utility Company railroad projects. These are special coal mine-site to electric power plant installations, however, and do not answer all of the questions which would arise in implementing electrification on a main line common carrier railroad. The electrification work associated with the Northeast Corridor Improvement Program more closely complements a main line freight operation, and this experience should add to the U.S. capability to undertake freight railroad electrification. Given the premise that railroad electrification will continue in the United States, technology assessments and improvement should be conducted to improve the cost, performance, and safety of electrified rail operations. A demonstration project, one of the best ways to reduce overall risk, should be thoroughly evaluated.

I. National Implications of Railroad Electrification

1. Industrial Activity:

The decision to initiate extensive railroad electrification in this country would probably involve, at first, conversion of above 10,000 miles of the most heavily utilized rail routes, ones that carry about 40 MGT or more annually. Then, as future economic and energy considerations might dictate, the next stage would be to extend electrification, perhaps, to approximately 26,000 miles, which would handle about 50 percent of the nation's rail freight ton-miles. A reasonable rate of conversion appears to be about 1,000 miles per year. Most of the industrial activity would be in civil construction, catenaries, substations, signals and communications modifications, transmission lines, added generating capacity (when and if needed) and locomotive manufacture.

a. Manufacturing Capability

At present, there are relatively few U.S. equipment suppliers of electric traction gear for railroad electrification. This is primarily due to the very limited domestic market. A few large U.S. electrical manufacturing firms plus several smaller suppliers do, however, offer a line of electrification hardware. Further, it would be a relatively easy shift for U.S. domestic locomotive manufacturers, to use at least a portion of their existing locomotive manufacturing facilities for the production of electric locomotives, as both major U.S. locomotive manufacturers have built electric locomotives recently.

Traction substation equipment, suitable for modern high voltage AC railroad electrification, is not an "off-the-shelf-item," but could be produced by several electrical equipment suppliers in this country, by making minor modifications to existing, commercially available products. Catenary components are currently offered by at least two U.S. manufacturers, and no doubt others would become interested if any major electrification program were undertaken.

Given enough time to increase production facilities, U.S. equipment manufacturers, if required, could conceivably handle up to several thousand miles of new electrification equipment and facilities a year. Also, foreign suppliers of electric locomotives and electrification equipment, all with a great deal of experience in the field, have demonstrated their willingness to license their products to U.S. manufacturers. This has been demonstrated on the Amtrak lightweight locomotive procurement.

Engineering design and construction management would comprise between 5 to 20 percent of the total project costs. (Ref. 3, p. 81) There are numerous large architectural and engineering firms, construction management companies and private consultants that are interested and have varying degrees of expertise in electrification that would be in a position to design and manage a large scale conversion program in this country.

b. Materials

The principal materials needed for railroad electrification construction would be aluminum, brass, and copper for transmission lines, catenaries, signal and communications systems; structural steel and concrete for civil construction and catenary supports; and copper and steel for the manufacture of transformers, switchgear, locomotives, and power generation equipment. Lesser amounts of other specialized materials would also be required, such as porcelain for insulators and neoprene for cable insulation.

Estimates place the amount of copper needed to construct a single-track route-mile of electrification at approximately six tons per mile. Thus, 1,000 miles of double-track electrification would require about 12 thousand tons of copper. This figure represents less than one half of one percent of this country's 1977 (projected) copper production. Copper is not a scarce mineral, and a one percent increase in consumption could easily be accommodated by the U.S. copper industry. (Ref. 7, p. 189)

Supplies of aluminum are even more plentiful than copper, although the supply depends on the availability of foreign sources, which may not be as secure. Structural steel, concrete and the relatively small quantities of porcelain and other specialized materials would not be a problem to supply.

c. Employment

The number of new jobs created by the construction of new electrification equipment and facilities, and the wages therefrom, have been estimated in two different ways. The first estimates the number of man-hours required directly for the manufacture and installation of equipment. Numbers are quoted in the range of 2.5 to 10 million man-hours per 1,000 route miles of electrification, which at the average (no overtime) pace of 2,000 hours per worker per year, would result in 1,250 to 5,000 new jobs annually. (Ref. 36 and 37) At an estimated average employee wage of $20,000 per year, this would inject $25 to $100 million into the economy. It should be noted that this represents only direct manufacturing and installation labor, without regard to the supporting workforce multiplier, which might be several times actual on-site employment.

The second estimate involves the total employment impact of railroad electrification, including the domino effect on other industries. This was done by means of a sophisticated economic technique known as input-output analysis. It involved the application of input-output ratios worked out by the U.S. Department of Commerce, so that a dollar spent in any one category, in this case electrified railroad construction, can be divided into approximately 80 pieces (industries) and allocated to the industries which ultimately would benefit from the expenditure. (Ref. 38) The use of this input-output analysis resulted in an estimate of approximately 27,000 new jobs (man-years) created by each 1,000 miles of railroad electrification. (Ref. 7) Using average earnings within each industry which would benefit, total wages generated by each 1,000 miles of railroad electrification were computed to be almost $350 million. Table 32 presents this in a condensed, summary form.

In addition to the jobs generated in the industrial sector, the shift from petroleum to a mix of fuels for railroad electrification would shift a small amount of employment from oil production to coal mining. It has been estimated that the additional 7.7 million tons of coal that would be needed to generate the necessary electric power for a 26,000 mile electrified rail network would create employment for roughly 1,800 additional miners based upon a National Coal Association's estimate of the 1976 average coal mining rate being 14.5 tons per man per day.

TABLE 32

ESTIMATED DIRECT AND INDIRECT EMPLOYMENT
IMPACT OF RAILROAD ELECTRIFICATION

(Construction of each 1,000 route-miles)

	Jobs (man-years)	Wages ($1,000's)
New construction	6,791	$103,792
Wholesale and retail trade	3,044	26,691
Fabricated metal products	1,834	23,054
Stone and clay products	1,472	18,581
Transportation and warehousing	1,470	20,992
Lumber and wood products	1,376	14,586
Business services	1,212	14,758
Primary iron and steel manufacturing	1,087	17,515
Total 8 Industries	18,286	$239,969
Other 71 Industries	8,567	107,500
Total	26,853	$347,469

Source: Unified Industries, Inc., Ref. 131

Long-term railroad employment would also be affected, primarily in the area of locomotive maintenance. It has been estimated that electrification of the full 26,000 mile network could potentially reduce total railroad employment by 10,000 jobs. Such a reduction, however, would be over a long period of time (possibly 30 years or more) while the electrification network is being constructed.

2. Energy Sources and Uses:

Electrification of 26,000 miles of the highest traffic-density routes could reduce the railroads' diesel oil consumption by up to 50 percent, or roughly 2 billion gallons per year. The electricity needed to power this 26,000 mile network would probably be generated from a mix of fuel sources, shown in table 33, based on the 1985 estimated mix. (Also shown in figure 19)

TABLE 33

SUMMARY OF NATIONWIDE FUEL SOURCES FOR ELECTRIFICATION

Percent of Railroad Load	Type of Fuel	Fuel Consumed Annually
45.7%	Coal	6.5 million tons
11.2%	Gas	45 billion cu. ft.
5.7%	Oil	(netted out of oil savings shown above)
37.4%	All other	non-fossil fuel

While an annual savings of 2 billion gallons of diesel oil would represent a small percentage of total petroleum required for transportation, it would, for example, release enough to provide the equivalent heating for 1.3 million average American homes. (This is based upon 7.4 million homes, consuming an average of 209 million BTU's each (Source: National Petroleum Council).

These estimates assume there would be no major changes in the relative price of oil and electricity. However, if there were a drastic increase in the price of petroleum, without a comparable increase in the price of electricity, the economic feasibility and desirability of electrification would greatly improve. This situation could also change traffic patterns and have other effects on railroads. The relatively high price of petroleum would encourage a shift of traffic from highway to rail, and since electrification ROI increases proportionately to savings in energy costs, a jump in the price of oil (without an increase in the price of electricity) would make railroad electrification very economically attractive.

a. Energy Effects of a Modal Shift

Modal shifts from highway to rail, due to the unavailability or relatively high price of petroleum, could have a dramatic effect on potential diesel oil savings with electrification. Even without electrification, the fuel savings of a relatively small shift of passengers and freight from highway to the more energy-efficient rail mode could be sizeable. Railroad electrification would amplify this potential petroleum savings. With an electrified 26,000 mile railroad network, and a 10 percent diversion from highway intercity freight and passenger traffic, a 5 billion gallon, annual reduction in petroleum consumption will result. The relationship between modal shift and fuel savings is shown in figure 29.

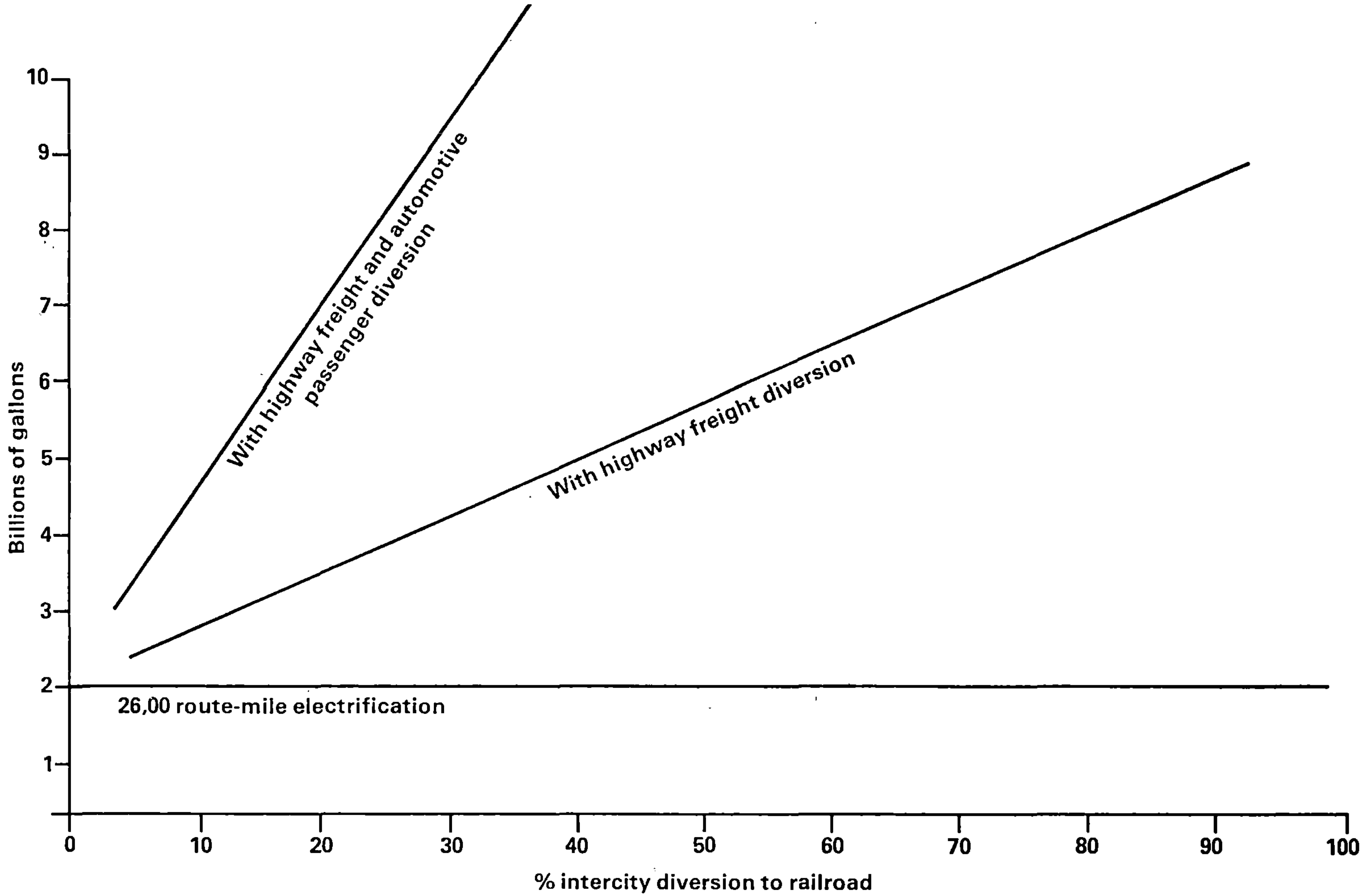
b. Effect of Energy Price Changes on Network ROI

A discounted cash flow analysis of the 10,000 and 26,000 mile networks (Network #1 and #2) was performed to measure the effect of major changes in energy prices and traffic levels on network ROI. The base assumptions for each network are shown in tables 34 and 35. Assuming no change in the relative prices of electricity and diesel fuel, the 10,000 and 26,000 mile networks would have base ROI's of 11 percent and 9 percent respectively. These "before tax" values are calculated assuming a 2 percent annual traffic growth and no inflation (i.e., constant dollars). If an energy differential rate, as was shown in figure 8, is introduced, the ROI's increase to 22 percent and 19 percent, respectively. By removing the energy differential rate and assuming, instead, an immediate doubling of the initial diesel fuel price, almost the same results can be obtained, i.e., the two network ROI's would be 21 percent and 18 percent. A tripling of the initial diesel fuel price, assuming no energy differential rate, would result in network ROI's of 31 percent and 27 percent, respectively. It can be seen from the above that ROI's would increase proportionately to the increase in the petroleum price.

Network ROI is also very sensitive to traffic levels. Because the investment would be essentially fixed, a doubling of traffic on the two networks (and the annual savings) would virtually double the respective ROI's. Thus, for example, if 10,000 miles were electrified and the initial price of diesel fuel and the base traffic level both doubled, the network ROI would jump to over 40 percent.

3. Balance of Payments:

United States dependence on petroleum imports, at record high levels, is growing. In 1976 the nation imported 41 percent of its oil at a price of around $36 billion, up from $3.7 billion spent on imported oil in 1971. (Ref. 19) Assuming the railroads utilized the same mix of domestic and imported oil as the country as a whole, they would have consumed roughly 1.6 billion gallons of imported oil in 1976. At an average of $0.30 per gallon, this amounts to potentially $480 million spent by railroads on foreign oil in 1976. If the 26,000 mile network had been electrified in 1976, approximately 44 percent of the railroad's fuel consumption -- over



Data Source: Ref. 136

FIGURE 29: POTENTIAL ANNUAL PETROLEUM SAVINGS THROUGH MODAL SHIFTS

TABLE 34

ROI ASSUMPTIONS FOR NETWORK #1 (10,000 miles)

Route Miles:	6,300 double track 3,700 single track and sidings
Track Miles:	10,000
Traffic Density:	502,470 mgt/year

INVESTMENT SCHEDULE

	$1000S
Catenary: 6,300 miles of double track @ $ 190,500/track-mile	1,200,150
4,255 miles of single track @ $ 98,348/track-mile	418,471
Substations: 10,000 miles @ $ 51,640 per mile	516,400
Utility connect costs: 10,000 miles @ $ 10,000 per mile	100,000
Signalling & communications modifications: 10,000 route miles @ $ 68,250/route mile	682,500
Civil reconstruction for catenary clearance:	361,625
Electric locomotives: 1,800 @ $ 940,000 each	1,692,000
Diesel locomotives transferred: 3,400 @ $ 375,000 each	-1,275,000

Net Investment	3,696,146

ANNUAL COSTS & CREDITS

	$1000S
Diesel locomotive replacement: 189 avg. @ $ 550,000	-103,950
Diesel energy: 950 million gal. @ 42.0 cents/gal.	-398,849
Diesel locomotive maintenance: 544.00 million miles @ 68.0 cents/mile	-369,920
Electric energy: 14,110 million kWH @ 2.7 cents/kWH	380,970
Electric locomotive maintenance: 333.00 million miles @ 29 cents/mile	96,570
Catenary maintenance: 10,000 miles @ $ 2,582/mile	25,820

Net Annual Savings	369,359

TABLE 35

ROI ASSUMPTIONS FOR NETWORK #2 (26,000 miles)

Route Miles: 10,400 double track 17,160 single track and siding
Track Miles: 26,000
Traffic Density: 945,800 mgt/year

INVESTMENT SCHEDULE

	$1000S
Catenary: 10,400 miles of double track @ $ 190,500/track-mile	1,981,200
17,160 miles of single track @ $ 99,909/track-mile	1,714,438
Substations: 26,000 miles @ $ 45,200 per mile	1,175,200
Utility connect costs: 26,000 miles @ $ 10,000 per mile	260,000
Signalling & communications modifications: 26,000 route miles @ $ 62,500/route mile	1,625,000
Civil reconstruction for catenary clearance:	858,000
Electric locomotives: 3,400 @ $ 940,000 each	3,196,000
Diesel locomotives transferred: 6,400 @ $ 375,000 each	-2,400,000

Net Investment	8,409,839

ANNUAL COSTS & CREDITS

	$1000S
Diesel locomotive replacement: 356 avg. @ $ 550,000	-195,800
Diesel energy: 1,760 million gal. @ 42.0 cents/gal.	-739,200
Diesel locomotive maintenance: 1,024.00 million miles @ 68.0 cents/mile	-696,320
Electric energy: 26,151 million kWH @ 2.7 cents/kWH	706,077
Electric locomotive maintenance: 629.00 million miles @ 29 cents/mile	182,410
Catenary maintenance: 26,000 miles @ $ 2,190/mile	56,940

Net Annual Savings	685,893

$200 million -- could have been saved in the balance of trade on foreign oil. In estimating the reduction in foreign oil imports effected through electrification, it could be rationalized that all diesel oil saved would be credited to reducing imports, thereby increasing the favorable impact on the balance of payments. Carrying this assumption ahead in time and assuming the price of oil will increase to $16 a barrel by 1990, a savings in balance of payments approaching $800 million annually could result. (Electrifying 26,000 miles could save approximately 48 million barrels of oil a year.)

4. Railroads' Economic Position:

American's railroads were the dominant form of intercity transportation up until the end of World War II. Since then, however, the railroads' share of intercity freight and passenger miles have declined markedly. (tables 36 and 37) Despite this decline in market share, railroad freight traffic has continued to grow, as illustrated in figure 30 and railroads remain the principal common carrier mode in terms of freight-ton miles. (Ref. 39)

The railroads' decline in market share can be attributed to many factors such as the rapid rate of technological development in rival forms of transportation, basic changes in market conditions, regulatory constraints, under-utilization of equipment and facilities, insufficient internal generation of capital, etc. It is possible that electrification could produce certain efficiencies in railroad operations which, together with other plant improvements, and regulatory pricing, and other reforms, could strengthen the industry and restore it to some of its earlier profitability. If such efficiencies could be translated into faster, more reliable and more economical service, railroads should also be able to attract new business and perhaps regain some of their recently lost market position. However, these potential benefits are very difficult to quantify and are the subject of a continuing debate between proponents and opponents of railroad electrification. No attempt has been made to quantify such benefits here.

5. Quality of the Environment:

The effects of widespread electrification on the quality of the environment were discussed at length in section V.D.

TABLE 36

VOLUME OF U.S. INTERCITY FREIGHT

(Billions of Ton-Miles)

Mode	1945 Amount	1945 %	1975 Amount	1975 %
Railroad	691	67.2	757	36.1
Truck	67	6.5	488	23.3
Oil Pipeline	127	12.4	507	24.2
Great Lakes	113	11.0	99	4.7
Rivers & Canals	30	2.9	243	11.6
Air	0.09	0.01	373	0.18
TOTAL	1,028	100	2,098	100

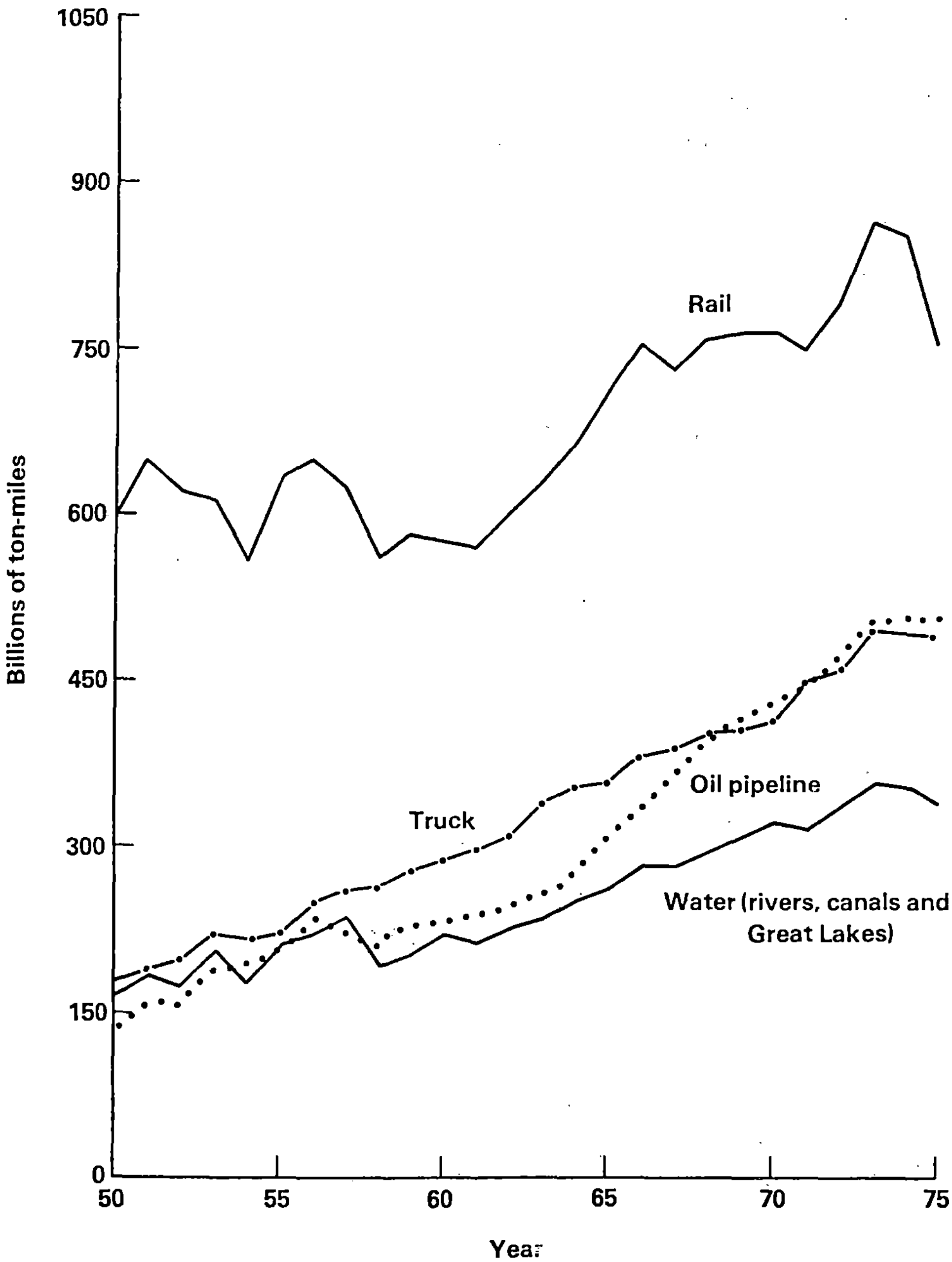
Source: TAA "Transportation Facts & Trends"

TABLE 37

INTERCITY PASSENGER TRAVEL BY MODE
(Billions of Passenger Miles)

Private Carrier	1945 Amount	1945 %	1975 Amount	1975 %
Auto	220.3	63.4	1,164.0	86.2
Air	--	--	11.1	0.8
TOTAL	220.3	63.4	1,175.1	87.0
Public Carrier				
Air	4.3	1.2	136.9	10.1
Bus	27.4	7.9	25.5	1.9
Rail	93.5	26.9	9.7	0.7
Water	2.1	0.6	4.0	0.3
TOTAL	127.3	36.6	176.1	13.0

Source: TAA "Transportation Facts & Trends"



Source:TAA"Transportation Facts & Trends

FIGURE 30: INTERCITY FREIGHT BY MODE

6. National Defense Transportation Considerations:

The Defense Department recently studied the U.S. railroad system and a Strategic Rail Corridor Network (STRACNET), composed of 30,000 corridor miles of railroad, was identified as being essential to national defense and strategic rail needs. (Ref. 40) Virtually all of the 26,000 route miles in the proposed electrification network are coincident with the STRACNET network.

Electrification would allow the strategic rail network to be powered from generating plants using primarily coal and uranium, both domestically abundant fuels, which might have important strategic implications.

One concern might be the increased vulnerability of the power supply to enemy attack in an electrified railroad network, compared to a non-electrified system. While certainly a valid consideration, this does not appear to be a strong deterrent, because, even if electrification were undertaken on a nationwide scale, only a small percentage of the diesel locomotive fleet would be displaced. At the end of 1975 there were over 28,000 diesel electric units in service on Class I railroads in the United States. At a maximum, electrification could displace up to 6,400 diesel-electric locomotives over the next 30 years. This means that even with widespread electrification, there would still be enough diesel-electric units remaining to handle an extreme emergency.

7. Conclusion:

The benefits of the relatively small fuel shift brought about by railroad electrification may be far more significant than the railroad's share of U.S. energy consumption might imply. Potential railroad efficiency benefits are certainly worth further evaluation and may be very significant. Electrification of the highest-density railroad routes would, if nothing else, substantially reduce the railroads' dependence on petroleum, an important consideration in long-range national policy decisions.

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IX. PRINCIPAL ABBREVIATIONS AND ACRONYMS

AAR	Association of American Railroads
AC	Alternating Current
AREA	American Railway Engineering Association
DC	Direct Current
DOE	United States Department of Energy
DOT	United States Department of Transportation
EPA	Environmental Protection Agency
ERDA*	Energy Research and Development Administration
FEA*	Federal Energy Administration
FPC**	Federal Power Commission
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
GW	Gigawatt (One Billion Watts)
GWH	Gigawatt-Hours
HZ	Hertz
ICC	Interstate Commerce Commission
KV	Kilovolt
KW	Kilowatt (One Thousand Watts)
KWH	Kilowatt - Hour
LIC	Line Identification Code
LRIC	Long Range Incremental Costing
MGTM	Thousand Gross Ton-Miles
MMBTU	Million BTU's
MMGTM	Million Gross Ton-Miles
MGT	Million Gross Ton-Miles per Route Mile per Year
VA	Megavolt-amperes
MW	Megawatt (One Million Watts)
MWH	Megawatt-Hour
NECIP	Northeast Corridor Improvement Program

OR&D	(FRA) Office of Research and Development
PIES	Project Independence Evaluation System
QUAD	Quadrillion BTU's
ROI	Return on Investment
SCR	Silicon Controlled Rectifier
STRACNET	Strategic Rail Corridor Network
TSC	Transportation Systems Center

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* Superseded by DOE

** Superseded by DOE (now part of Federal Energy Regulatory Commission).

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