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The Energy and Environmental Impact of Railroad Electrification

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13 - Electrification

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16. Abstract

This report describes the potential effects of railroad electrification for high traffic density lines in the United States. Two high traffic density groupings of routes are identified as candidates for electrification. The primary group consists of eleven highly utilized routes with traffic density of at least 40 million gross ton-miles per route mile per year. This grouping makes up 5% of the nation's total route mileage and carries about one-fourth of the total freight traffic. Sixty-six other high density routes are also identified as possible electrification candidates. A network of all candidates would total just under 40,000 miles, or 20% of the U.S. total, and carry two-thirds of the total freight traffic.

Energy consumption for the traffic on these candidate routes is estimated for the time frame of 1975 to 1990 in terms of current diesel fuel usage and the alternative electricity requirements. Effects of electricity generation and related changes in fuel usage are estimated for the electrification changeover. Based on 1975 railway traffic levels and utility fuel mixes, high level electrification would shift annual energy consumption from 2.39 billion gallons of diesel fuel to 35,540 gigawatt-hours of electricity primarily generated from 8.46 million tons of coal, 282 million gallons of fuel oil, and 63.5 billion cubic feet of natural gas. Environmental effects of railroad electrification are described and found to be quite minor when compared to current diesel power operations.

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INTRODUCTION

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, but it was not until 1879 in Germany that Werner von Siemens built and successfully demonstrated a small electric locomotive at an exhibition in Berlin.[1] The use of electricity from a stationary generating plant offered an attractive alternative to the steam locomotive on mountain lines and in underground railways. In the United States, electrification projects were undertaken as early as 1895 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 adjoining track. Passenger terminals and suburban lines were electrified to speed services and increase track capacity through utilization of the higher acceleration capability of electric traction compared to steam power. Heavy freight routes were electrified 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. After World War II, the picture changed. The nationalized European railroads, faced with rebuilding their fixed plant as well as replacing equipment, undertook extensive electrification, frequently aided by the availability of hydro-electric power in mountainous regions. The investor-owned railroads of the United States faced extensive capital requirements for replacing worn motive equipment and undertaking maintenance-of-way projects. They chose the diesel-electric locomotive units that now dominate railroad motive power in the nation's railroads. Today, as shown in Table I, many countries have sizeable portions of their railroad systems electrified. The North American countries are noticeable exceptions.

TABLE I

COMPARISON OF WORLD'S RAILROADS

COUNTRY	LAND AREA	POPULATION	RAILROAD ROUTE MILES	% ELECTRIFIED
UNITED STATES	3,675,545	208,615,000	200,000	LESS THAN 1%
U.S.S.R.	8,649,500	243,722,000	84,000	27%
CANADA	3,851,809	21,530,000	41,000	nil
INDIA	1,261,597	548,806,000	37,000	9%
FRANCE	211,208	51,402,000	23,000	25%
WEST GERMANY	95,961	61,620,000	19,000	29%
JAPAN	142,727	102,948,000	17,000	40%
MEXICO	761,604	50,636,000	15,000	LESS THAN 1%
POLAND	120,665	32,912,000	14,000	17%
UNITED KINGDOM	94,224	56,112,000	13,000	16%
ITALY	116,304	53,600,000	12,000	47%
SWITZERLAND	15,941	6,270,000	9,000	99%
SWEDEN	173,666	8,083,000	7,000	60%
NORWAY	125,182	3,876,000	3,000	57%
NETHERLANDS	13,961	13,095,000	2,000	52%

References: 2, 3, 4

Both the United States government and the railroads have shown recent interest in railroad electrification. A joint government-industry task force examined the subject and in 1974 recommended continued cooperation in evaluating its benefits.[2] The discussion continues today both in open forum, such as conference sessions devoted to the issue[5] and in statements of interest by railroad officials.[6]

The interest of the railroads in electrification is essentially economic. It involves the potential for an improved profit (primarily by reducing operating costs) through the investment of capital (in fixed plant). This question of capital investment and the return on it determines the potential of electrification for a railroad.

The interest of the government, however, centers on what can be termed national benefits - the effects on the national economy and the social costs in terms of energy, the environment, and safety. Railroad electrification can affect these costs. The primary effect would be in energy. Electrification provides a means of shifting railroad operations from petroleum-derived diesel fuel to other sources. It thus provides an option to change a portion of the nation's transportation energy consumption from an essentially 100 percent petroleum base. With present technology, it is the only feasible and efficient way to do so. The shift from petroleum, however, would be relatively small compared to total consumption by the transportation sector.

In calling for the study of railroad electrification in Section 901 (7) of the Railroad Reorganization and Regulatory Reform Act of 1976,[7] the Congress expressed an interest in comparing the potential petroleum savings and the economic and social benefits with the costs of electrification. Such data will allow railroad electrification to be ranked in relationship to the benefits and costs of other energy actions and policy options. This report deals with quantifying and assessing the energy and environmental impact involved in an extensive undertaking of railroad electrification. The study considers high traffic density railroad lines having suitable operational characteristics as potential candidates for electrification. Two levels of implementation are projected and evaluated. A number of railroads have considered electrifying portions of their routes, but a more extensive electrified network is established in this study in order to develop a substantial fuel shift.

The portions of the nation's rail system and the rail freight traffic that show potential for conversion to electrified operation are identified in the next section. The energy consumption - diesel fuel and fuel for the generation of electricity - are then estimated for the alternatives of diesel-electric and all-electric motive power. Next, the environmental factors associated with a shift to electric operations are identified. The report closes with conclusions drawn from the data that have been developed.

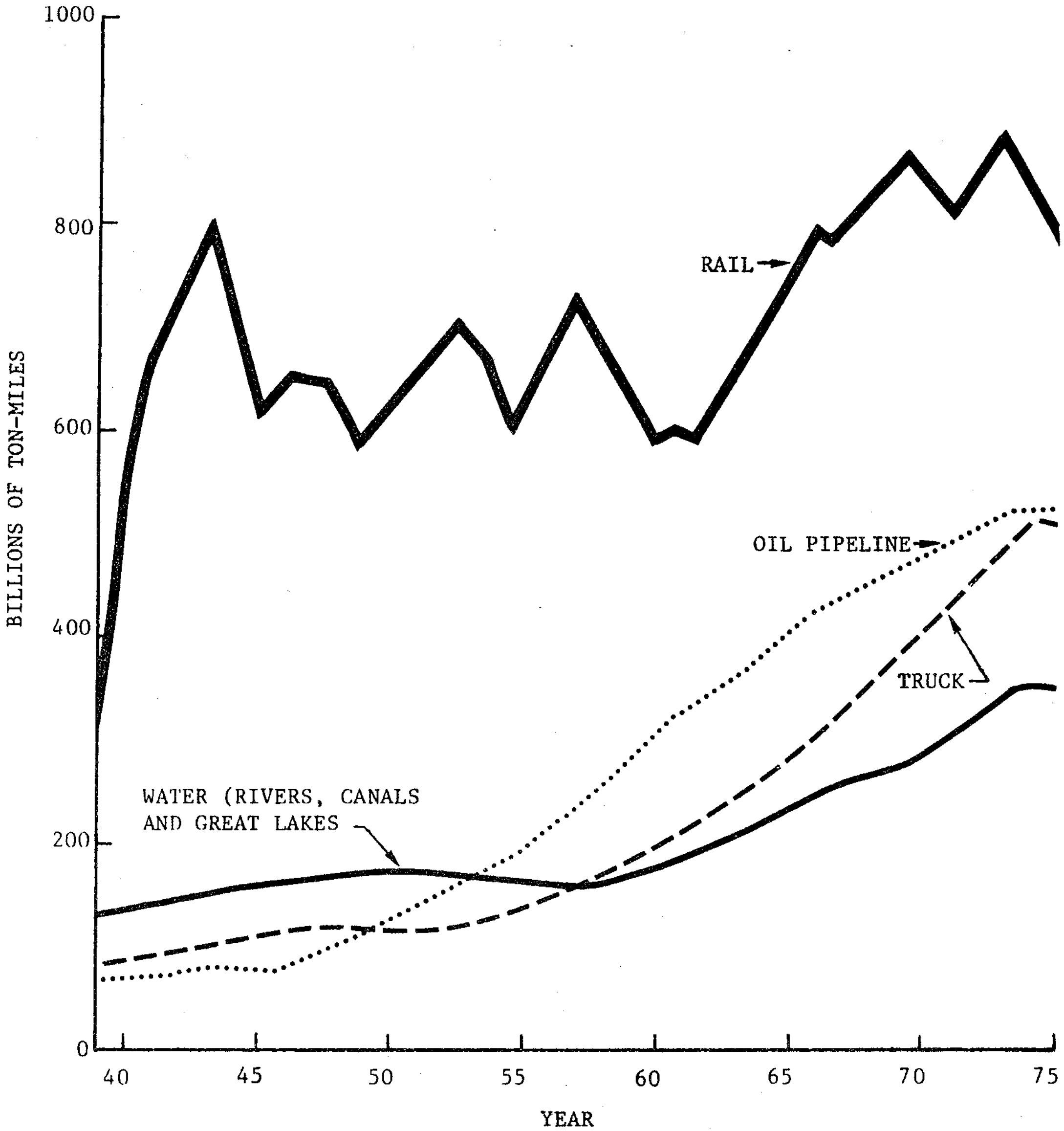
RAILROAD OPERATIONS AND ELECTRIFICATION

BACKGROUND

The term *United States Rail System* carries several connotations. The term might refer to the railroad facilities and routes throughout the nation; it might refer to the many railroad operating companies themselves; or it might refer to some portion of those facilities and companies for which numerical statistics are readily available. Under any of these definitions the system is marked by diversity. The size of the operating companies varies from giants of the industry to those that are very small, the utilization of track varies from trackage that carries several trains every hour to other that supports only a few car movements a year, and the characteristics of railroading operations vary from the all-inclusive major railroad to those performing very specialized small functions. Thus, when speaking of the characteristics of the U.S. rail system, one is usually talking about some convenient aggregation of factors. In describing the physical characteristics of the U.S. rail system, it is convenient to use the characteristics of Class I railroads[8] (the Interstate Commerce Commission defines a Class I railroad as one with an annual gross income of over $10,000,000). These companies dominate the railroading statistics and provide a good evaluation of the position of the railroad industry in the United States transportation picture. There were 52 Class I line-haul railroads in April 1977.

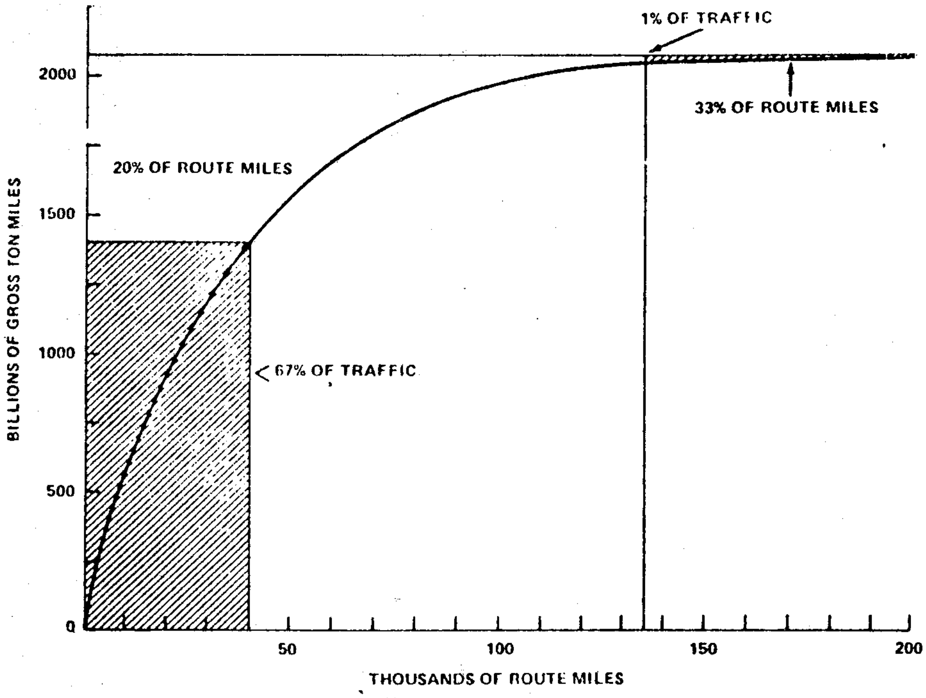
The Class I railroads now operate about 193,500 miles of route.[9] The total, considering the Class I and all other line-haul roads and the switching and terminal companies, comes to approximately 200,000 miles of line-haul route while the total trackage, including multiple main tracks, sidings and yard tracks, comes to about 325,500 miles. Both trackage and route structure have been decreasing for the past fifty years. The operations of Class I railroads include 403 million freight train-miles, carrying 761,000 million freight ton-miles annually. The railroads have generally maintained a growing record of freight movement, as shown in Figure 1, remaining the number one common carrier mode in terms of freight ton-miles, although the market share is one-half of that enjoyed by the railroads in 1930. Passenger service is not now a major factor in railroading, accounting for only 65 million train-miles and 10,000 million passenger miles, 5.7 percent of U.S. passenger travel. Another measure of utilization is the traffic passing over each individual mile of line. The operations of a railroad are frequently expressed in terms of gross tons - that is the weight of freight, cars and locomotives. In terms of an average, each mile of route carries about 10 million gross tons of traffic annually. The distribution of this traffic varies widely, however, with the 20 percent of the total mileage that is most heavily utilized accounting for over 67 percent of the total traffic. On the other hand, the most lightly used 33 percent of the total accounts for only 1 percent of the traffic. The correlation of freight traffic and route miles is illustrated in Figure 2.

Diesel-electric locomotives (diesel engine, electric drive) are the standard motive power of the industry in the United States. The steam locomotive was predominant through the end of World War II, but the diesel-electric essentially replaced it in the decade from 1946 through 1955. All-electric locomotives, drawing power from an electrical distribution system, while popular in Europe, are used only to a small degree here. The United States did lead the world in electrification in 1932 with 2500 miles of electrified route in operation, but by 1974 the mileage had dropped to 1122 miles of route (3525 miles of track).



Reference: 10

FIGURE 1
INTERCITY FREIGHT BY MODE



Reference: 9

FIGURE 2
A CORRELATION OF RAIL FREIGHT CARRIED AND ROUTE MILES FOR CLASS I RAILROAD LINES IN THE UNITED STATES

ROUTES WITH POTENTIAL FOR ELECTRIFICATION

The capital investment required to electrify a rail line dictates that the route must be highly utilized 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 - 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. One convenient measure of route utilization is traffic density (annual traffic between two points in ton-miles divided by the route length in miles). The identification of the high density lines with suitable operational characteristics for electrification comprised the first step of this study.[11] The selection of specific rail lines in the United States rail system as candidate segments for electrification was performed at a level of detail sufficient to assess the factors associated with a conversion to electrified operations.

Candidate Segments

Candidate segments for electrification reflect a high traffic density and suitable end points for electrified operations by the individual railroads. Appendix I presents the factors and procedures used to select these candidate segments, which were classified into two levels of service. Service Level 1 indicates the highest density routes, generally with a traffic density of over 40 MGT (million gross ton-miles per route mile per year). Service Level 2 indicates other high density routes, generally with a traffic density of 20 MGT to 40 MGT, that could be suitably operated as electrified lines. The Service Level 1 lines are listed in Table II and the Service Level 2 lines are listed in Table III. Both levels are shown in Figure 3 (Table IV presents the railroad codes used in Figure 3).

TABLE II

CANDIDATE RAILROADS/ROUTES FOR ELECTRIFICATION SERVICE LEVEL I

RAILROAD - ROUTE	TOTAL ROUTE MILES
ATCHISON, TOPEKA & SANTA FE	
CHICAGO, IL-LOS ANGELES, CA	2288.60
CHESSIE SYSTEM (BALTIMORE & OHIO)	
CHICAGO, IL-WASHINGTON, D.C.-BALTIMORE, MD	789.40
CHESSIE SYSTEM (BALTIMORE & OHIO)	
TOLEDO-CINCINNATI, OH	181.50
CHICAGO & NORTHWESTERN	
CHICAGO, IL-COUNCIL BLUFFS, IA	506.30
CALIFORNIA JCT., IA-FREMONT, NB (BRANCH ROUTE)	34.00
CONRAIL	
CLEVELAND, OH-NEWARK, NJ	597.50
PITTSBURGH-JOHNSTOWN, PA (SECOND ROUTE)	91.80
HARRISBURG-PARKESBURG, PA (SECOND ROUTE)	65.00
CONRAIL	
CHICAGO, IL-SELKIRK, NY	850.80
NORFOLK & WESTERN	
BELLEVUE, OH-NORFOLK, VA	712.00
NARROWS-ROANOKE, VA (SECOND ROUTE)	80.00
ROANOKE-BURKEVILLE, VA (SECOND ROUTE)	208.00
SOUTHERN	
CINCINNATI, OH-ATLANTA, GA	470.50
SOUTHERN PACIFIC	
EL PASO, TX-LOS ANGELES, CA	838.50
SOUTHERN PACIFIC	
OGDEN, UT-ROSEVILLE, CA	589.10
UNION PACIFIC	
COUNCIL BLUFFS, IA-SALT LAKE CITY, UT	1016.70
GIBBON, NB-KANSAS CITY, KS (BRANCH ROUTE)	282.00
GRANGER, WY-POCATELLO, ID (BRANCH ROUTE)	215.00

TABLE III

CANDIDATE RAILROADS/ROUTES FOR ELECTRIFICATION

SERVICE LEVEL II

RAILROAD - ROUTE	TOTAL ROUTE MILES
ATCHISON, TOPEKA, & SANTA FE CLOVIS, NM-TEMPLE, TX	452.10[1]
ATCHISON, TOPEKA, & SANTA FE BARSTOW-RICHMOND, CA	455.10[2]
ATCHISON, TOPEKA, & SANTA FE KANSAS CITY, KS-HOUSTON, TX	844.00[3]
BESSEMER & LAKE ERIE CONNEAUT, OH-UNITY JCT., PA	130.00
BURLINGTON NORTHERN CHICAGO, IL-LAUREL, MT	1410.50[4]
BURLINGTON NORTHERN CHICAGO, IL-VANCOUVER, WA-PORTLAND, OR	2237.50[4]
CHENEY-PASCO, WA (SECOND ROUTE)	149.20
BURLINGTON NORTHERN FARGO, ND-LAUREL, MT	615.00
BURLINGTON NORTHERN MINNEASPOLIS, MN-CASSELTON-NOLAND, ND	283.00
BURLINGTON NORTHERN SUPERIOR, WS-FARGO, ND	345.50
BURLINGTON NORTHERN LINCOLN, NB-KANSAS CITY, MO	208.10
BURLINGTON NORTHERN ALLIANCE, NB-FT. WORTH, TX	993.70
DENVER-WALENSBURG, CO (SECOND ROUTE)	169.00
CHESSIE SYSTEM (BALTIMORE & OHIO) BALTIMORE, MD-PHILADELPHIA, PA	100.20
CHESSIE SYSTEM (BALTIMORE & OHIO) CUMBERLAND, MD-GRAFTON, WV	90.00
CHESSIE SYSTEM (CHESAPEAKE & OHIO) TOLEDO, OH-NEWPORT NEWS, VA	745.50

TABLE III (CONTINUED)

RAILROAD - ROUTE	TOTAL ROUTE MILES
CHESSIE SYSTEM (CHESAPEAKE & OHIO)	
CHICAGO, IL-DETROIT, MI	333.10[5]
CHESSIE SYSTEM (CHESAPEAKE & OHIO)	
TOLEDO, OH-SAGINAW, MI	125.00
CHESSIE SYSTEM (CHESAPEAKE & OHIO)	
CATTLETTSBURG-ELKHORN CITY, KY	128.00
CHICAGO & NORTHWESTERN	
NELSON-E. ST. LOUIS, IL	216.50
CONRAIL	
NEWARK, NJ-SELKIRK, NY	141.40
CONRAIL	
E. ST. LOUIS, IL-CONWAY, PA	574.50[6]
CONRAIL	
DETROIT, MI-CINCINNATI, OH	271.60[7]
UNION CITY-CLEVELAND, OH (BRANCH ROUTE)	194.00[7]
COLUMBUS-DAYTON, OH (BRANCH ROUTE)	62.50
CONRAIL	
NEWARK, NJ-ALEXANDRIA, VA	222.70
PHILADELPHIA-DOWINGTOWN, PA (BRANCH ROUTE)	27.60
PERRYVILLE, MD-HARRISBURG, PA (BRANCH ROUTE)	72.00[8]
CONRAIL	
BOSTON, MA-SELKIRK, NY	189.70
CONRAIL	
HARRISBURG-RENOVO, PA	162.00[9]
CONRAIL	
ASHTABULA, OH-PITTSBURGH, PA	114.60[10,11]
DULUTH, MISSABE & IRON RANGE	
DULUTH, MT.-IRON, MN	63.00
DENVER & RIO GRANDE WESTERN	
SALT LAKE CITY, UT-DENVER, CO	538.70
DOTSERO-PUEBLO, CO (BRANCH ROUTE)	224.00
FAMILY LINES (CLINCHFIELD)	
ELKHORN CITY, KY-GREENWOOD, SC	335.50
FAMILY LINES (LOUISVILLE & NASHVILLE)	
CHICAGO, IL-NASHVILLE, TN	458.50[12,13]

TABLE III (CONTINUED)

RAILROAD - ROUTE	TOTAL ROUTE MILES
FAMILY LINES (LOUISVILLE & NASHVILLE)	
NASHVILLE, TN-NEW ORLEANS, LA	516.80
FAMILY LINES (LOUISVILLE & NASHVILLE)	
LOUISVILLE, KY-ATLANTA, GA	478.30[13,14]
FAMILY LINES (LOUISVILLE & NASHVILLE)	
CINCINNATI, OH-ATLANTA, GA	434.30[14]
FAMILY LINES (LOUISVILLE & NASHVILLE)	
WINCHESTER-HAZARD, KY	118.00
FAMILY LINES (SEABOARD COAST LINE)	
RICHMOND, VA-TAMPA FL	829.50[15,16]
HAMLET, NC-DILLON, SC (BRANCH ROUTE)	38.00
SAVANNAH-WAYCROSS, GA (BRANCH ROUTE)	91.10[16]
FAMILY LINES (SEABOARD COAST LINE)	
RICHMOND, VA-ATLANTA, GA	573.10[15]
FAMILY LINES (SEABOARD COAST LINE)	
JACKSONVILLE, FL-ATLANTA, GA	330.30
GRAND TRUNK WESTERN	
CHICAGO,IL-PORT HURON, MI	320.50
DURAND-DETROIT, MI (BRANCH ROUTE)	71.70
ILLINOIS CENTRAL GULF	
CHICAGO, IL-NEW ORLEANS, LA	919.40
EDGEWOOD, IL-FULTON, KY (SECOND ROUTE)	167.50
MILWAUKEE ROAD	
CHICAGO, IL-ST. PAUL, MN	445.80
MISSOURI PACIFIC	
ST. LOUIS, MO-FORT WORTH, TX	776.30[17]
BALD KNOB, AR-MEMPHIS, TN (BRANCH ROUTE)	88.30
MISSOURI PACIFIC	
KANSAS CITY-ST. LOUIS, MO	296.80[18]
MISSOURI PACIFIC	
CHICAGO-E. ST. LOUIS, IL	293.00[12]
NORFOLK & WESTERN	
KANSAS CITY, MO-BUFFALO, NY	934.80
NORFOLK & WESTERN	
CHICAGO, IL-FORT WAYNE, IN	159.20

TABLE III (CONTINUED)

RAILROAD - ROUTE	TOTAL ROUTE MILES
NORFOLK & WESTERN BELLEVUE, OH-PITTSBURGH, PA	180.90
NORFOLK & WESTERN NORTON-BLUEFIELD, VA	101.00
PITTSBURGH & LAKE ERIE ASHTABULA, OH-PITTSBURGH, PA	173.00[10,19]
RICHMOND, FREDICKSBURG & POTOMAC RICHMOND-ALEXANDRIA, VA	118.50
ST. LOUIS - SAN FRANCISCO MEMPHIS, TN-KANSAS CITY, MO	475.00
ST. LOUIS - SAN FRANCISCO MEMPHIS, TN-BIRMINGHAM, AL	235.40
ST. LOUIS - SAN FRANCISCO ST. LOUIS, MO-OKLAHOMA CITY, OK	528.00
SOUTHERN E. ST. LOUIS, IL-DANVILLE, KY	366.00
SOUTHERN HARRIMAN JCT.-KNOXVILLE, TN	50.00
SOUTHERN ATLANTA, GA-ALEXANDRIA, VA	614.10
SOUTHERN NEW ORLEANS, LA-ATLANTA, GA	528.30[20]
SOUTHERN MEMPHIS, TN-BIRMINGHAM, AL	282.20
SOUTHERN CHATTANOOGA, TN-SALISBURY, NC	366.00[21]
SOUTHERN ATLANTA-MACON, GA	87.50
SOUTHERN PACIFIC EL PASO, TX-NEW ORLEANS, LA	1158.80
SOUTHERN PACIFIC PORTLAND, OR-ROSEVILLE, CA	627.00
SOUTHERN PACIFIC ROSEVILLE-OAKLAND, CA	71.00

TABLE III (CONCLUDED)

RAILROAD - ROUTE	TOTAL ROUTE MILES
SOUTHERN PACIFIC SACRAMENTO-COLTON, CA	462.00[2]
SOUTHERN PACIFIC (ST. LOUIS-SOUTHWESTERN) E. ST. LOUIS, IL-FLATONIA, TX	979.50[17]
UNION PACIFIC POCATELLO, ID-PORTLAND, OR	715.10
UNION PACIFIC SALT LAKE CITY, UT-LOS ANGELES, CA	784.60[22]
WESTERN PACIFIC SALT LAKE CITY, UT-SACRAMENTO, CA	773.10

1. 10.1 miles included in AT&SF, CHICAGO, ILL-LOS ANGELES, CA
2. 65.0 miles included in AT&SF, BARSTOW-RICHMOND, CA and SOUTHERN PACIFIC, SACRAMENTO-COLTON, CA
3. 174.0 miles included in AT&SF, CHICAGO, IL-LOS ANGELES, CA
4. 45.0 miles included in BN, CHICAGO, IL-LAUREL, MT and BN, CHICAGO, IL-VANCOUVER, WA-PORTLAND, OR
5. 61.8 miles included in CONRAIL, CHICAGO, IL-SELKIRK, NY
6. 34.0 miles included in CONRAIL, CLEVELAND, OH-NEWARK, NJ
7. 16.0 miles included in CONRAIL, DETROIT, MI-CINCINNATI, CH and CONRAIL, UNION CITY-CLEVELAND, OH
8. 40.0 miles included in CONRAIL, CLEVELAND, OH-NEWARK, NJ
9. 7.0 miles included in CONRAIL, CLEVELAND, OH-NEWARK, NJ
10. 53.0 miles included in CONRAIL, ASTABULA, OH-PITTSBURGH, PA and PLE, ASHTABULA, OH-RIVERTON, PA
11. 26.6 miles included in CONRAIL, CLEVELAND, OH-NEWARK, NJ
12. 89.0 miles included in FAMILY LINES (LOUISVILLE & NASHVILLE), CHICAGO, IL-NASHVILLE, TN and MP, CHICAGO, IL-E. ST. LOUIS, MO
13. 10.0 miles included in FAMILY LINES (LOUISVILLE & NASHVILLE), CHICAGO, IL-NASHVILLE, TN and FAMILY LINES, LOUISVILLE, KY-ATLANTA, GA
14. 42.3 miles included in FAMILY LINES (LOUISVILLE & NASHVILLE), LOUISVILLE, KY-ATLANTA, GA and FAMILY LINES, CINCINNATI, OH-ATLANTA, GA
15. 20.1 miles included in FAMILY LINES (SEABOARD COAST LINE), RICHMOND, VA-TAMPA, FL and FAMILY LINES, RICHMOND, VA-ATLANTA, GA
16. 3.1 miles included in FAMILY LINES (SEABOARD COAST LINE), RICHMOND, VA-TAMPA, FL and FAMILY LINES, SAVANNAH-WAYCROSS, GA
17. 183.5 miles included in MISSOURI PACIFIC, ST. LOUIS, MO-FORT WORTH, TX and SOUTHERN PACIFIC, E. ST. LOUIS, IL-FLATONIA, TX
18. 13.8 miles included in AT&SF, CHICAGO, IL-LOS ANGELES, CA
19. 58.6 miles included in CHESSIE SYSTEM, CHICAGO, IL-WASHINGTON, DC-BALTIMORE, MD

20. 10.0 miles included in SOUTHERN, CINCINNATI, OH-ATLANTA, GA

21. 17.0 miles included in SOUTHERN, CINCINNATI, OH-ATLANTA, GA

22. 87.0 miles included in AT&SF, CHICAGO, IL-LOS ANGELES, CA

TABLE IV

RAILROAD CODES USED IN FIGURE 3

RR ABBREV.	RAILROAD NAME
BLE	BESSEMER & LAKE ERIE
BN	BURLINGTON NORTHERN
BX	BALTIMORE & OHIO
CCX	CLINCHFIELD
CH	CHICAGO & NORTH WESTERN
CR	CONRAIL
CX	CHESAPEAKE & OHIO
DMI	DULUTH, MISSABE & IRON RANGE
DRG	DENVER & RIO GRANDE WESTERN
GTW	GRAND TRUNK WESTERN
ICG	ILLINOIS CENTRAL GULF
LN	LOUISVILLE & NASHVILLE
MP	MISSOURI PACIFIC
MW	CHICAGO, MILWAUKEE, ST. PAUL & PACIFIC
NW	NORFOLK & WESTERN
PLE	PITTSBURGH & LAKE ERIE
RFP	RICHMOND, FREDRICKSBURG & POTOMAC
S	SOUTHERN RAILWAY SYSTEM
SF	ATCHISON, TOPEKA & SANTA FE
SL	ST. LOUIS-SAN FRANCISCO
SP	SOUTHERN PACIFIC
SZ	SEABOARD COASTLINE
UP	UNION PACIFIC
WP	WESTERN PACIFIC

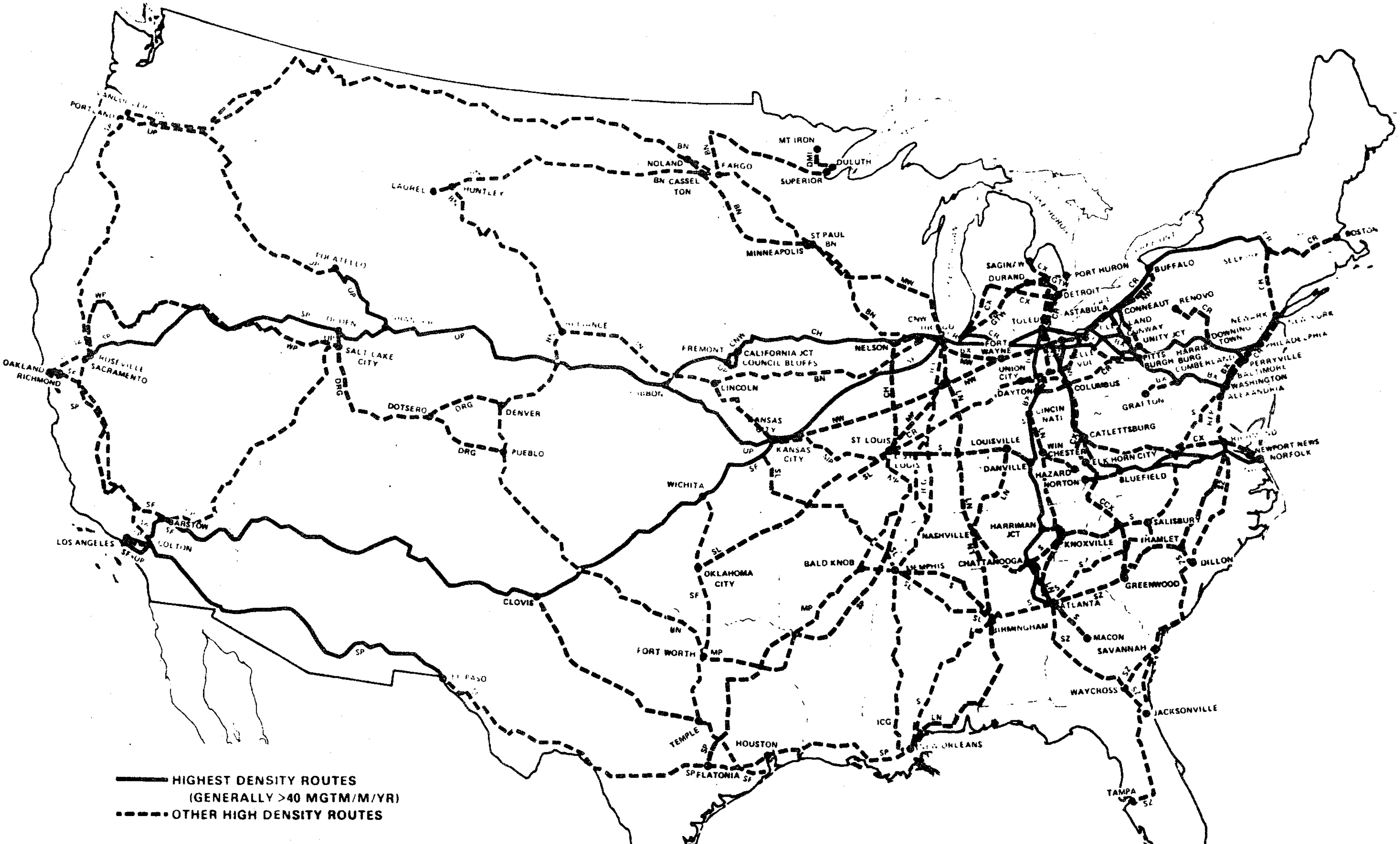


Figure 3
ROUTES WITH SUITABLE CHARACTERISTICS FOR ELECTRIFIED OPERATIONS

The Service Level 1 routes, taken together, form a fairly basic network. The Santa Fe route extends from Chicago to Los Angeles while a Chicago to northern California (Roseville) route is provided by Chicago & Northwestern, Union Pacific, and Southern Pacific. The basic Union Pacific segment includes branches to Kansas City and Pocatello (the latter based on operational requirements rather than traffic density). The Southern Pacific also has a southern route, El Paso to Los Angeles. Conrail routes extend eastward from Chicago, with one route to Selkirk, N.Y., and another branching off at Cleveland and extending to Newark (Oak Island Yard), N.J., via Conway Pa. and Harrisburg, Pa. The routing from Harrisburg to Oak Island includes a new connection near Philadelphia currently being considered by Conrail. The section from Harrisburg to the new connection is currently electrified and Conrail is studying electrification of the entire Conway to Oak Island portion of this route. The Chessie System also provides a route eastward from Chicago to Baltimore via Washington. A north-south route from Toledo to Atlanta is provided by the Chessie System and Southern Railway System. The high density coal route of the Norfolk and Western extends from Bellevue, Ohio to Norfolk, Va. These eleven basic route segments, with branches and secondary routings, have a total of 9817 route miles.

The 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). Within the Service Level 2 lines are three lines of the Burlington Northern with an historical low level of traffic but with a recent or an anticipated jump in service due to new coal traffic. These routes serve the mines at Decker, Montana, providing connections to Kansas City, Ft. Worth, and the transloading facility at Superior, Wisconsin.

The structure of these candidate segments reflects each individual railroad's operations. The railroad identification for each route indicates the operating railroad rather than the owning railroad. End points were established at logical terminals for electrified operations - major yards or logical power change points. The particular format of the route structure in Tables II and III was established for convenience in generating operational data. If a route branches to two or more terminals, the branch routes were included if they support the electrified operations. Thus when a route has a branch route listed with it, both should be considered as one electrification project. If a railroad splits its traffic on two separate lines over a portion of a longer route, both lines are included. In this case the route has a second route listed with it, denoting the section over which the traffic is split. For study purposes, any combination of Service Level 2 routes may be added to the Service Level 1 network.

Traffic and Growth

Current traffic level (1975) on the candidate segments was adjusted from the reported density[12] to reflect only the traffic that could be handled by electric motive power. Assumptions concerning the use of electric and diesel motive power followed the philosophy usually adopted by railroads studying electrification - only through service line-haul traffic will be handled by electric locomotives. Yard switching and branch line traffic will be handled by diesel power. The trains with electric locomotives will set off and pick up traffic at branch line junctions, but line-haul traffic from a yard to a non-electrified route will still be handled by diesels operating under the catenary. A further reduction was made to account for local traffic, such as that dropped off and picked up from industrial sidings; that would also be handled by diesels operating under the catenary.

For Service Level 1, the traffic allocated to electrified operations is greater then 500 billion gross ton-miles (GTM), or roughly one-fourth of the total rail freight traffic. For the combination of Service Level 1 and Service Level 2, the traffic is greater than 1300 billion GTM, or almost two-thirds of the nation's total rail freight traffic.

The amount of traffic a railroad carries in the future will depend on the nature of the industrial growth in the market served by that railroad. Two factors that will affect the growth experienced by a railroad are the commodities making up its traffic and its geographical location. These factors, along with traffic trends, have been considered in developing growth factors for individual railroads.[13] Appendix II gives data on the commodities carried by the individual railroads and forecasts of commodity growth by region (for the five territories used in reporting freight statistics). Table V further summarizes the background information and the growth factors. For each railroad the major commodities (by originated tonnage) and the historical annual traffic trend (based on linear regression of 1966 to 1975 system ton-miles) are presented. The forecast 5 year growth factors, developed from these data and other relevant information such as the formation of Conrail, were applied to the adjusted 1975 traffic level to obtain future traffic estimates. In general, one factor is used throughout a railroad's system. The exceptions are the railroads of the Northeast, where coal and merchandise services are given different factors, and the potential coal routes of the Burlington Northern, where nominal 1975 traffic equivalent to 4 unit trains a day is assumed, with an increase of another 2 more unit trains every 5 years. The overall annual growth rate for all the traffic represented by the candidate segments is very close to 2%.

TABLE V

PREDICTION OF RAILROAD TRAFFIC GROWTH

RAILROAD	MAJOR COMMODITY BY TONNAGE	ANNUAL TRAFFIC TREND	FORECAST 5 YEAR GROWTH
ATSF	Farm Products (20%)	+ 2.0%	10%
B&LE	Coal, Steel & Iron	0.0%	0%
BN	Coal (22%)	+ 3.0%	0% Merchandise
			7.5% Coal
			50% New Coal
CHESSIE	Coal	B&O - 1.1%	0% Merchandise
		C&O - 4.7%	15% Coal
C&NW	Farm Products (16%)*	+ 2.9%	10%
CONRAIL	Coal (27%)	- 1.3%	15%
DM&IR	Iron Ore (90%)	+ 2.5%	10%
D&RGW	Coal (24.7%)*	+ 1.7%	10%
CLIN	Coal (69%)	+ 3.1%	15%
L&N	Coal (41%)	+ 3.1%	15%
SCL	Non-Metallic Minerals (31%)	+ 1.1%	5%
GTW	Transportation Equip. (35%)	+ 2.0%	5%
ICG	Coal (24%)	+ 2.8%	5%
MILW	Farm Products (14%)	+ 0.2%	0%
MP	Chemicals (18%)	+ 3.2%	15%
N&W	Coal (50%)	- 0.1%	15%
P&LE	Coal[1]	- 2.9%	0%
RF&P	Lumber, Coal, Chemicals[2]	- 4.7%	5%
STL-SF	Food Products (16%)	+ 1.8%	10%
SOUTH	Coal (24%)	+ 2.6%	12.5%
SP	Non-Metallic Minerals (13%)	+ 1.0%	5%
UP	Farm Products (18%)	+ 2.6%	12.5%
WP	Food & Kindred Products (32.5%)*	+ 1.5%	12.5%

*Revenues

[1] Based on Conrail

[2] Based on SCL

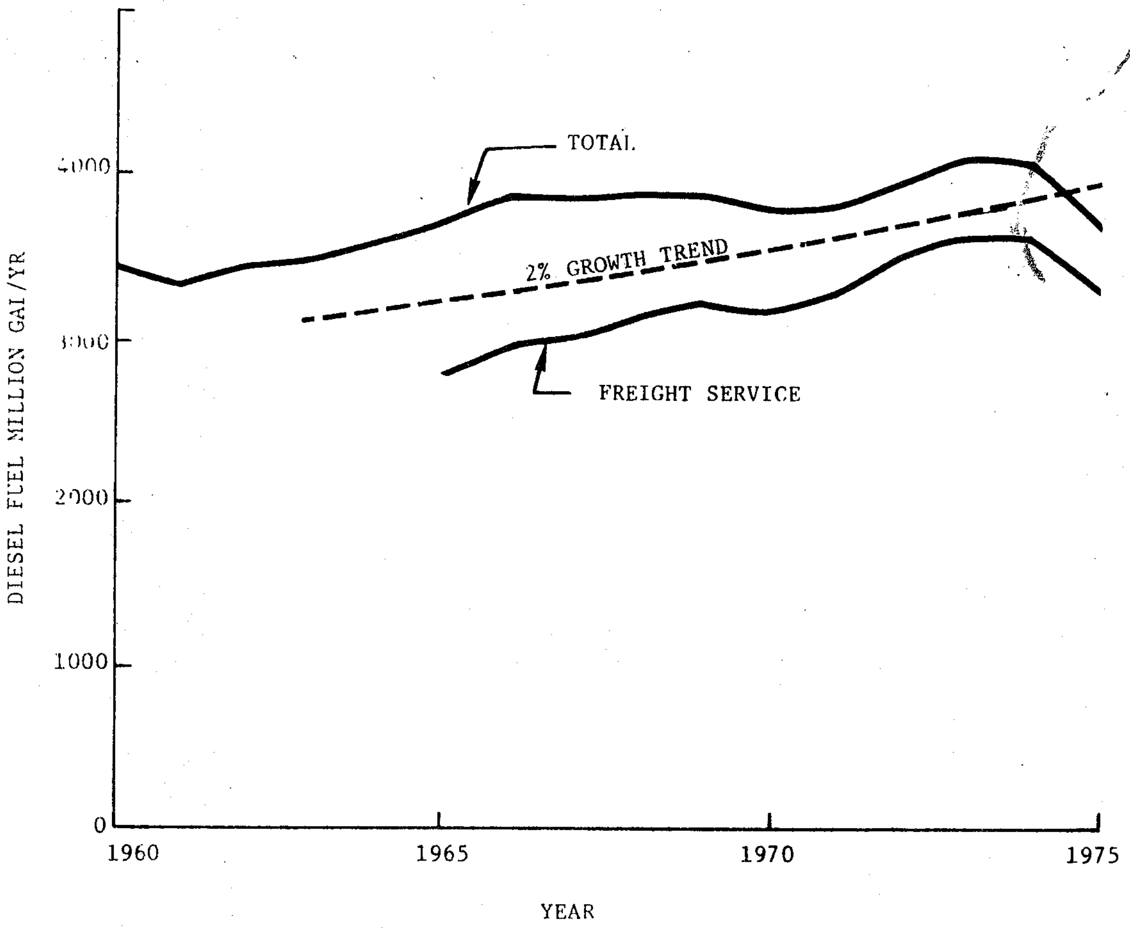
ENERGY IMPACT

BACKGROUND

Diesel-electric locomotives (diesel engine, electric drive) are the standard motive power of the industry in the United States. At the end of 1975, there were over 28,000 diesel-electric units in service. The railroads consume about 4 billion gallons of diesel fuel a year, as shown in Figure 4, with about 90% going into road freight service and the balance into passenger, yard switching, and work train service. The electricity used by the smaller number of electric locomotives accounts for less than 0.2 percent of the railroads' energy consumption.

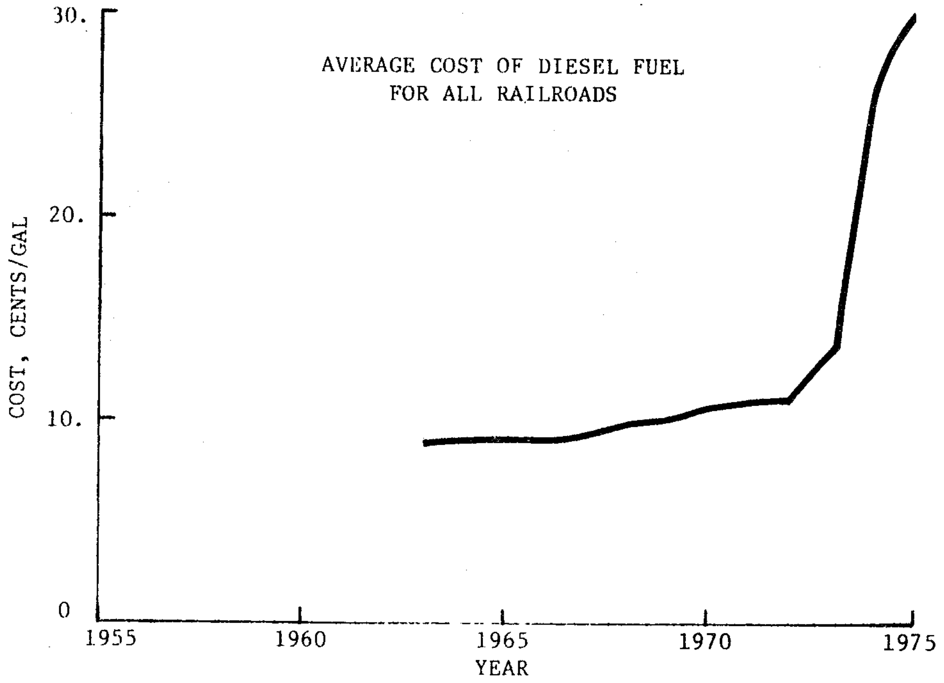
From the point of view of the railroads, the amount of fuel consumed has not been a major item of concern. Fuel consumption has little effect on a railroad's profitability, historically accounting for about 4 percent of the operating costs, and no effect on its service characteristics or its relations with customers and suppliers. This attitude has changed somewhat, but not greatly, since the 1973 fuel crisis with its resulting increase in the price of energy, illustrated in Figure 5. Fuel, now about 7 to 8 percent of the operating costs, is still a relatively minor cost factor. Fuel consumption can be decreased through improved practices in the maintenance of locomotives, in the assembling and dispatching of trains, and particularly in the selection of operating speed, but these factors are usually determined by other service and operating efficiency requirements. If a railroad chooses to stress fuel economy, however, a concerted effort can yield fuel savings.[16]

Looking at the energy consumption of the entire nation, the fuel consumed in the United States by the transportation sector, including both passenger travel and freight movement, amounts to approximately twenty-five percent of the nation's energy usage. This transportation energy comes almost entirely from petroleum as shown in Figure 6,



Data Source: Reference 14

FIGURE 4
HISTORICAL NATIONWIDE DIESEL FUEL CONSUMPTION
BY RAILROAD



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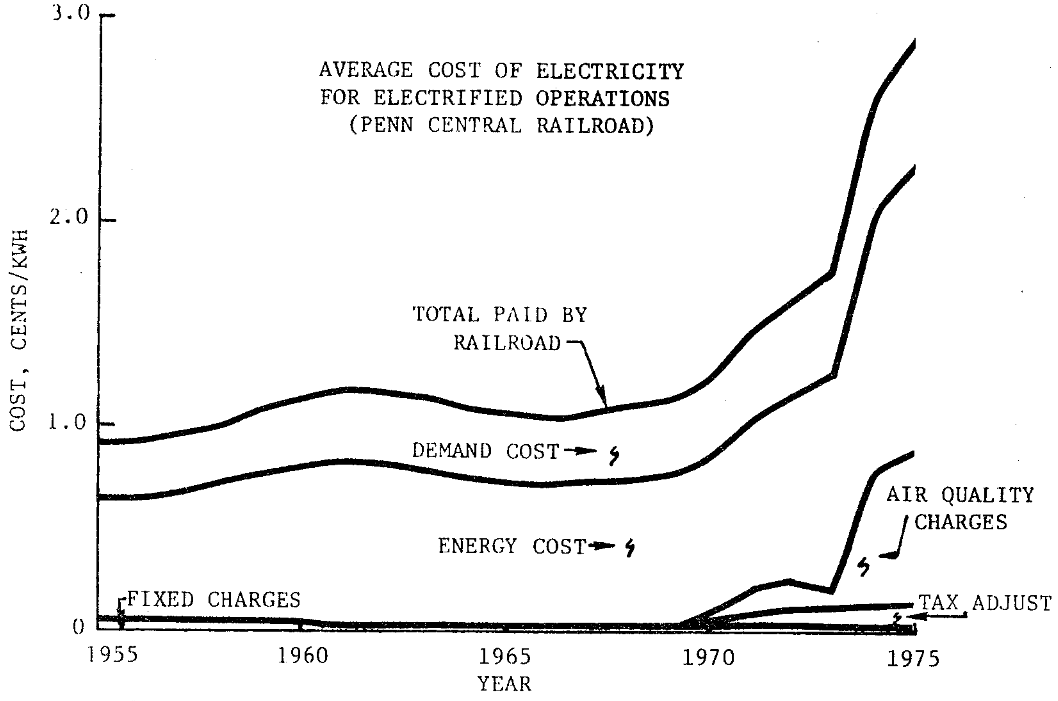
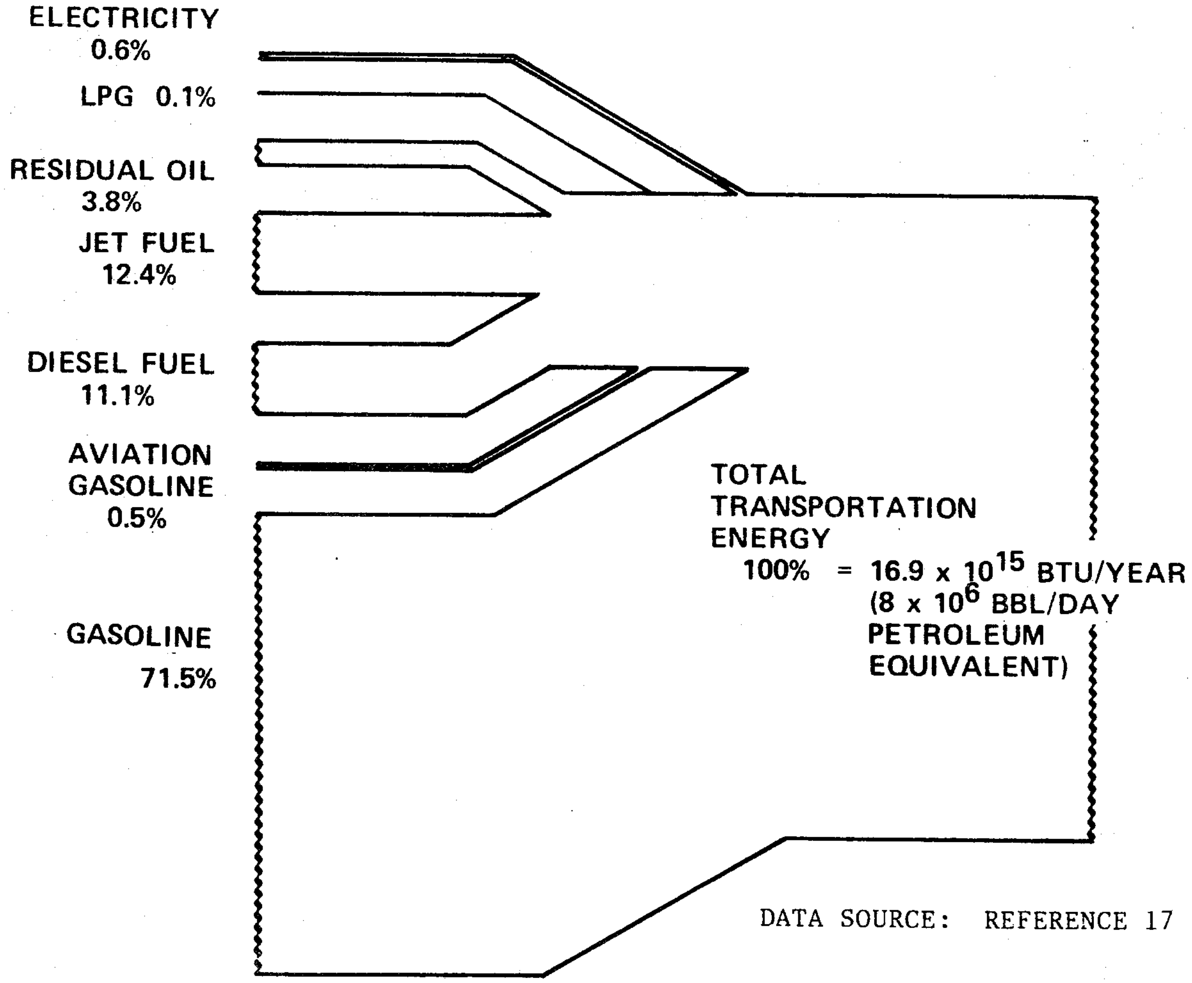


DATA SOURCE: REFERENCE 5

FIGURE 5
RAILROAD ENERGY COSTS



DATA SOURCE: REFERENCE 17

FIGURE 6
U.S. TRANSPORTATION ENERGY BY TYPE OF FUEL, 1972

accounting for roughly half of the petroleum used by the nation. Figure 7 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 the transportation energy. The almost total reliance of all transportation modes on petroleum make the supply of crude oil critical to a continuation of present transportation practices. Any short term interruption in the supply can create disruptions; the long term supply picture indicates that eventually changes will occur.

ENERGY ESTIMATES

The energy impact of railroad electrification is measured primarily by the amount of additional electricity that must be generated for electrified railroad operations and by the changes in fuel sources - the additional coal required for electricity generation and the net savings in petroleum consumption. To measure this impact requires an accurate prediction of the energy needed for the rail operations. The methodology developed to estimate the energy consumption on a route-by-route basis[18] is summarized in Appendix III. The energy predictions for the alternatives of diesel-electric and all-electric motive power were then made for the candidate segments for electrification[19] presented in the previous section. The traffic represents only that which can be converted to electrified operations, and predictions for the future carried as far as 1990. Additional details of the methodology used to obtain railroad fuel predictions are presented in Appendix IV. To assess the impact of railroad energy use, data for the individual lines were aggregated by census regions for two levels of electrification: Service Level 1 (Level 1) and Service Level 1 combined with Service Level 2 (Level 1 + 2). The breakdown of the nation into census regions is presented in Figure 8.

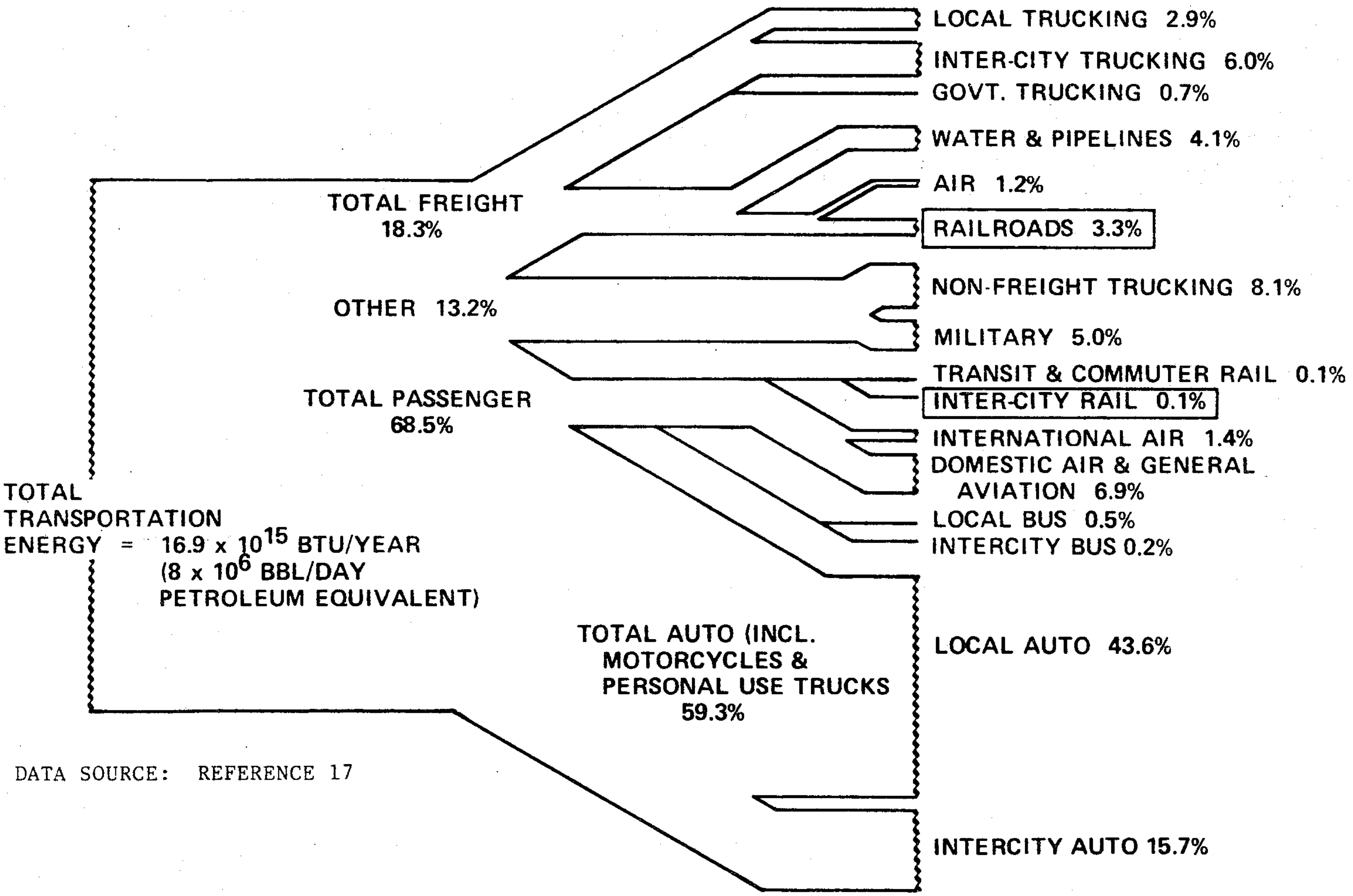


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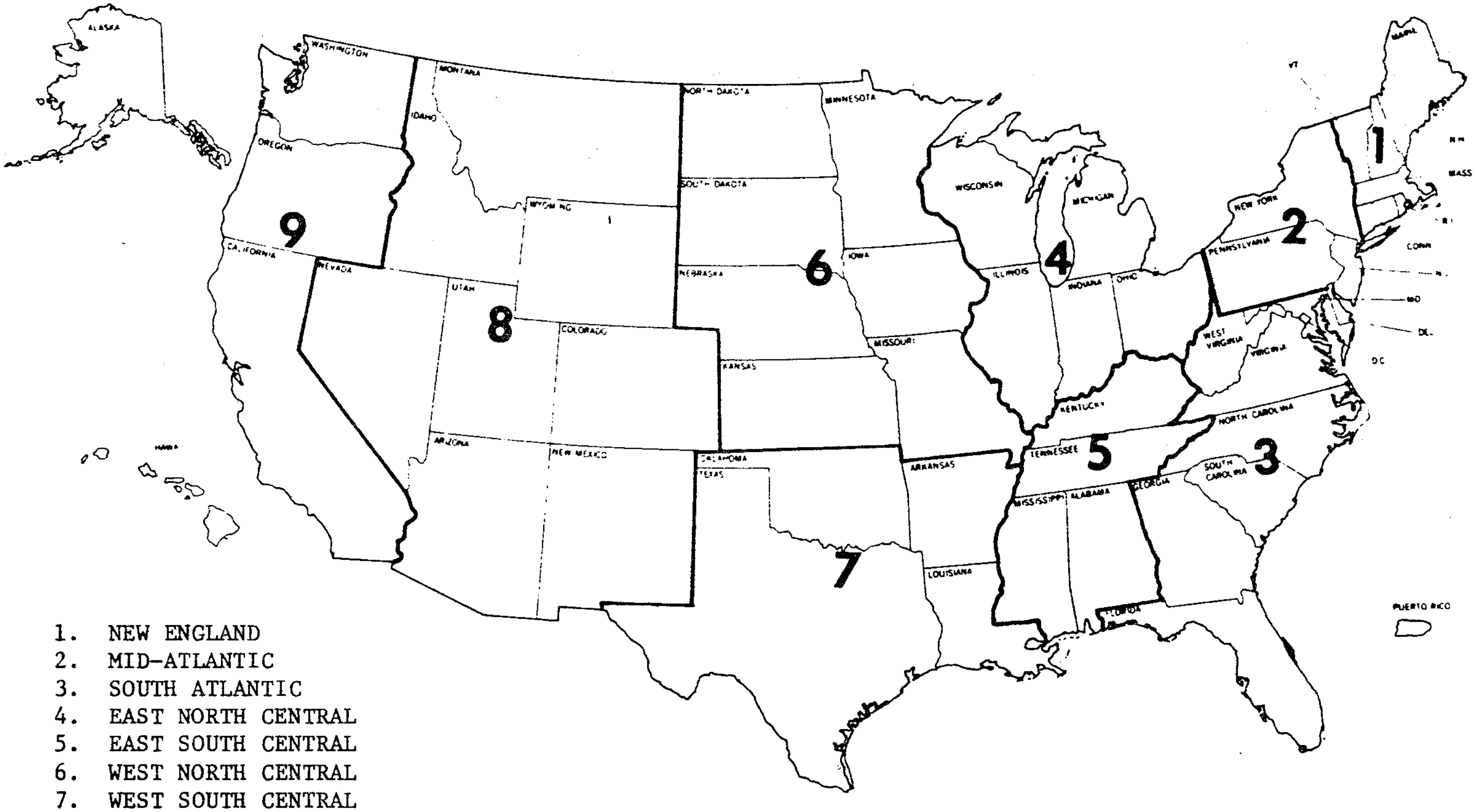
FIGURE 7
U.S. TRANSPORTATION ENERGY BY MODE, 1972



1. NEW ENGLAND
2. MID-ATLANTIC
3. SOUTH ATLANTIC
4. EAST NORTH CENTRAL
5. EAST SOUTH CENTRAL
6. WEST NORTH CENTRAL
7. WEST SOUTH CENTRAL
8. MOUNTAIN
9. PACIFIC

FIGURE 8
CENSUS REGIONS

Diesel Fuel Consumption

As a baseline, the diesel fuel consumption for the traffic under consideration is presented in Table VI for Level 1 and in Table VII for Level 1 + 2. For these calculations, Conrail operations that are currently electrified were assumed to be handled by diesel power. The projected nationwide total diesel fuel consumption for the traffic under consideration is summarized in Figure 9. In this figure the curve given as the railroad total represents an extrapolation of the 2% growth trend given previously in Figure 4. For 1975, the Level 1 traffic accounts for approximately 950 million gallons of diesel fuel or about 24 percent of the total for all railroad operations. The Level 1 + 2 traffic accounts for approximately 2390 million gallons or approximately 60 percent of the total. The annual growth rate of the diesel fuel consumption for Level 1 is about 2.2% and for Level 1 + 2 is very close to 2%.

Electricity Consumption

Electricity consumption for all the traffic under consideration has been calculated for the time frame of 1975 to 1990. The hypothetical 1975 case is useful in assessing the scale of electrification effects in terms of existing conditions. Full electrification might be reached toward the end of the time frame, at the earliest, considering the lead time from go-ahead to operations and the rate at which electrification equipment and facilities could be fabricated and installed. If the entire electrified network were in operation, the resulting electricity consumption by the railroads for the traffic under consideration, by census region and for the nation, is presented in Table VIII for Level 1 and in Table IX for Level 1 + 2. For 1975 traffic levels, Level 1 requirement is about 14,110 gigawatt-hours (GWH) of electricity, and the Level 1 + 2 requirement is about 35,540 GWH. The growth rates are the same as for the diesel fuel case above.

TABLE VI

DIESEL FUEL DATA SUMMARY FOR LEVEL 1

Census Region	Route Miles	1975 Traffic 1000 MGTM/yr	Estimated Diesel Consumption, Million Gals/yr			
			1975	1980	1985	1990
NE	0.0	0.0	0.0	0.0	0.0	0.0
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

MGTM - million gross ton-miles

TABLE VII

DIESEL FUEL DATA SUMMARY FOR LEVEL 1 + 2

Census Region	Route Miles	1975 Traffic 1000 MGTM/Yr	Estimated Diesel Consumption, Million Gals/Yr			
			1975	1980	1985	1990
NE	162.70	4.50	7.51	8.63	9.93	11.42
MA	2237.40	93.57	145.53	166.17	189.98	217.43
SA	7681.20	254.69	424.35	470.52	523.21	582.93
ENC	6178.30	196.31	373.76	412.73	455.49	502.22
ESC	5382.30	172.71	276.13	305.83	339.45	377.32
WNC	3899.10	115.37	191.01	215.72	243.85	275.65
WSC	4901.10	139.70	288.77	316.57	346.87	379.76
MTN	6794.80	224.67	453.31	495.91	542.72	593.89
PAC	3817.80	115.77	231.57	248.70	267.50	287.87
USA	41054.7	1317.30	2391.93	2640.78	2918.98	3228.49

MGTM - million gross ton-miles

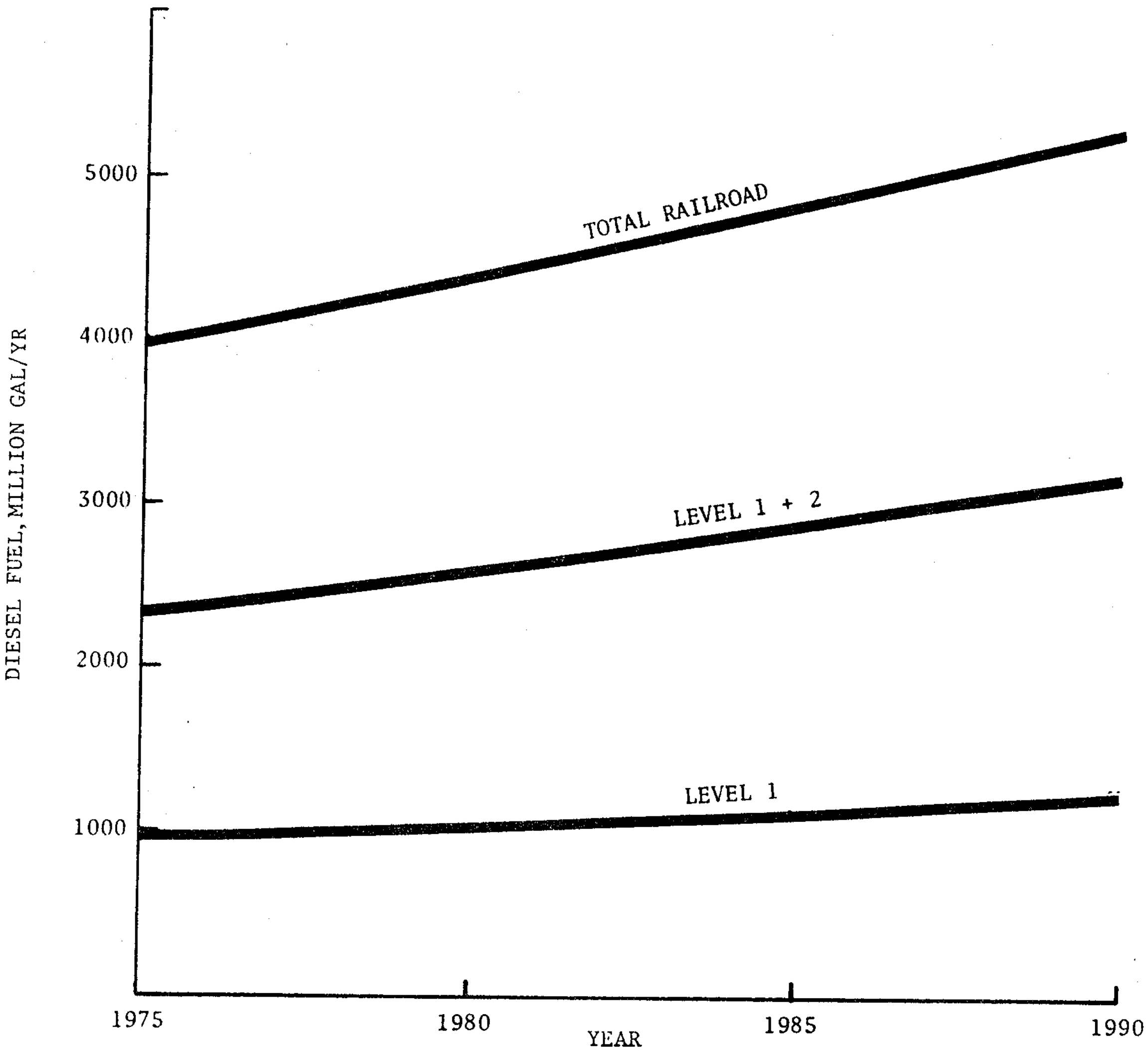


FIGURE 9
PROJECTED NATIONWIDE DIESEL FUEL CONSUMPTION
BY RAILROADS

TABLE VIII

ELECTRICITY SUMMARY FOR LEVEL 1

Census Region	Route Miles	1975 Traffic 1000 MGTM/Yr	Estimated Electrical Energy Requirements, GWH/Yr 1975	1980	1985	1990
NE	0.0	0.0	0.0	0.0	0.0	0.0
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

MGTM - million gross ton-miles

GWH - gigawatt hours

TABLE IX

ELECTRICITY SUMMARY FOR LEVEL 1 + 2

Census Region	Route Miles	1975 Traffic 1000 MGTM/yr	Estimated Electrical Energy Requirements, GWH/yr			
			1975	1980	1985	1990
NE	162.70	4.50	111.53	128.26	147.56	169.64
MA	2237.40	93.57	2162.58	2469.29	2823.10	3231.01
SA	7681.20	254.69	6305.84	6991.93	7774.90	8662.34
ENC	6178.30	196.31	5554.07	6133.17	6768.58	7462.99
ESC	5382.30	172.71	4103.29	4544.63	5044.23	5606.98
WNC	3899.10	115.37	2838.45	3205.55	3623.55	4096.17
WSC	4901.10	139.70	4291.17	4704.16	5154.45	5643.19
MTN	6794.80	224.67	6736.19	7369.22	8064.82	8825.21
PAC	3817.80	115.77	3441.13	3695.68	3975.05	4277.75
USA	41054.70	1317.30	35544.08	39242.00	43376.04	47975.36

MGTM - million gross ton-miles

GWH - gigawatt hours

In order to assess the impact of the railroads' demand for electricity generation, projections of the generation of electricity by the nation's utilities is required. Estimates, developed by the Federal Energy Administration (FEA) and summarized in the 1976 National Energy Outlook,[20] are presented in Table X, along with 1975 data from the Federal Power Commission (FPC).[21] The estimates come from the Project Independence Evaluation System (PIES) model that balances supply and demand models for the future U.S. energy situation. A number of scenarios were evaluated[22] by FEA using PIES. For this study the $13 per barrel and $16 per barrel petroleum baseline scenarios were used to represent 1980 and 1990 conditions. To provide an idea of the possible range of future conditions, 14 additional scenarios developed by FEA for possible conditions in 1985 were used and the maximum and minimum values were tabulated. The baseline scenarios produce a 5 percent annual growth rate in electricity generation.

The overall impact of railroad electrification is indicated by Tables XI and XII which show the estimated electrical energy requirements for the railroads (Level 1 and Level 1 + 2) as a function of net utility generation. Nationwide, Level 1 would require an increase of less than 1 percent of the nationwide total while Level 1 + 2 would require an increase of between 1 and 2 percent. Furthermore, the additional load for railroad electrification is small compared to the range created by the other energy supply and demand situations evaluated in the FEA 1985 scenarios, as indicated in Table X. The additional requirements, expressed as a percentage of the nominal projections, decrease with time since the overall generation growth rate is greater than the rail traffic growth rate. Figure 10 illustrates the nationwide picture of additional demand.

TABLE X

ESTIMATED ANNUAL NET GENERATION OF ELECTRIC UTILITIES, 1000 GWH

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

GWH - gigawatt hours

*ACTUAL FPC DATA

Data Sources" References 20, 21

TABLE XI

ESTIMATED ELECTRICAL ENERGY REQUIREMENTS AS A PERCENTAGE OF NET UTILITY GENERATION

LEVEL 1

CENSUS REGION	1975	1980	1985	1990
NE	0.0	0.0	0.0	0.0
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 Service Level 1 is assumed to be in place for the above years.

TABLE XII

ESTIMATED ELECTRICAL ENERGY REQUIREMENTS AS A PERCENTAGE OF NET UTILITY GENERATION

LEVEL 1 + 2

CENSUS REGION	1975	1980	1985	1990
NE	0.16	0.14	0.11-0.17	0.15
MA	0.91	0.68	0.48-0.61	0.49
SA	1.83	1.55	1.17-1.39	1.11
ENC	1.56	1.33	1.00-1.19	0.92
ESC	2.37	1.80	1.54-1.77	1.43
WNC	2.16	1.81	1.39-1.62	1.30
WSC	1.83	1.71	1.18-1.63	1.25
MTN	6.08	6.20	4.63-5.28	4.13
PAC	1.28	1.25	1.00-1.15	0.90
USA	1.85	1.58	1.18-1.45	1.14

NOTE: Electrification of Service Levels 1 + 2 is assumed to be in place for the above years.

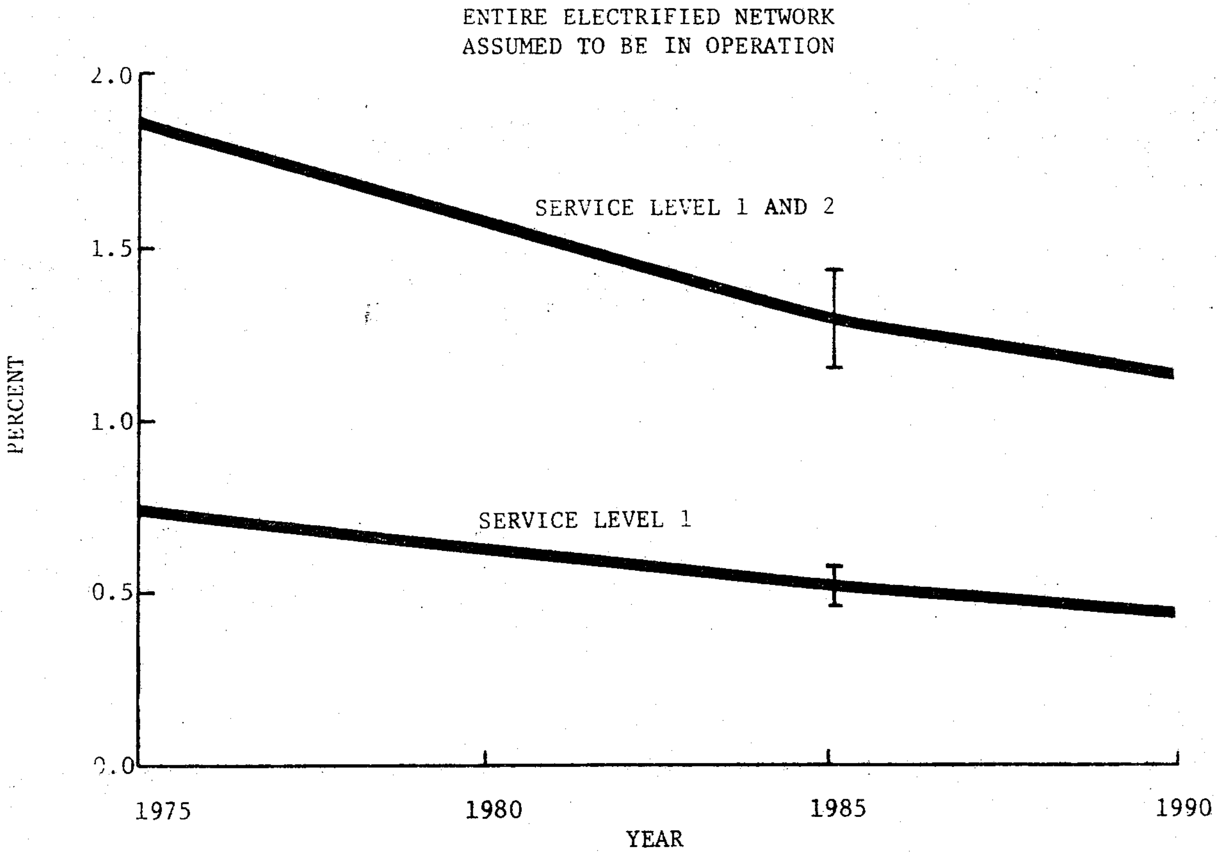


FIGURE 10
ESTIMATED NATIONWIDE ELECTRICITY REQUIREMENTS
AS A PERCENTAGE OF NET UTILITY GENERATION

The greatest regional impact would occur in the Mountain Region. The additional electricity demand due to the Mountain Region railroads is illustrated in Figure 11. Three major high traffic density lines go through this region, which has a relatively small generating capacity. Electrification at Level 1 for 1975 traffic levels would require about 4380 GWH of electricity per year, a 4 percent increase over the present regional consumption; at Level 1 + 2, about 6740 GWH per year, a 6 percent increase. The utility generation growth in this region is projected to be at a low level during the next 5 years, and thus railroad electrification would have the greatest effect if it is carried out during the near term.

Fuel Sources

The mix of fuels used for the generation of electricity varies throughout the nation and also with the passage of time as illustrated in Figure 12 and Table XIII. Data again comes from FPC statistics and FEA projections. Coal has traditionally been the major fuel source and is expected to maintain its share of the fuel mix. Petroleum is currently the major source in the North East and the West South Central Regions, but the percentage contribution is expected to drop considerably in the next 10 years. Hydro power is a major source in the Pacific Region. Nationwide, nuclear power now accounts for less than 10 percent of electricity generation, but is expected to grow to more than 26 percent by 1985. The effect of new technologies as sources for electricity will remain small in the current planning time frame, as indicated in Figure 13.

In the study the fuels required to generate electricity for railroad electrification are allocated on the basis of the overall fuel mix for each region for each time frame considered. This assumption implies that the electricity a railroad draws from a utility cannot be associated with a particular unit, but rather, that on the average, the railroad load would draw equally from all fuels used with a region

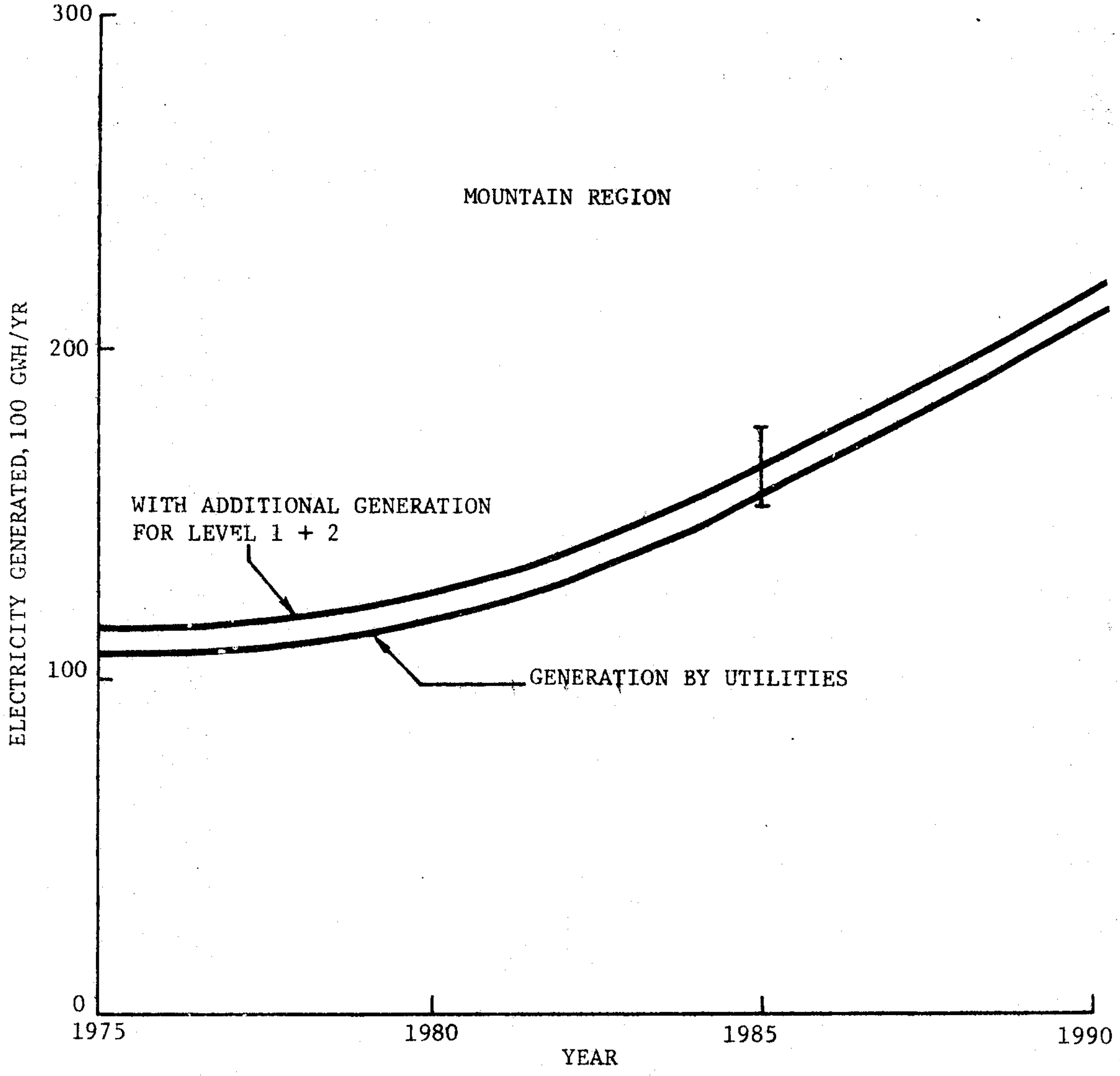
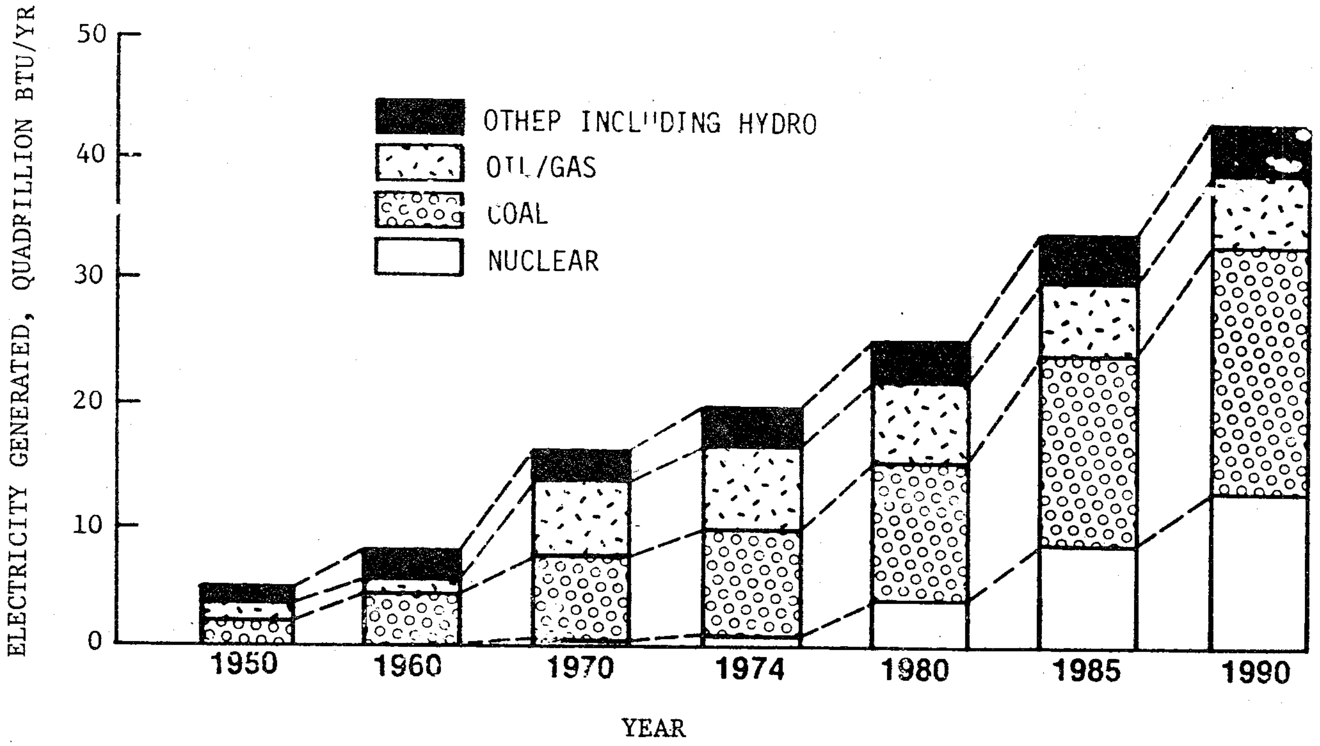


FIGURE 11
PROJECTED GENERATION OF ELECTRICITY FOR MOUNTAIN REGION



Reference: 20

FIGURE 12
SOURCES OF ELECTRICITY

TABLE XIII

PERCENT CONTRIBUTION FROM EACH FUEL TO REGIONAL AND TOTAL U.S. ELECTRICITY GENERATION

Region	Coal			Oil/Gas			Nuclear			Hydro			Other		
	1960	1974	1985*	1960	1974	1985*	1960	1974	1985*	1960	1974	1985*	1960	1974	1985*
New England	50.3	7.4	26.8	31.7	61.3	28.4	0.1	24.4	41.0	17.9	6.9	3.9	---	---	---
Middle Atlantic	69.3	42.7	47.9	18.5	36.2	13.6	0.2	8.5	29.9	12.0	12.6	7.3	---	---	1.2
East North Central	93.5	82.0	66.4	3.8	8.7	5.8	0.2	8.3	26.3	2.5	1.0	0.6	---	---	1.0
West North Central	40.3	54.4	70.1	46.9	27.2	4.9	---	7.7	17.2	12.6	10.7	7.7	0.2	---	---
South Atlantic	66.3	54.9	52.6	20.2	32.5	10.3	---	7.4	32.0	13.5	5.2	7.3	---	---	1.2
East South Central	74.5	76.5	50.8	5.5	5.4	4.5	---	3.6	37.3	20.0	14.5	7.4	---	---	---
West South Central	---	3.0	20.6	95.7	92.6	55.3	---	0.2	22.8	4.3	4.2	1.4	---	---	---
Mountain	11.8	46.3	48.7	36.6	23.2	16.9	---	---	14.9	51.6	30.5	15.2	---	---	3.7
Pacific	---	1.7	4.7	42.0	27.8	19.9	---	2.8	10.2	58.0	66.7	62.2	---	1.0	2.5
Nation	53.5	44.5	45.4	27.1	33.2	16.1	0.1	6.0	26.1	19.3	16.1	11.5	---	0.1	1.0

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* 1985 $13 Reference Scenario

Reference: 20

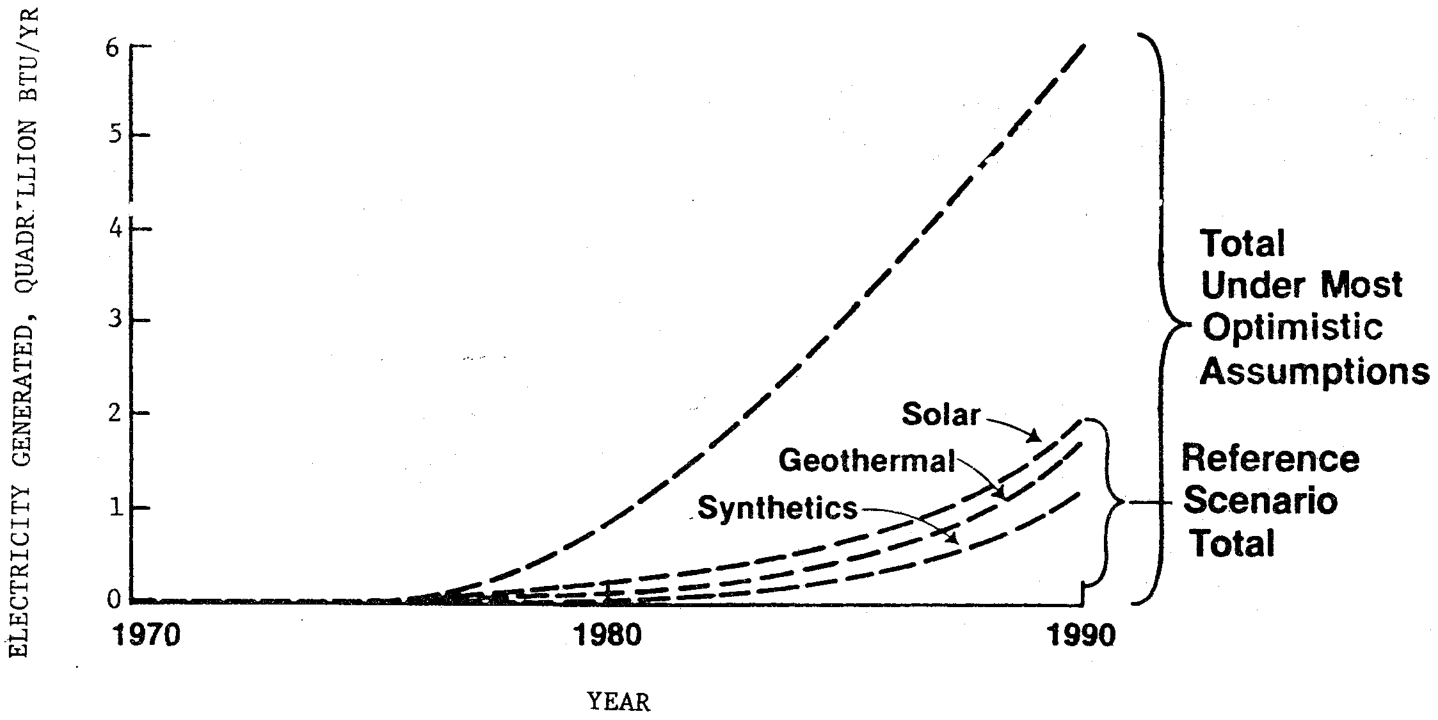

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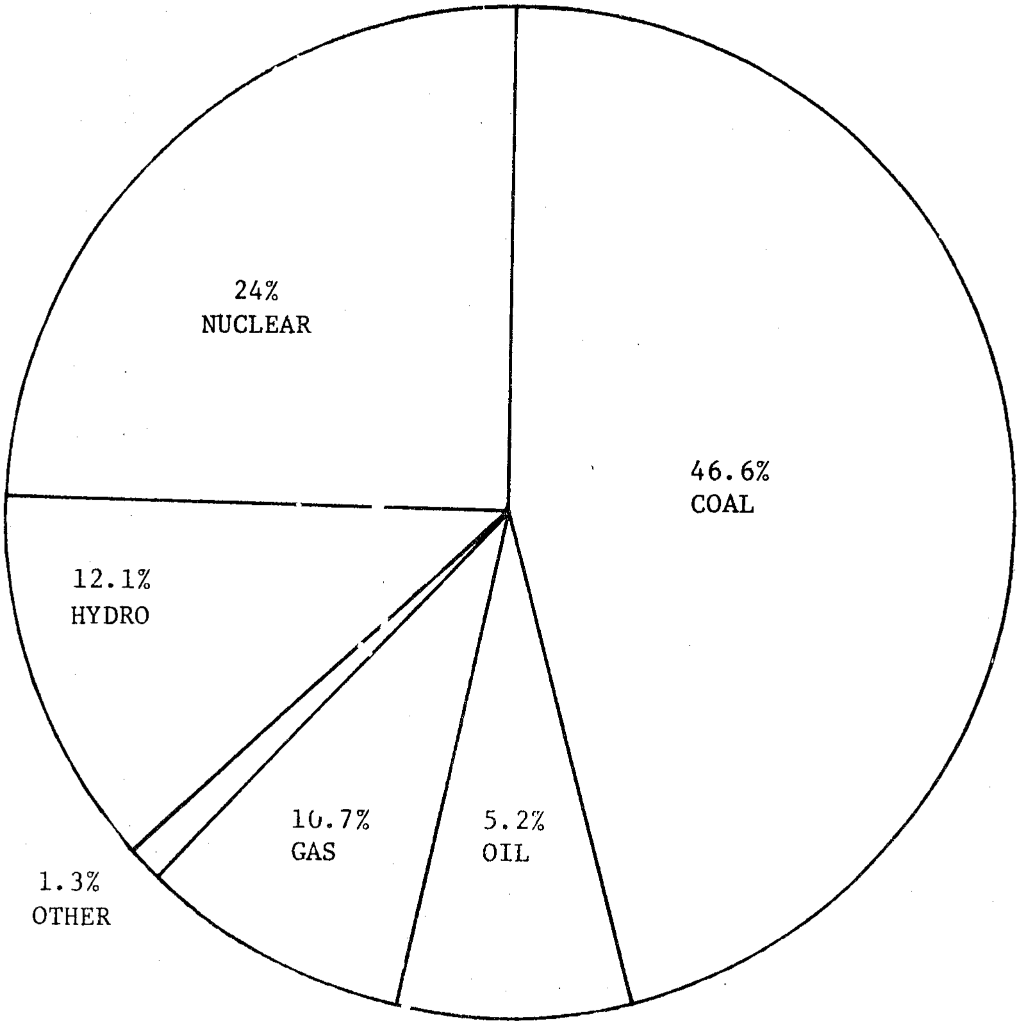
FIGURE 13
CONTRIBUTION OF NEW TECHNOLOGIES TO ELECTRICAL GENERATION

for electricity generation. An overall indication of the energy sources contributing to electrified rail operations, based on 1985 utility fuel mixes, is given in Figure 14.

The utility coal requirements for the additional railroad load are given in Tables XIV and XV (Level 1 and Level 1 + 2); the nationwide coal requirements for railroad electrification are summarized in Figure 15 for Level 1 + 2. The annual coal requirements for 1975 conditions are 3.63 million tons for Level 1 and 8.46 million tons for Level 1 + 2. The growth rate for the nationwide coal requirement, which takes into account the regional variation in utility fuel mix and railroad traffic, is about 1.5% per year. The utility coal requirements are divided into high sulfur and low sulfur coal, reflecting the need of some utilities to burn low sulfur coal to meet pollution standards. For comparison, the overall nationwide coal consumption in 1974 was 611 million tons and the FEA projections show an increase of about 5% annually, reaching 1040 million tons in 1985, with the production distribution shown in Figure 16. The largest increases in coal production will come from underground mining in the East and from surface mining in the West. The growth in coal production assumes a firm long-term utility demand and resolution of major environmental and transportation issues. The regional and nationwide coal requirements reflect these factors, as indicated by the wide range of projections resulting from the additional 1985 scenarios.

A small portion of the railroads' requirements for electricity will still be provided by petroleum and natural gas. Utility distillate and residual fuel oil requirements for the additional railroad load are given in Tables XVI and XVII (Level 1 and Level 1 + 2). The nationwide utility oil requirement for electrification is shown in Figure 17, along with the diesel fuel requirement for the traffic under consideration if the operations are not electrified. Since the fuels are

ELECTRICITY SOURCES FOR TRAFFIC ON CANDIDATE SEGMENTS (LEVEL 1 & 2)



(1985, $13 Reference Scenario)

FIGURE 14
ENERGY SOURCES

TABLE XIV
ESTIMATED ANNUAL UTILITY COAL REQUIREMENTS FOR RAILROAD ELECTRIFICATION (MILLION TONS/YR)
LEVEL I

	1975	1980		1985		1990	
		High Sulfur	Low Sulfur	High Sulfur	Low Sulfur	High Sulfur	Low Sulfur
NE	0	0	0	0	0	0	0
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	3.625	1.74	2.19	1.94-2.14	2.35-3.25	2.09	2.53

TABLE XV

ESTIMATED ANNUAL UTILITY COAL REQUIREMENTS FOR RAILROAD ELECTRIFICATION (MILLION TONS/YR)

LEVEL 1 + 2

	1975	1980		1985		1990	
		High Sulfur	Low Sulfur	High Sulfur	Low Sulfur	High Sulfur	Low Sulfur
NE	0.0	0.0	0.0	0.0-0.02	0.0-0.03	0.02	0.01
MA	0.4	0.2	0.2	0.2-0.4	0.2-0.5	0.4	0.3
SA	1.4	1.3	0.5	1.0-1.3	0.3-1.1	1.0	0.94
ENC	2.2	0.7	1.2	0.8-1.2	0.5-1.4	0.75	1.40
ESC	1.4	0.8	0.4	0.6-1.0	0.2-0.6	0.5	0.6
WNC	0.9	0.65	0.4	0.5-0.7	0.4-0.7	0.5	0.8
WSC	0.2	0.2	0.04	0.2	0.1-0.7	0.2	0.7
MTN	1.9	0.6	1.6	0.6-0.8	1.1-1.8	1.1	1.2
PAC	0.06	0.03	0.0	0.0-0.2	0.0-0.1	0.0	0.0
USA	8.46	4.48	4.34	3.2-5.82	2.8-6.93	4.47	5.95

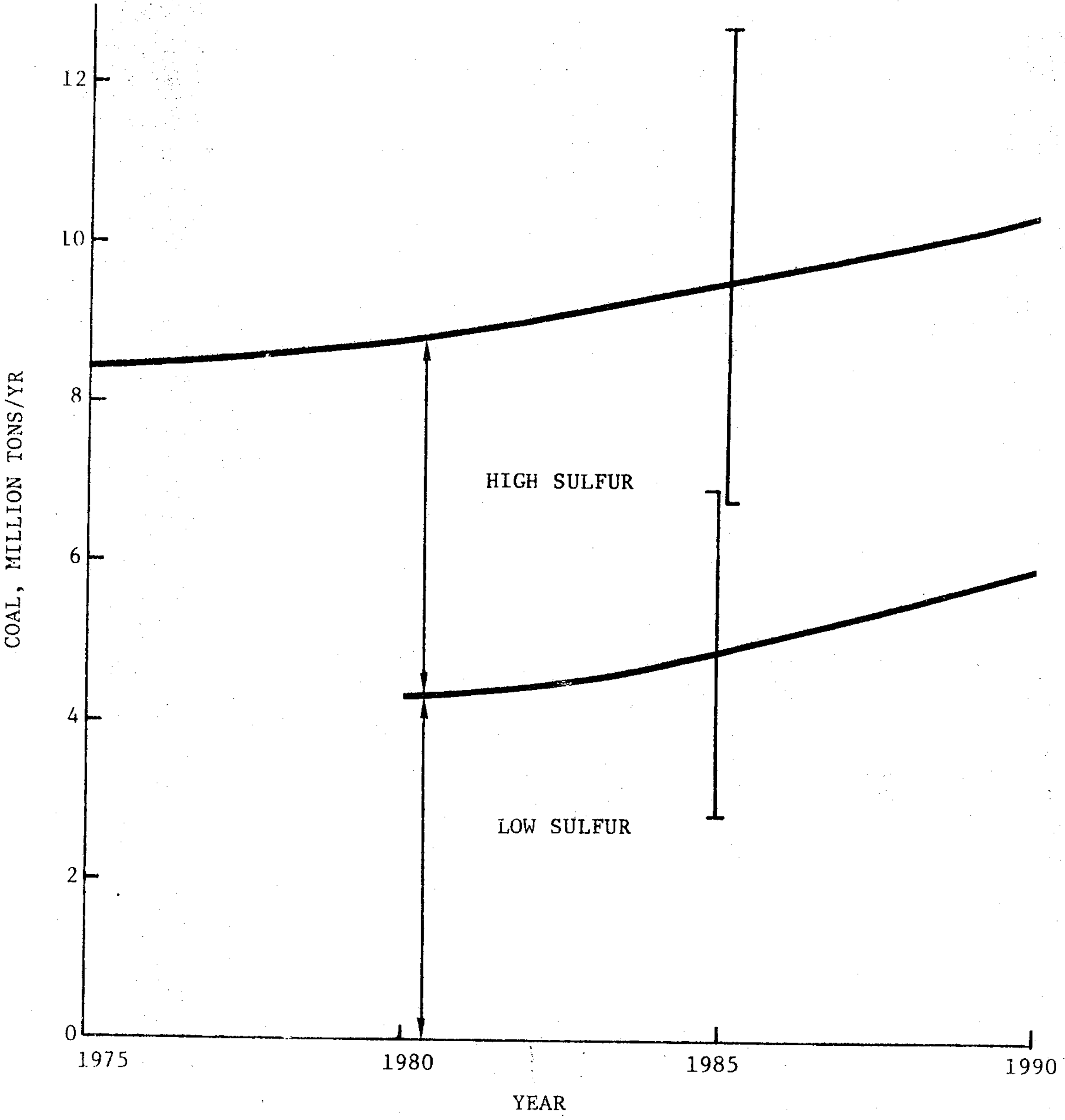
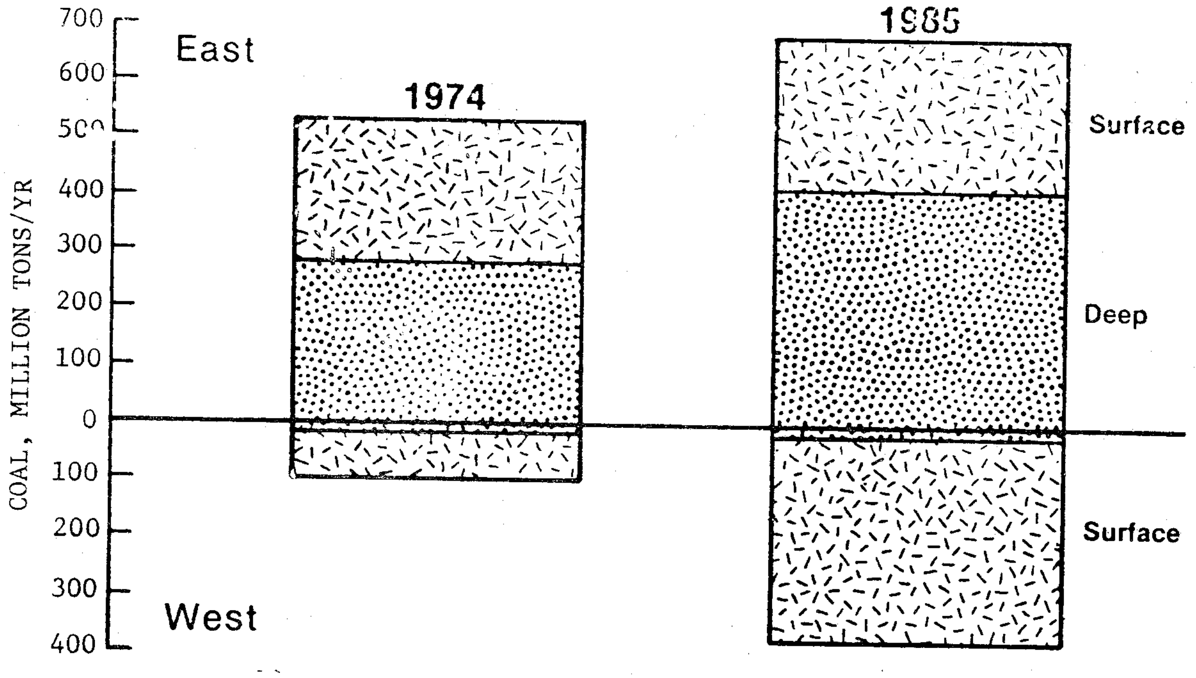


FIGURE 15
COAL REQUIREMENTS FOR RAILROAD ELECTRIFICATION



Reference: 20

FIGURE 16
COAL PRODUCTION

TABLE XVI

ESTIMATED ANNUAL UTILITY OIL REQUIREMENTS
FOR RAILROAD ELECTRIFICATION (MILLION GALS/YR)
SERVICE LEVEL 1

	1975	1980		1985		1990	
		Dist.	Res.	Dist.	Res.	Dist.	Res.
NE	0	0	0	0	0	0	0
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	27.38	59.45	1.1-141.6	0.6-74.36	37.65	111.2

TABLE XVII

ESTIMATED ANNUAL UTILITY OIL REQUIREMENTS FOR RAILROAD ELECTRIFICATION (MILLION GALS/YR)

LEVEL 1 + 2

	1975	1980		1985		1990	
		Dist.	Res.	Dist.	Res.	Dist.	Res.
NE	4.7	0	5.2	0-2.5	2.6-4.9	0.3	4.0
NA	49.8	19.6	30.1	0-42.7	0-27.9	3.1	23.0
SA	106.5	0.5	59.0	0-74.6	0-68.2	11.3	43.2
ENC	22.0	19.8	14.2	0.7-85.1	0-21.9	12.4	14.5
ESC	11.4	4.4	10.6	1.0-66.9	0-7.9	8.6	9.3
WNC	9.2	2.7	0.4	0-62.3	0-0.4	6.8	7.3
WSC	9.3	6.2	0	3.0-10.0	0	8.5	124.2
MTN	31.0	0.6	0	0-4.3	0	15.3	57.4
PAC	47.7	3.2	17.0	0-23.3	1.7-47.6	35.6	39.7
USA	291.6	57.0	136.5	4.7-372.0	4.3-178.8	101.9	322.6

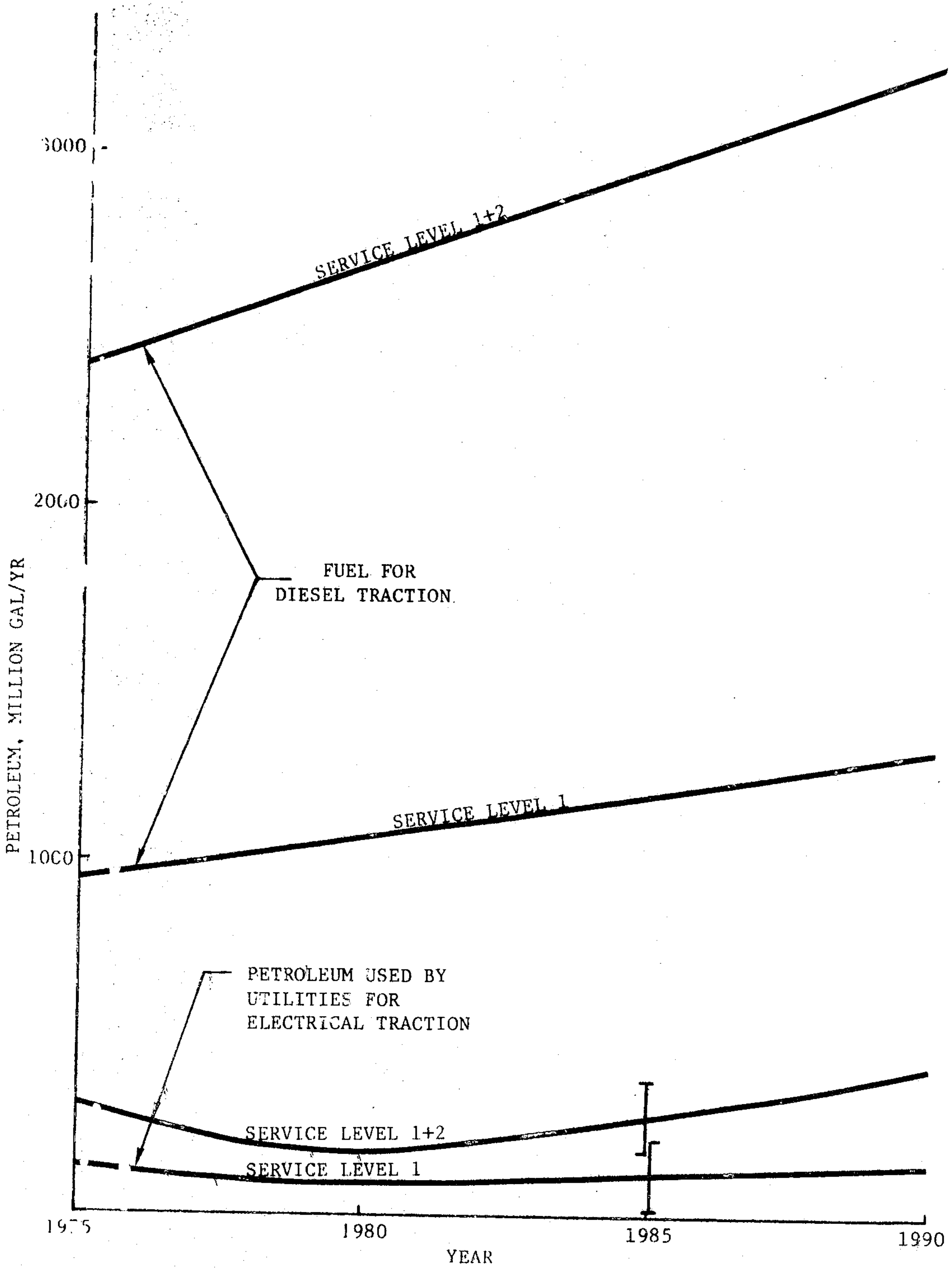


FIGURE 17
NATIONWIDE PETROLEUM CONSUMPTION FOR SERVICE LEVEL 1 AND SERVICE LEVEL 1+2 WITH AND WITHOUT ELECTRIFICATION

essentially equivalent on an energy basis, the difference illustrates the petroleum savings of converting all the traffic under consideration to electrified operations. The savings in 1975 would be about 820 million gallons per year for Level 1 and 2100 million gallons per year for Level 1 + 2 and would grow somewhat in future years, reaching 1160 million gallons per year for Level 1 and 2800 million gallons per year for Level 1 + 2 in 1990. The amount of petroleum fuel used in electricity generation is highly sensitive to price and other supply factors. A tight supply picture (higher price) would tend to reduce usage to a very low level; a good supply situation could tend to double its usage. The utility natural gas requirements for the additional railroad load are given in Tables XVIII and XIX (Level 1 and Level 1 + 2). The 1975 nationwide total for Level 1 operations is 16300 million cubic feet and for Level 1 + 2 operations is 63,500 million cubic feet. This level of usage of natural gas is less than 1/2% of the nation's total. The future supply picture for natural gas is particularly unclear, and projections for future years show a wide variation.

Additional Energy Considerations

Overall Thermal Efficiency

The change in railroad operations from direct fuel use to electricity has been examined in terms of a potential petroleum savings. In an energy substitution of this type, a change in thermal efficiency should not be overlooked. For example, changing a building from combustion heating to electric resistance heating would lower the overall efficiency of the fuel-to-useful heat energy cycle. In the case of electrifying railroad operations that currently utilize diesel-electric locomotives, however, the overall energy cycles are very similar. The factors affecting thermal efficiency are discussed in considerable detail in Appendix III and Appendix IV. Within the range of values achieved by typical components under consideration and for comparable operations, there appears to be no consistent energy advantage of one

TABLE XVIII

ESTIMATED ANNUAL UTILITY NATURAL GAS REQUIREMENTS FOR RAILROAD ELECTRIFICATION (MILLION CU FT/YR)

LEVEL 1

	1975	1980	1985	1990
NE	0.0	0.0	0.0	0.0
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.	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.

TABLE XIX

ESTIMATED ANNUAL UTILITY NATURAL GAS REQUIREMENTS FOR RAILROAD ELECTRIFICATION (MILLION CU FT/YR)

LEVEL 1 + 2

	1975	1980	1985	1990
NE	4.0	42.0	26.0-42.0	0.0
MA	212.6	1510.0	1230.0-1510.0	1.0-423.0
SA	3641.1	1644.0	750.0-1610.0	11.0-1330.0
ENC	1850.0	2041.0	1520.0-2265.0	200.0-460.0
ESC	894.0	1974.0	1670.0-2460.0	0.0-1520.0
WNC	5707.0	1938.0	1320.0-2090.0	0.0-300.0
WSC	37452.5	36900.0	17200.0-37780.0	780.0-10130.0
MTN	10020.0	10680.0	14000.0-19750.0	2920.0-12160.0
PAC	3767.7	5490.0-7920.0	87.0-11070.0	0.0-74.0
USA	63548.9	16170.-18600.	37803.-78577	3912.-26397.

mode of operation over the other. This opinion is also held by a locomotive manufacturer who suggests that the overall fuel to tractive work conversion capabilities of electric and conventional railroad systems are the same. Consequently, railroad electrification can achieve a fuel shift without affecting energy efficiency.

Energy Investment

A full examination of the total energy cycle, in addition to considering losses in energy conversion, should also include the need for energy to fabricate and construct the facilities involved. This "energy investment" has not been studied in detail for railroad electrification. A relevant article[23] has included energy investment in examining energy cycles for power generation. That source estimates that the fabrication and construction of a 1000-MW power plant would involve an equivalent electric power requirement of 0.6 to 0.7 x 10^9 KWH, or one-time energy expenditure equivalent to 10% of its annual output (7 x 10^9 KWH/yr). Transmission facilities contain relatively high energy-input materials, and the same source estimates that two 500 kV AC transmission lines (300 miles) would require an equivalent electric power input of 0.5 x 10^9 KWH, based on an energy usage coefficient of 3.6 KWH per dollar of capital expenditures. Since extensive transmission and distribution facilities are required for railroad electrification and the load factor is relatively low, the ratio of energy investment to energy transmitted may turn out to be several times higher than that of a typical power system.

ENVIRONMENTAL IMPACT

BACKGROUND

The relationship of the railroads to the environment appears in at least three major aspects -- their place in the nation's socio-economic structure; their relationship to natural systems, and the introduction of the danger of accidents.

The railroads have always had a notable impact on social and economic conditions, playing a major role in the development and industrialization of the country and at times drastically affecting the growth of cities and local regions. This role has diminished in comparison with other transportation modes as the passenger carrying operations have decreased drastically and the freight operations have not grown as fast as competing modes. Some measures of the present economic impact of railroads are their revenue, number of employees and taxes. The operating revenue of the Class I railroads exceeded $16 billion in 1975. These railroads employed nearly 500,000 people and paid over $1.5 billion in taxes, of which nearly one-third went to state, county and municipal governments. With only small changes in the level of operations, railroads create little change in social areas such as community cohesiveness or in local economic areas such as land use and value, although the existing pattern of features in the community may be the result of the presence of the railroads.

The effect of the railroads on natural systems has also declined in comparison to that of other industries, although increasing concern in recent years for the protection of the environment has focused attention on sources of pollution arising from railroad operations.[24] The steam locomotive, for all the nostalgia now associated with it, created at least local air quality problems. Transportation is still the major contributor to air pollution, but the share from the railroads is small. Several atmospheric emissions have been designated as critical air pollutants by the Environmental Protection Agency (EPA). The contributions resulting from the consumption of fuel by the railroads are given in Table XX. Railroads contribute no more than 1/2% of the total particulates, sulfur oxides, carbon monoxide, and unburned hydrocarbons released into the atmosphere. The nitrogen oxides (NO_x), prevalent with diesel engine combustion, are the most significant pollutant, with railroads contributing about 3.3% of the NO_x emissions. Noise is also a factor with railroad operations.[27] The EPA has estimated that approximately 2.29 million people are subjected to noise exposure levels from railroad traffic at or above a Ldn volume of 55 dB(A), a level that has been determined to have an adverse effect on the health and welfare of those exposed. EPA regulations could eventually relieve approximately 520,000 people from railroad noise levels in excess of 55 dB(A), Ldn. Minor local problems with water pollution also occur from the fueling and maintenance of diesel locomotives. Pollution may result from spillage during fueling or from the drainage of tanks and the cleaning of locomotives during repairs and maintenance. Additional pollution may result when chemical engine coolants are discarded by draining directly onto the ground or into sewers Another minor hazard, primarily in the arid regions of the West, is the setting of roadside fires by sparking from the exhaust system and from braking. These pollution problems are recognized by the railroads and environmental protection programs are directed toward their control.

Railroad operations present hazards to both employees and a segment of the general population. Table XXI summarizes the casualties in railroading in 1974 by both type of accident and class of person. The 15,620 injuries and 140 fatalities of employees on duty indicate the hazards to railroad workers, while the 1224 deaths and 3255 injuries in grade crossing accidents indicate another significant safety problem to people not involved in railroad operations. In addition,

TABLE XX

AIR POLLUTANTS FROM RAILROADS

POLLUTANTS	EMISSION FACTOR LB/1000 GAL	EMISSIONS 10^3 TONS/YR	CONTRIBUTION TO U.S. ATMOSPHERIC POLLUTANTS (BY WEIGHT)
PARTICULATES	25	50	.2%
SO_x	57	114	.3%
CO	130	260	.2%
HC	94	188	.2%
NO_x	370	740	3.3%

Data Sources: References 25, 26

TABLE XXI

RAILROAD INJURIES AND FATALITIES, 1974

	KILLED	INJURED
BY TYPE OF ACCIDENT		
Rail-Highway Grade Crossing	1,224	3,255
Train and Train Service Accidents	607	10,534
Non-train Accidents	77	7,029
BY CLASSIFICATION OF PERSON		
Employees on Duty	140	15,620
Employees not on Duty	4	382
Passengers	7	574
Non-trespassers	1,192	3,568
Trespassers	565	674
TOTAL	1,908	20,818

Data Source: Reference 28

a significant number of persons are killed and injured while trespassing on railroad property.

ENVIRONMENTAL FACTORS IN ELECTRIFICATION

Three aspects of railroad electrification will affect the environment to some degree. The initial effect occurs with the construction of electrification facilities while the long term effect comes with the change in operations of the railroads from diesel to electric power. A substantial environmental impact can come with the change in the supply of fuel from direct petroleum usage to a mix of energy sources for electricity generation. These various functions will affect both the social environment and the natural environment. A checklist of potential environmental impact, developed for evaluating the Northeast Corridor Improvement Project (NECIP),[28] provides a convenient means for assessing the factors affected by railroad electrification. This overview is given in Table XXII. The listing of social systems and natural systems are taken from the NECIP study; energy, which was included, has been discussed fully in the previous section, while safety has been added as a related factor. The potential environmental impact is classified as a direct, primary effect; a minor, secondary effect; or an essentially negligible effect. In some cases the impact will be favorable; in others, unfavorable. A detailed discussion of these factors follows.

Construction of Electrification Facilities

The construction activities required to build the catenary structure, substations, and transmission lines for electrified railroad operations should not seriously impinge upon 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 while stimulating employment and business activity. The construction activity would cause some adverse visual or aesthetic impact. The construction, compared to typical transportation projects, would involve relatively little earth movement and therefore would not seriously affect geological

TABLE XXII
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

or hydrological systems. The air polluting emissions, the noise and the vibration from construction equipment would also be relatively minor. The construction of electrical transmission facilities involves hazards to the workers, but training, education and safety programs in this type of activity can be instrumental in keeping accidents at a low level.

Electrified Operations

Social Systems

The electrified railroad operations, when compared to the diesel-electric railroad operations they would replace, would have relatively little impact on social systems. The little additional land that would be required for fixed facilities will generally not create any impact. Electrification may or may not have an effect on property taxes and land value - it is difficult to judge a local jurisdiction's reaction and assessment of electrification facilities or the public reaction reflected in the value of adjacent land. The biggest changes in employment patterns will occur at locomotive repair facilities, with jobs related to the maintenance of diesel engines eliminated. A direct aesthetic visual impact will occur from the presence of aerial transmission and distribution facilities. Careful design and location procedures can lessen the impact, with the greatest potential benefit arising from the possibility of "joint use" corridors - utilizing railroad rights-of-way that are already dedicated to railroad operations as locations for new transmission facilities by the utilities.

Natural Systems

Geological systems will generally not be affected by electrified operations. Some benefits will occur in hydrological systems because of the elimination of certain fueling, cleaning and maintenance operations associated with the diesel internal combustion engines.

Many of the environmental problems associated with control of oils, solvents, and coolants will be eliminated. Electric locomotives and substation equipment currently use components with PCB as a coolant. Mishandling of this environmentally damaging fluid can allow its drainage into hydrological systems. Because of the newly recognized danger of PCB, it will not be used as a coolant in future electrical equipment. The presence of the transmission and distribution equipment presents a minor hazard for wildlife.

Air Quality

One measurable environmental effect of railroad electrification is the change in the critical air polluting emissions associated with the burning of fuels. The shift in fuel usage described previously under energy impact (with the energy sources for electrification summarized in Figure 14) will result in a change in the emissions. The methodology for calculating these emissions is presented in Appendix V. The total emissions generated by the traffic under consideration are illustrated in Figures 18 (Level 1) and 19 (Level 1 + 2) for the alternatives of diesel-electric and all-electric traction. Two levels of control of emissions from utility power plants are shown. Since the air pollutants from railroads are not a major problem (in comparison to the overall national picture, as described earlier), a single nationwide case is presented. The problem areas with diesels and other internal combustion engines are carbon monoxide, unburned hydrocarbons, and oxides of nitrogen. The problem areas with utilities, reflecting the reliance on coal, are particulates and oxides of sulfur. National standards for these emissions have been established for new power plants and further standards on existing power plants have been instituted at the state level. Evaluating the effects of railroad electrification, if the desired control levels can be reached on stationary generating stations, the air pollution emissions due to railroad operations will all be decreased, except for the oxides of

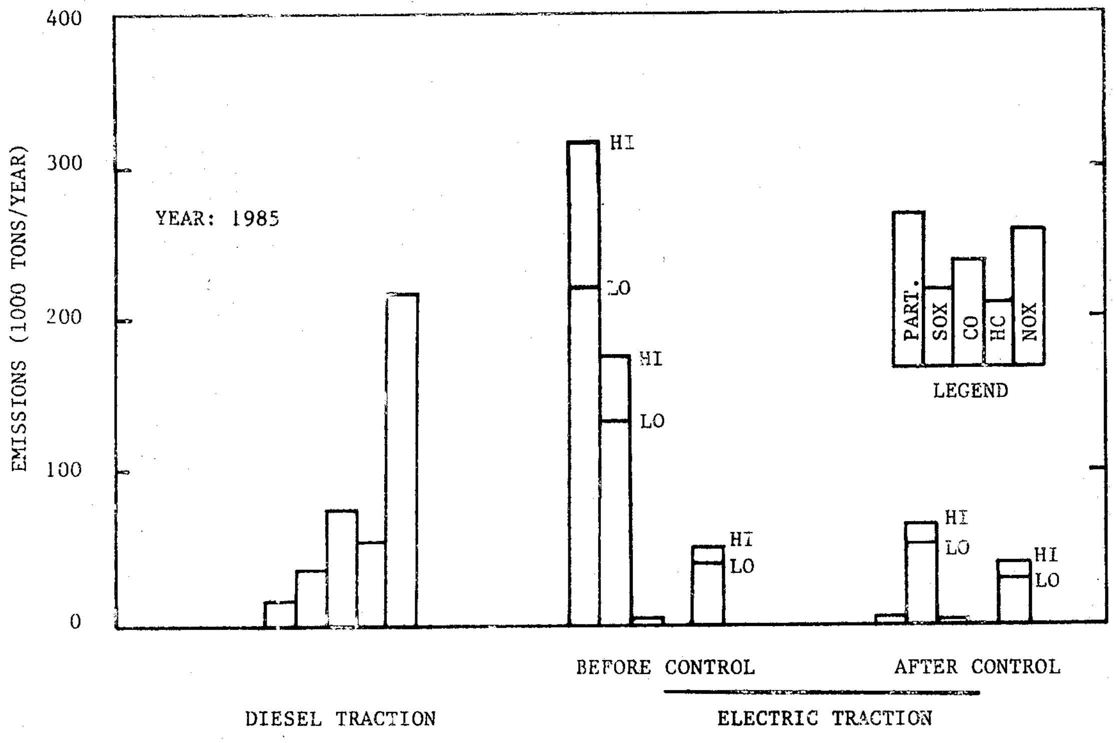


FIGURE 18
NATIONWIDE ESTIMATED ANNUAL EMISSIONS SERVICE LEVEL 1

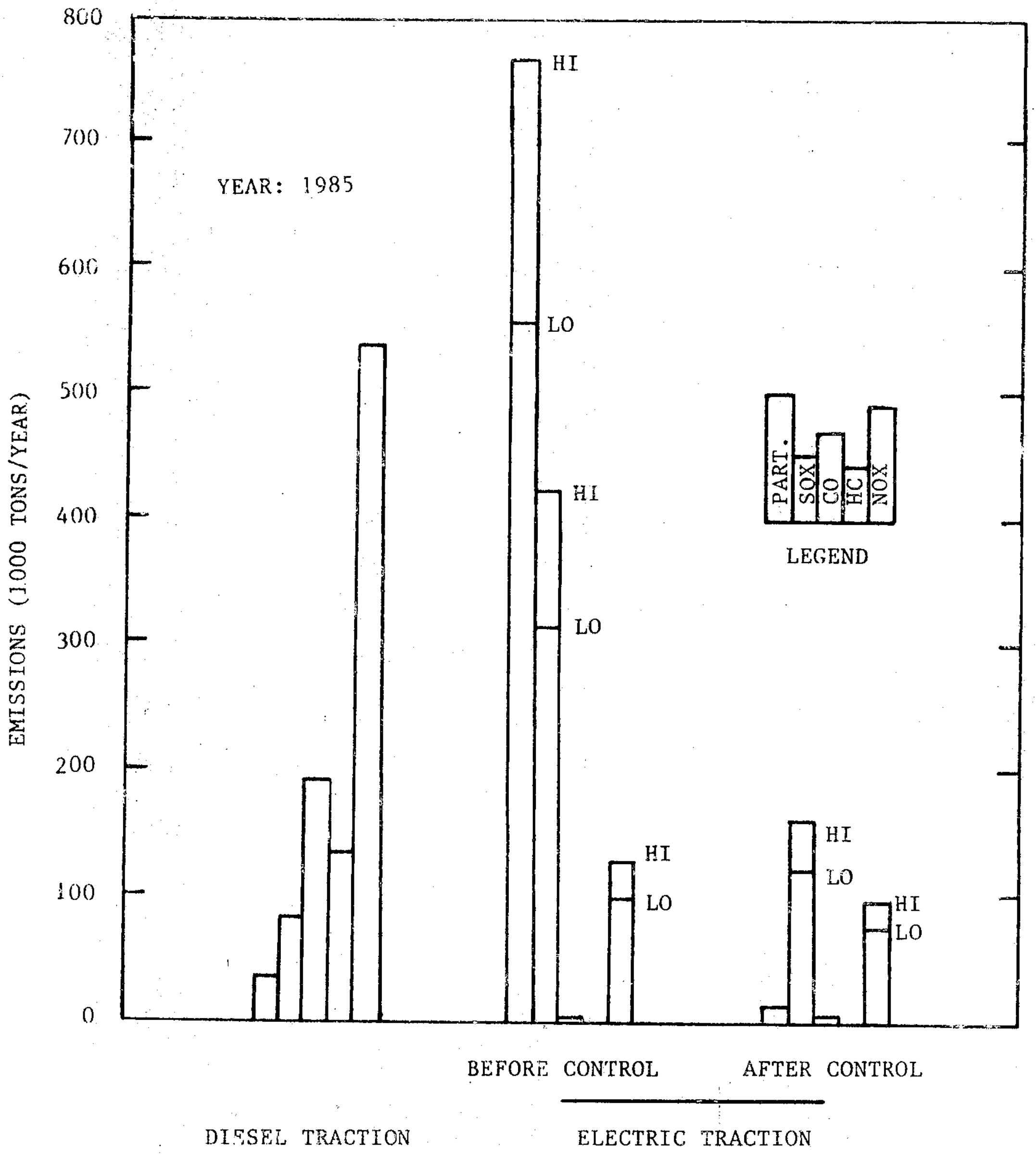


FIGURE 19
NATIONWIDE ESTIMATED ANNUAL EMISSIONS SERVICE LEVEL 1 AND 2

sulfur. In general, however, the contribution of electrified railroads will have less impact than those other factors affecting future emissions from the utilities.

One major difference in emissions due to railroads converting to electrified operations is the location at which both air pollutants and heat emissions are generated. The emissions from diesel-electric locomotives are distributed along the rail line whereas the electrical generating stations are a stationary source. It is difficult to assign a preference to either case; arguments exist against both.

Noise and Vibration

Limits on railroad noise sources have been established by the Environmental Protection Agency (EPA).[27] Standards have been set for locomotive operation under stationary and moving conditions and for rail car operations. These regulations are primarily directed toward the diesel engine itself as the major noise producer. The all-electric locomotive is much quieter. The noise from diesel-electric operations, and all-electric operations are illustrated in relationship to the Federal regulations in Figure 20. A switch to electric locomotives will present a favorable impact, particularly in low speed operations. This is particularly true since the high density lines considered for electrification are those producing the largest number of noise exposures per day.

Electro-Magnetic Interference (EMI)

Conversion of present railroads to electrified operation will result in electromagnetic disturbances along the right-of-way. The primary source of the problem is the single-phase catenary that supplies power to the train. The magnetic field produced by a typical catenary has a magnitude comparable to the magnetic field of the earth.

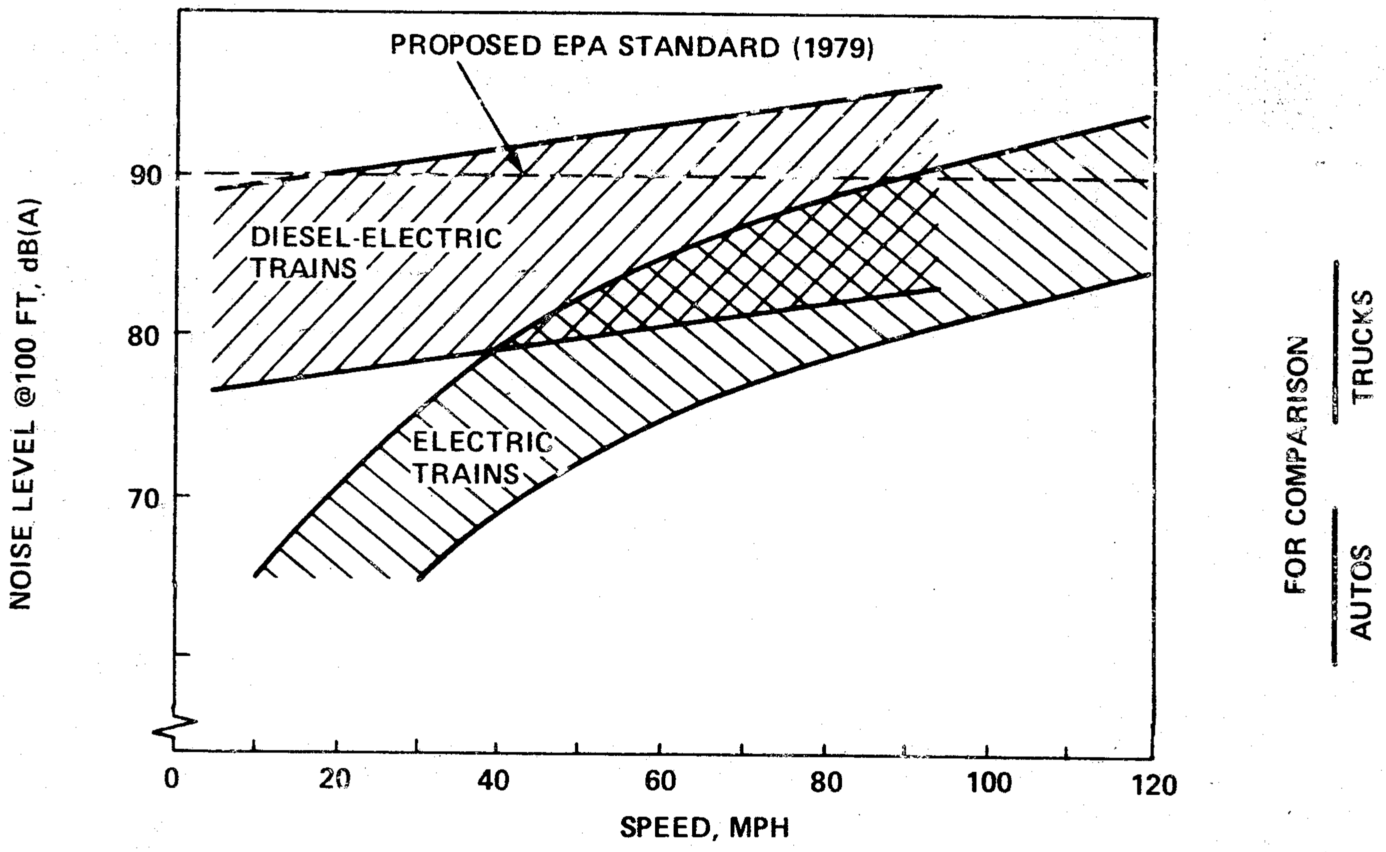


FIGURE 20
NOISE LEVEL OF TRAINS

Thus the magnetic field itself will have little direct influence on humans. The time variation of the magnetic field, however, can result in the induction of voltages in the order of 100 V/km in wires that are 5 m distant from the catenary. This can severely affect telecommunication cables, especially those used for voice-frequency telephony, but techniques for dealing with this problem are well known.

An electric field that parallels the rails is associated with electromagnetic induction from a time varying current. The potential difference between the catenary and ground results in a significant electric field directed from the catenary to ground. It is easy to shield electrical equipment from this field. However, humans contacting a long wire parallel to the ground can provide a current return from this wire to ground. The situation is that of being connected to the catenary through a capacitance. Should this capacitance become too large, a dangerously large current could flow through the person. The danger level of current is taken as 15 milliamps. This current together with the length of the wire contacted and the catenary voltage and frequency define a danger zone. For a 50 kV system the potential danger zone is within a few meters of the catenary for a meter-long wire and within approximately 40 meters of the catenary for a wire one kilometer long.

Recently, there has been considerable concern about the non-heating effects of non-ionizing microwave radiation.[30] These effects are formation of cataracts, heart-beat irregularities, carcinoma, effects related to the central nervous system, etc. In the U.S. it is generally agreed that microwave radiation in excess of 10 mW/cm^2 is hazardous, whereas in Russia this level is taken to be three orders of magnitude less, 10 μW/cm^2. There are several factors that lead to the conclusion that the electric field from a catenary system will not cause problems to humans. First, the occupants of a train are almost completely screened from the electric field of the catenary by the grounded metalwork of the coaches. Second, even if the humans were subjected to the full electric field, there is considerable doubt of harmful effects because the frequency of the field is seven orders of magnitude less than that of microwaves. Studies now being sponsored by the Electric Power Research Institute are aimed at determining the ecological effects of fields in the order of 10 kV/m and above at commercial power frequencies, such as might be found under million-volt power transmission lines. It appears that adverse effects have been observed at these high field levels.

Induced and electrostatic fields are not the only sources of electromagnetic interference produced by a catenary system. It is known that severe disturbances to electronic equipment can be produced by harmonics on the catenary. These most often are the result of locomotives employing electronic (thyristor) power control for the traction motors. The locomotive equipment generates the harmonics and the catenary radiates and conducts them, leading possibly to effects over a wide area. Some of these effects are the induction of spurious signals on telephone lines and possible interference with the operation of such equipment as automotive electronics, pacemakers, etc. Also, additional interference to electronic equipment, especially to radio receivers (including television sets), can result from corona discharge and arcing at the power contact points.

Some possible difficulties not thought to be very significant are the formation of ozone in tunnels due to electrical discharge, electrolysis effects in the vicinity of the rails, and lightning strikes influenced by the catenary structure.

Summarizing, there appear to be no severe problems with EMI; the major trouble areas can be covered by adequate design. The establishment of design standards would be useful, however. If any evidence of biological effects of electric fields appears in the future, the results should be evaluated with respect to the parameters applicable to railroad electrification.

Safety

The presence of the overhead catenary with its high voltage potential to ground introduces a certain safety risk. A number of work operations involve careful procedures; training and education programs can make employees aware of the dangers and teach them proper procedures for normal operations and emergency conditions. The element of danger is also presented to others - particularly to juvenile trespassers who climb on cars under the catenary and on the catenary support structure itself. The Penn Central Railroad (now Conrail) experience provides some insight in the matter of safety problems with electrification. During the year 1975, seven juvenile trespassers were injured and two killed as a result of contacting the overhead catenary.[31] This railroad experience with trespassers certainly indicates a potential problem. The data cannot be directly extrapolated, however, because a large portion of the existing electrified track is in highly built-up urban areas where the problems with trespassers could be expected to be at their worst. The Nation Transportation Safety Board, in investigating an accident involving the electrocution of a juvenile trespasser on Penn Central tracks,[32] recommended several actions to minimize the hazards associated with the catenary such as improved procedures to restore power when circuit breakers are interrupted by an unknown cause, more effective prevention of trespassing on railroad tracks and right-of-ways, and better training of emergency crews responding to emergencies in areas exposed to an electrified catenary.

Fuel Supply For Electrification

Railroad electrification involves a shift in fuel sources, as previously discussed. The change in fuel is from complete petroleum usage to a mix, which by 1985 is projected to be nearly 50% coal and 25% nuclear. Adding the electricity requirements for railroad operations will not be a forcing factor on electricity generation or the supply of fuel, however. The environmental impact of the new fuel sources should be noted, but the environmental problems must be resolved within the context of a national energy outlook rather than because of railroad electrification.

In terms of social systems, coal mining tends to be more disruptive than petroleum production since land and labor requirements are greater. With natural systems coal mining also, tends to have more disruptive environmental impacts, although petroleum production does entail environmental risks in exploration and production, in transportation, and in refining. The environmental problems of increased coal production have been widely publicized. One major factor is the despoiling of the land with surface strip mines. The need for versus cost of landscape restoration has been widely debated. Surface water problems such as erosion, sedimentation, silting, ponding and changes in the quality of water also exist. Mining may also change the characteristics of aquifers. If this environmental damage cannot be accepted, preventive measures and remedial action must be taken during and after the mining cycle. Additional environmental problems are associated with the transportation of coal. Since most coal is transported by train, the opening of a new mine and supply routes can mean a greatly increased number of trains, with resulting problems in noise, dust, and disruption. Coal mining and transportation also introduce safety hazards in terms of mining accidents, illness, and train accidents.

CONCLUSIONS

STUDY RESULTS

Routes

Freight traffic is concentrated on a small portion of the nation's railroad route structure. Electrifying these segments would produce a considerable shift from conventional to electrified rail operations. This effort has identified specific routes that carry a high traffic density and have the other suitable characteristics to make them prime candidates for electrification. Two groupings have been established for further study. Eleven highly utilized routes, with a traffic density generally of at least 40 million gross ton-miles per route mile per year (MGT), totaling just over 9800 miles (5% of the United States total for Class I railroads) and carry approximately one-fourth of the total freight traffic. To establish an extensive scope of possible electrified operations, sixty-six other high density routes, generally with at least 20 MGT, have been identified, supplementing the first level candidates. A network composed of all the routes would total just under 40,000 miles (20% of the United States total) and carry almost two-thirds of the total freight traffic.

Energy Requirements

The present and future (to 1990) traffic that could be handled by electric motive power on the candidate routes for electrification and the energy consumption for this traffic has been estimated for the alternatives of continued use of diesels and the conversion to all-electric power. The diesel fuel requirements at current traffic levels (1975) are approximately 950 million gallons per year for the first level and approximately 2390 million gallons per year when the second level is added. This fuel usage would grow at annual rate of about 2%. The lower level amounts to 24% of the total railroad fuel consumption and 26% of that used in freight service; the higher level amounts to 60% of the total and 66% of that used in freight service. If the routes were electrified at this point in time, (1975) the electricity requirements would be approximately 14,110 GWH per year and approximately 35,540 GWH per year at the two levels considered.

Electricity Generation Effects

The requirements for electricity and the fuels used in electricity generation have been evaluated using projections developed by the Federal Energy Administration (FEA) in the 1976 National Energy Outlook. On a national basis, the additional electricity requirements, at current levels, are small, amounting to 0.73% and 1.85% of the total current electricity consumption for the lower and higher levels. The effect of such an additional load will diminish with time since electricity consumption is projected to increase at a faster rate than freight traffic. In fact, the addition of an extensive railroad electrification burden on the utilities creates a smaller variation in future projections than that possibly created by changes in energy supply and demand conditions. The detailed effect of a particular railroad load must be evaluated on a case-by-case basis. The largest problems in supplying a new demand for railroad electrification would probably occur in the Rocky Mountain region, characterized by a relatively large railroad load and low generating capacity. Extensive railroad electrification there would create a load equal to approximately 4 to 6% of the current electricity consumption.

Fuel Effects

The fuels and other energy forms used in the generation of electricity come from a variety of sources that vary throughout the country. The fuels required for railroad electricity have been estimated assuming that the fuels will contribute according to the overall proportion in a regional mix. Coal contributes slightly less than one-half the energy for electricity generation, and although its proportion has been dropping for a long while, it is now projected to remain fairly constant. The annual coal requirement for railroad electrification, at current traffic levels, would be about 3.63 million tons for the lower level and 8.46 million tons at the higher level. This accounts for 0.6 to 1.4% of the current coal consumption. (As late as 1945, the railroads accounted for 20% of the nation's coal consumption.) The nationwide coal consumption rate is projected to grow at an annual rate of 5%, reaching a consumption of over 1000 million tons annually by 1985. Such a growth rate requires a concerted effort that will not be greatly affected by an additional load due to railroad electrification. A smaller proportion of the electricity generation load is supplied by petroleum sources. The net petroleum savings that can be accomplished by railroad electrification are the difference between that which would be consumed by diesel power and the railroad's share of the petroleum used in electricity generation. At current traffic levels, the net savings would be 820 million gallons per year at the lower level of electrified service and 2100 million gallons per year at the higher level of service. By 1985, these numbers would grow to 1160 million gallons per year and 2800 million gallons per year, respectively. These estimates are subject to considerable variation, however, since the petroleum used in electricity generation is projected to vary widely depending on the supply situation. The values presented for current possible petroleum savings represent only a 0.6 to 1.5% share of the petroleum used by transportation and a 0.3 to 0.8% share of the total petroleum usage of the nation. Natural gas will also supply a portion of the electricity generation load. The annual natural gas requirement for railroad electrification, at current traffic levels, would be about 16.3 billion cubic feet at the lower level and 63.5 billion cubic feet at the higher level. These amounts are equivalent to only 0.1% to 0.3% of the current nationwide consumption of natural gas.

Environmental Effects

Environmental effects of railroad electrification first appear during the construction of facilities, a short term consideration, while the lasting effects come with the change in operations from diesel to electric power. Indirect effects arise in obtaining the supply of fuel used in the operations. The impacts, some positive and some negative, are measured by several different factors, but all appear to be quite minor.

The construction activity places temporary loads on the local community and its facilities while stimulating business activity. The construction activity could adversely affect geological or hydrological systems and create some air pollution, noise and vibration problems. There should be, however, no serious consequences if normal environmental control practices are invoked. The magnitude of the effects, particularly when compared to typical transportation projects, should be small.

The electrified railroad operations create some changes in social systems, the biggest being in employment patterns at locomotive repair facilities, with jobs related to the maintenance of diesel engines eliminated. The general public is also affected by the visual impact of aerial electrical transmission and distribution facilities. Careful design is required to lessen the impact, with a trade-off possible by utilizing railroad rights-of-way as locations for other new utility transmission facilities.

Electrified operations will affect several aspects of natural systems. A beneficial impact would be the elimination of certain fueling, cleaning and maintenance operations that in the past have polluted hydrological systems. Air pollution created by the burning of fuels will be changed, but not drastically. With controls on the emissions of utility power plants, particulate, carbon monoxide, and nitrogen oxide emissions due to railroad operations will be decreased by electrification, while sulfur oxide emissions will be increased. However, the contribution of railroads to the total air pollution situation is so small that any changes in railroad operations would have little overall effect. Another favorable impact from electrification would be the reduction in noise by the elimination of the on-board internal combustion engine. The effect would be greatest in areas of low speed operation. Electrical facilities and equipment introduce the possibility of several forms of electromagnetic interference. There appear to be no severe problems, however, and troublesome areas can be covered by adequate design. Electrification facilities also bring a safety risk because of the high voltage catenary. Training, education and design practices can minimize the danger.

The indirect environmental effects of electrification come with a change in fuel supply, from a completely petroleum base, to a utility fuel mix in which coal predominates. Adding the electricity requirements for railroads will be only a minor factor in the future supply of fuel for utilities, and environmental problems will have to be resolved on the basis of a national energy outlook.

RAILROAD ELECTRIFICATION IN COMPARISON TO OTHER ENERGY PROGRAMS AND OPTIONS

This study has shown that railroad electrification, normally considered by the railroads as a means of increasing the profitability of operations, can produce a national annual net petroleum savings of 2100 million gallons of diesel fuel (although a savings of this extent might require electrifying lines that would not provide what would normally be considered an attractive return on investment). It is therefore of interest to compare a savings of 2100 million gallons per year (137 thousand barrels per day) of petroleum to other energy programs and options.

Transportation Conservation Measures

Since automobile travel is the largest use of petroleum it is the natural place to achieve substantial savings. FEA has estimated the effects of several possible policy measures affecting automobile travel.[33] The impact of these actions is presented below.

Policy	Estimated energy savings (thousand barrels per day) 1980	Estimated energy savings (thousand barrels per day) 1985
Increase percentage of urban travel carried by mass transit from 2.5 percent in 1973 to 5.0 percent in 1980 and 7.5 percent in 1985	52	122
Increase carpooling sufficiently to reduce work-trip auto travel by 10 percent in 1980 and 1985	69	105
Increase gasoline prices by 20 percent starting in 1975	484	700
Increase new car fuel economy from 14 mpg in 1974 to 20 mpg in 1980 and 22 mpg in 1985.	568	1327

In comparison to these savings, extensive railroad electrification would be more effective than shifts in urban travel from auto to mass transit or in increasing carpooling. Measures which decrease overall gasoline consumption, by either higher prices or improved fuel economy, are much more effective, however.

Electric Cars

Electric and hybrid vehicles appear to be attractive options for reducing petroleum consumption in the future.[34] Electric vehicle characteristics could substantially impact the buying trends of second and third car households. At present, the number of vehicles owned as second and third cars is 26 million. This substitution would result in a savings of about 400 million barrels of oil annually (1.1 million barrels per day) by the year 2000. Again, the high automobile consumption shows that electric and hybrid cars can be very effective if a high market penetration is reached.

Coal Conversion

Instead of utilizing coal to generate electricity, it can be converted to oil and gas by several tested processes. An Extensive effort is currently underway to combine such processes into a large-scale system that will manufacture the oil and gas at reasonable cost.[35] Since the oil could be used directly in diesel engines, this alternative should be compared to railroad electrification. A typical coal conversion plant might process 25,000 tons of coal per day. The capital investment would be about $1.5 billion and the output would be 50,000 barrels per day of liquid products and 205 million standard cubic feet of gas. To supply the fuel needs of the railroad traffic that could be handled by electrification (2100 million gallons per year) would require the energy output of three such conversion plant. Consequently a substantial capital investment would be required for coal conversion, just as with electrification. Furthermore, these coal conversion plants are expected to show a thermal efficiency of only 55 to 70%. Using coal-derived oil in a diesel-electric locomotive would thus lower the overall energy efficiency of the fuel-to-motive work cycle, making it considerably lower than that occurring of the electric locomotive.

Improved Efficiency of Generating Stations

In terms of overall thermal efficiency (i.e. fuel to tractive work), railroad operations are comparable whether using diesel-electric locomotives or all-electric locomotives obtaining power from a fossil fuel burning generation station. The least efficient process in each power cycle is the conversion of fuel energy to mechanical work - the diesel engine used to drive the alternator in a locomotive and the boiler/steam turbine (or other components) used to drive the generator in a utility plant. Although some improvement in thermal efficiency might be achieved in a diesel-electric arrangement, there appears to be more likelihood, and therefore more interest, in achieving improvements in the efficiency of control generation stations. Considerable research is underway in advanced power generation techniques that can use coal or coal-derived fuels. Promising techniques are fluidized-bed combustion for power plants using conventional steam conditions and combined gas turbine-steam turbine cycle plants, e.g., an advanced open cycle gas turbine discharging into a steam bottoming plant. Development of more advanced technology might lead to the use of fuel cells for electricity generation. Conservation measures, such as waste-as-fuel and waste heat recovery, also hold good potential for improving overall fuel utilization in utility plants. Improving the efficiency of the nation's generating system would come slowly, however, because of the size of the existing base. Any improvement in electrical generating plants would be reflected in raising the overall energy efficiency of electrified railroads.

APPENDIX I

IDENTIFICATION OF CANDIDATE SEGMENTS

BACKGROUND

When looking at anything but gross characteristics, the United States rail system must be divided into its components not only because of its diverse ownership but also because of the wide variations in operating and physical conditions that occur throughout the various parts of the system. In order to evaluate various aspects of railroad electrification, the study sponsors, the Federal Railroad Administration (FRA) and the Federal Energy Administration (FEA), decided not to utilize overall statistics but rather to develop a realistic indication of extensive electrified operations by the nation's railroads. Thus an early objective of this railroad electrification study was to identify specific route segments that formed logical possibilities for conversion to electrified operations. The basic criterion for profitable electrified operations is a high traffic density between points that are suitable terminals for the electric motive power. Additional physical factors concerning the route also affect the required capital investment, and thus profitability.

The nation's rail routes have been examined and the high density lines with suitable operational characteristics for electrification have been identified. The identification of these rail lines was performed at a level of detail sufficient to assess the cost of electrification, the petroleum savings, the electricity demand, and the environmental impact of the conversion. The scope of the electrified network was made large enough to consider a portion of the nation's rail lines sufficient to achieve a substantial impact in fuel shift. Consequently the routes greatly extend beyond those that individual railroads have already studied for electrification. The detailed description of the candidate segments for electrification was presented for project use in Reference 11.

METHODOLOGY

The primary source and basis for the information used to identify potential routes for electrification is the data compiled by The Department of Transportation (DOT) in creating the reports[12] submitted in accordance with Section 503 of the Railroad Revitalization and Regulatory Reform Act of 1976. DOT has formed a data base from information supplied by the railroads, structuring it into a network modeling project at FRA/Office of Policy and Program Development (OP&PD). The DOT/FRA data base has been used for the information source rather than seeking primary information directly from the railroads.

Line Identification

The following steps were followed to identify railroad routes that are candidate segments for an electrified railroad system.

1. Line segments with a traffic density of at least 20 million gross ton miles per route mile per year (MGT) were identified on a railroad-by-railroad basis. The density category tabulation served as the data source and the LIC (line identification code) provided line segment identification.

2. The high density line segments were developed into high density routes for the individual railroads. End points for these routes were established at locations that would be logical terminals for the railroad's electrified operations. These end points were generally major classification yard locations or major traffic generation points. For individual railroads other operational considerations, such as carrying two branches of a major route to logical end points and including the separate routing where a railroad splits traffic between two separate tracks, were incorporated. In the process of establishing a route, the logical segments suitable for electrified operations emerged and isolated high density stretches were dropped.

3. The candidate segments were coded by LIC and the FRA/OP&PD data base was used to obtain detailed data for each route. Continuity of the LIC segments was checked; and the route structure was corrected extraneous LIC segments were eliminated.

4. The route structure was reviewed throughout the process to incorporate individual railroad operational considerations. Information was provided by FRA, the Association of American Railroads, and several railroads.

Two levels of service were used to classify the candidate segments for electrification. Service Level 1, in general indicates routes with a substantial portion of which have a traffic density of over 40 MGT. For this study these lines, presented previously in Table 2, form a minimum network. Several Level 2 indicates routes with a traffic density generally of over 20 MGT that appear to be suitable route segments for an individual railroad's operations. These routes are presented in Table 3. End points also frequently provided connections to other segments (with the same and/or different roads). The Service Level 2 segments include several routes with a current low level of traffic but with an anticipated high level in future years because of expected coal shipment.

For Service Level 1, 11 basic routes were identified. These routes have three branches and four second route segments identified with them. The total mileage of these lines is 9816.7 miles. For Service Level 2, 66 basic routes were identified. These routes have nine branches and three second route segments identified with them. The total mileage for the individual routes is 31,238.0 miles, but 1066.9 miles of this total is duplicated. Thus the electrification of all routes identified as candidate segments (Service Level 1 plus Service Level 2) would encompass 39,987.8 miles of line.

Traffic Density

For this study, assumptions concerning the use of electric and diesel motive power were made to follow the philosophy adopted by railroads studying electrification. It was assumed that only line-haul traffic would be handled by electric motive power. Yard switching and branch line traffic would be handled by diesel power. The trains with electric locomotives would set off and pick up traffic at branch line junctions, but line-haul traffic from a yard to a non-electrified route would still be handled by diesels operating under the catenary.

The traffic density contained in the FRA/OP&PD data base represents the total traffic for a LIC segment. For the route listing, the traffic density was adjusted to represent the traffic of the operating railroad over the specified route. Consequently, changes in traffic density were made for trackage rights and route structure. Several other changes in traffic density were made as appropriate. Obvious errors in traffic density were also replaced with estimates.

A further correction was necessary to account for local traffic such as that set out and picked up at industrial sidings that would not be electrified. It was assumed that local traffic would average 1 MGT annually (2 trains per day, 20-30 cars per train, 5-7 days a week). For the industrial Northeast 2 MGT was assumed and for some Western routes and coal traffic feeders no local traffic was assumed.

SUMMARY

Portions of the nation's rail system have been identified as candidate segments for electrification. These are specific routes with suitable characteristics for electrified operations. Information on routing by LIC, distance, number of tracks, type of signaling system and traffic density has been generated for project use. The traffic density has been adjusted to represent that portion which would be handled by electric motive power. A basic system of the highest density lines covers approximately 9800 route miles. Additional segments can extend the electrified network to approximately 40,000 miles.

APPENDIX II

ESTIMATION OF TRAFFIC GROWTH

BACKGROUND

The decision to electrify is made a long time before trains can start running under the catenary, and furthermore, electrification is a long-lived investment. Therefore, future traffic growth patterns are crucial to determining the desirability of electrifying a line, since traffic density is the most important consideration when deciding whether to electrify or not. Traffic growth was estimated using individual railroad traffic trends and commodity growth projections. The commodity growth estimates were prepared for five territories as well as for the country. The regional forecasts can be compared with those of the individual railroads to assess the likelihood of a railroads past trends continuing into the future. The details of this work are presented in Reference 13.

METHODOLOGY

The railroad forecasts were prepared by using linear regression analysis. The variables were tons and ton-miles for each year. The last ten years were used except in cases where mergers or other changes in mileage necessitated a shorter period.

The commodities of interest are those that make up the bulk of the traffic of the railroads. The commodities carried by the individual railroads are presented in Table XXIII. The commodity forecasts were prepared for the five railroad territories, shown in Figure 21, that are used in reporting freight traffic statistics. Each territorial share of the national railroad tonnage for each commodity was computed for the years since 1964 for which data were available. These shares were then used as the dependent variables in a regression analysis, and territorial shares were predicted to 1985. Existing forecasts of national railroad tonnage to 1985[36] were then multiplied by each territory's share to

TABLE XXIII

COMMODITIES CARRIED BY RAILROADS IN 1974(4)

Railroad	Commodity	Tonnage (000 omitted)	Percent of Total
BN	Farm Products	28,227	19.3%
	Metallic Ores	14,892	10.2%
	Coal	31,550	21.5%
	Food & Kindred Products	13,598	9.3%
	Lumber & Wood Products	14,354	9.8%
B&O	Coal	43,899	38.8%
	Chemicals	7,785	6.9%
	Primary Metals	7,235	6.4%
	Transportation Equipment	3,779	3.3%
ATSF	Farm Products	18,082	19.9%
	Non-Metallic Ores	10,677	11.8%
	Food & Kindred Products	10,188	11.2%
	Chemicals	12,803	14.1%
C&O	Coal	63,637	57.1%
	Chemicals	7,314	6.6%
	Transportation Equipment	4,239	3.8%
CONRAIL (1973 data) Including PC, RDG, LV, CNJ, & AA (excludes EL)	Metallic Ores	33,851	9.6%
	Coal	95,567	27.1%
	Non-Metallic Minerals	20,771	5.9%
	Food & Kindred Products	25,621	7.3%
	Pulp & Paper	21,092	6.0%
	Chemicals	22,409	6.4%
	Primary Metal Products	28,641	8.1%
D&H	Food & Kindred Products	1,761	13.4%
	Pulp & Paper	3,727	28.3%
	Stone Clay & Glass	1,395	10.6%
EL	Metallic Ores	4,556	11.0%
	Coal	5,583	13.5%
	Food & Kindred Products	4,865	11.8%
	Primary Metal Products	5,015	12.1%
	Misc. Mixed Shipments	1,770	4.3%
ICG	Coal	27,886	26.4%
	Food & Kindred Products	10,186	9.6%
	Lumber	15,611	14.8%
	Chemicals	13,298	12.6%

COMMODITIES CARRIED BY RAILROADS IN 1974 (CONTINUED)

Railroad	Commodity	Tonnage	Percent of Total
MP	Farm Products	15,589	15.9%
	Coal	10,037	10.3%
	Non-Metallic Minerals	9,562	9.8%
	Food & Kindred Products	8,389	8.6%
	Chemicals	17,102	17.5%
N&W	Coal	79,132	49.9%
	Transportation Equipment	6,051	3.8%
SL-SF	Coal	4,016	10.2%
	Food Products	6,387	16.2%
	Chemicals	4,751	12.1%
SCL	Coal	15,024	9.5%
	Non-Metallic Minerals	48,190	30.6%
	Food & Kindred Products	10,684	6.8%
	Lumber	22,766	14.5%
	Pulp & Paper	9,485	6.0%
	Chemicals	17,411	11.1%
L&N	Coal	53,296	41.4%
	Chemicals	7,137	5.5%
CRR	Coal	14,963	68.5%
	Chemicals	944	4.3%
SP	Farm Products	10,659	8.5%
	Metallic Ores	14,766	11.7%
	Non-Metallic Minerals	17,036	13.5%
	Food Products	15,031	11.9%
	Lumber	16,281	12.9%
	Chemicals	13,713	10.9%
	Transportation Equipment	2,500	2.0%
SOU	Coal	36,916	24.1%
	Non-Metallic Minerals	18,833	12.2%
	Lumber	17,753	11.6%
	Pulp & Paper	9,636	6.3%
	Chemicals	14,780	9.6%
	Stone Clay & Glass	13,454	8.7%
UP	Farm Products	15,612	17.6%
	Coal	12,573	14.2%
	Non-Metallic Minerals	8,469	9.6%
	Food Products	9,934	11.2%
	Lumber	8,252	9.3%
	Chemicals	8,483	9.6%

Railroad Abbreviations:

BN	Burlington Northern
ATSF	Atchison, Topeka and Santa Fe
B&O	Baltimore & Ohio
C&O	Chesapeake & Ohio
CRIP	Chicago,Rock Island & Pacific
EL	Erie Lackawanna
PC	Penn Central
RDG	Reading
LV	Lehigh Valley
CNJ	Central of New Jersey
SP	Southern Pacific
SOU	Southern
UP	Union Pacific
AA	Ann Arbor
D&H	Delaware & Hudson
ICG	Illinois Central Gulf
KCS	Kansas City Southern
MP	Missouri Pacific
N&W	Norfolk & Western
SL-SF	St. Louis & San Francisco
SCL	Seaboard Coast Line
L&N	Louisville & Nashville
CRR	Clinchfield

Data Source: Reference 37

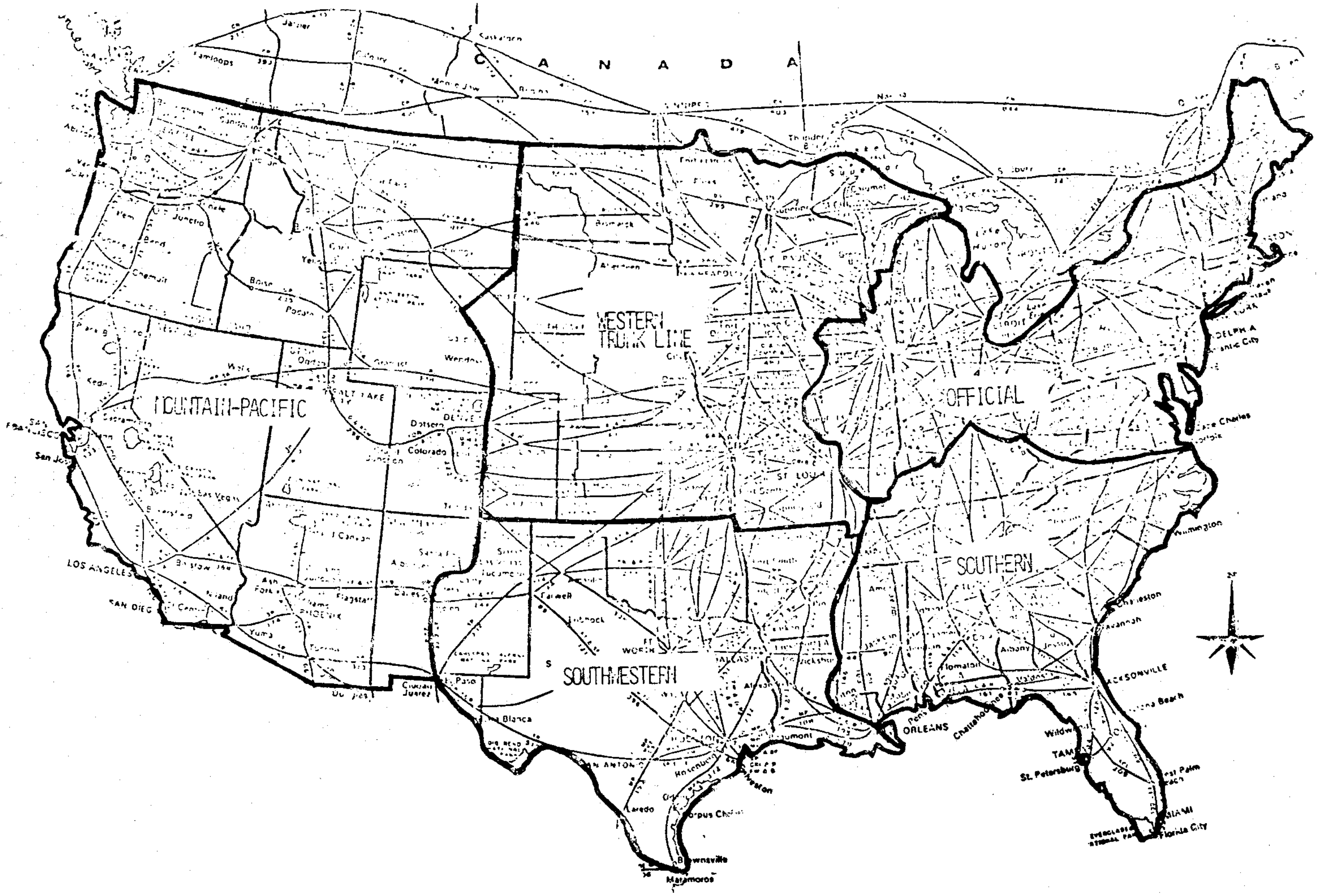


FIGURE 21
RAILROAD TERRITORY BOUNDARIES

predict territorial tonnage to 1985. Additional modifications were made in the case of coal to consider different energy scenarios. Tables XXIV through XXXIV present the forecasts for the individual commodities. Note there are two forecasts for coal, one assuming past trends continue and the other assuming more of a shift to the West and the Northeast.

TERRITORIAL SUMMARY

Summing up the forecasts of commodity growth by each territory gives an overall regional growth forecast. These forecasts are presented in Table XXXV. Three forecasts are given to illustrate the impact of the various assumptions on coal traffic. Forecast I assumes no growth at all in coal traffic. This forecast illustrates the non-coal traffic growth for each territory. Forecast II includes the coal traffic projections derived from the historic trends, which predict relatively more growth in the South. Forecast III is an adjusted coal forecast, giving more weight to post-energy crisis conditions. This forecast allocates more traffic to the Official and Mountain-Pacific Territories than Forecast II. Total coal tonnage is the same in Forecast II and III.

Looking at the individual regions, the Official Territory seems to be facing a period of slow growth or, if past trends in coal traffic continue, no growth. In any case, annual growth should be less than one percent. Slow overall regional growth rather than any particular industry is the cause of this slow growth in tonnage.

The Southern Territory shows fairly high growth rates no matter what forecast is used. Forecast I shows Southern Territory non-coal traffic growing nearly 4% a year, due to the broad based growth of the region. Lumber and chemicals are the leading sources of traffic growth. Depending on which coal forecast is used, growth could be

TABLE XXIV

FARM PRODUCTS (STCC 1)

TONNAGE ORIGINATED BY TERRITORY

(MILLIONS OF TONS)

	Total RR Originated Tons(5)	Market Shares by Territory(1,2)									
		Official		Southern		Western Trunk Lines		Southwestern		Mountain-Pacific	
		%	Tons	%	Tons	%	Tons	%	Tons	%	Tons
1973	156.1	16.5	25.8	5.8	9.1	42.9	67.0	21.0	32.8	13.7	21.4
1975	136.4	16.8	22.9	6.9	9.4	40.4	55.1	21.9	29.9	13.9	19.0
1980	158.4	12.3	19.5	7.4	11.7	47.1	74.6	20.5	32.5	12.7	20.1
1985	170.4	9.4	16.0	8.0	13.6	50.0	85.2	21.6	36.8	10.9	18.6
CHANGES IN TONS											
1973-1980			-6.3		2.6		7.6		- .3		-1.3
1980-1985			-3.5		1.7		10.6		4.3		-1.5
TOTAL CHANGE			-9.8		4.5		18.2		4.0		-2.6

Data Source: Reference 38 and 39

TABLE XXV

METALLIC ORES (STCC 10)

TONNAGE ORIGINATED BY TERRITORY

(MILLIONS OF TONS)

	Total RR Originated Tons(5)	Market Shares by Territory (1,2)									
		Official		Southern		Trunk Lines		Southwestern		Mountain-Pacific	
		%	Tons	%	Tons	%	Tons	%	Tons	%	Tons
1973	125.1	34.2	42.8	3.0	3.8	46.9	58.7	2.8	3.5	13.1	16.4
1975	120.9	34.7	42.0	3.1	3.7	48.7	58.9	2.3	2.8	11.2	13.5
1980	140.7	30.0	42.2	3.0	4.2	52.3	73.6	2.7	3.8	12.0	16.9
1985	161.1	28.0	45.1	2.9	4.7	54.8	88.3	2.9	4.7	12.0	19.3
CHANGES IN TONS											
1973-1980			- .6		0.4		14.9		-.3		.5
1980-1985			2.9		0.5		14.7		.9		2.4
TOTAL CHANGE			2.3		.9		29.6		1.2		2.9

Data Source: Reference 38 and 39

TABLE XXVI

COAL (STCC 11)

TONNAGE ORIGINATED BY TERRITORY

(MILLIONS OF TONS)

		Market Shares by Territory (1,2)									
	Total RR Originated Tons (5)	Official %	Official Tons	Southern %	Southern Tons	Western Trunk Lines %	Western Trunk Lines Tons	Southwestern %	Southwestern Tons	Mountain-Pacific %	Mountain-Pacific Tons
1973	375.7	58.9	221.3	27.9	104.8	4.8	18.0	0.6	2.3	7.8	29.3
1975	396.4	53.0	210.1	29.3	116.1	5.2	20.6	0.7	2.8	11.8	46.8
1980	518.9	42.1	218.5	37.9	196.7	5.3	27.5	1.0	5.2	13.6	65.4
1985	589.0	30.7	180.8	44.8	263.9	5.6	33.0	1.3	7.7	17.5	103.1
CHANGE IN TONS											
1973-1980			-2.8		91.9		9.5		2.9		36.1
1980-1985			-37.1		67.2		5.5		2.5		38.3
TOTAL CHANGE			-40.5		159.1		15.0		5.4		74.4

Data Source: Reference 38 and 39

TABLE XXVII

REVISED COAL FORECAST (STCC 11)

(ASSUMES HISTORIC TRENDS CHANGE)

TONNAGE ORIGINATED BY TERRITORY

(MILLIONS OF TONS)

	Total RR Originated Tons (3)	Market Shares by Territory (1, 2)									
		Official		Southern		Western Trunk Lines		Southwestern		Mountain-Pacific	
		%	Tons	%	Tons	%	Tons	%	Tons	%	Tons
1973	375.7	58.9	221.3	27.9	104.8	4.8	18.0	0.6	2.3	7.8	29.3
1975	396.4	53.0	210.1	29.3	116.1	5.2	20.6	0.7	2.8	11.8	46.8
1980	518.9	44.2	229.4	30.2	156.7	5.3	27.5	0.8	4.2	19.5	101.3
1985	589.0	44.0	259.2	30.2	177.9	5.4	31.8	0.9	5.3	19.5	114.8
CHANGE IN TONS											
1973-1980			8.1		51.9		9.5		1.9		72.0
1980-1985			29.8		21.2		4.3		1.1		13.5
TOTAL CHANGE			37.9		73.1		13.8		3.0		85.5

Data Source: Reference 38 and 39

TABLE XXVIII

NON-METALLIC MINERALS (STCC 14)

TONNAGE ORIGINATED BY TERRITORIES

(MILLIONS OF TONS)

	Total RR Originated Tons (5)	Market Share by Territory (1,2)									
		Official		Southern		Western Trunk Lines		Southwestern		Mountain-Pacific	
		%	Tons	%	Tons	%	Tons	%	Tons	%	Tons
1973	170.0	25.7	43.7	42.3	71.9	7.2	12.2	15.9	27.0	8.8	15.0
1975	176.5	23.9	42.2	39.9	70.4	6.9	12.2	19.2	33.9	10.0	17.6
1980	191.3	22.0	42.1	45.0	86.1	5.9	11.3	18.0	34.4	9.1	17.4
1985	203.9	19.8	40.4	47.5	96.9	4.0	9.8	18.6	37.9	9.1	18.6
CHANGE IN TONS											
1973-1980			-1.6		14.2		-.9		7.4		2.4
1980-1985			-1.7		10.8		-1.5		3.5		1.2
			-3.3		25.0		-2.4		10.9		3.6

Data Source: Reference 38 and 39

TABLE XXIX

FOOD AND KINDRED PRODUCTS (STCC 20)

TONNAGE ORIGINATED BY TERRITORY

(MILLIONS OF TONS)

	Total RR Originated Tons	Market Share by Territory (1,2)									
		Official		Southern		Western Trunk Lines		Southwestern		Mountain-Pacific	
		%	Tons	%	Tons	%	Tons	%	Tons	%	Tons
1973	106.1	31.9	33.8	14.6	15.5	23.6	25.0	14.6	15.5	15.4	16.3
1975	107.4	30.7	33.0	14.8	15.9	23.6	25.3	14.8	15.9	16.0	17.2
1980	121.9	27.6	33.6	17.5	21.6	22.9	28.9	16.0	19.5	16.0	19.5
1985	137.5	24.7	34.0	19.7	27.1	22.2	30.	17.0	23.4	16.4	22.6
CHANGES IN TONS											
1973-1980		-.2			6.1		2.9		4.0		3.2
1980-1985		0.4			5.5		2.6		3.9		3.1
TOTAL CHANGE		0.2			11.6		5.5		7.9		6.3

Data Source: Reference 38, 39

TABLE XXX

LUMBER (STCC 24)

TONNAGE ORIGINATED BY TERRITORIES
(MILLIONS OF TONS)

	Total RR Originated Tons(5)	Market Share by Territories (1,2)									
		Official		Southern		Trunk Lines		Southwestern		Mountain-Pacific	
		%	Tons	%	Tons	%	Tons	%	Tons	%	Tons
1973	107.6	5.4	5.8	43.2	46.5	4.4	4.7	12.3	13.2	34.8	37.4
1975	109.7	4.0	4.4	44.5	48.8	4.0	4.4	12.6	13.8	35.0	38.4
1980	136.8	2.7	3.7	47.7	65.3	4.1	5.6	14.6	19.3	31.6	43.2
1985	167.0	1.0	1.7	50.7	84.7	3.9	6.5	15.0	25.1	29.9	49.9
Change in Tons											
1973-1980			-2.1		18.8		0.9		6.1		5.8
1980-1985			-2.0		19.4		0.9		5.8		6.6
Total Change			-4.1		38.2		1.8		11.9		12.5

Data Source: Reference 38, 39

TABLE XXXI

PULP AND PAPER (STCC 26)
TONNAGE ORIGINATED BY TERRITORY
(MILLIONS OF TONS)

		Market Share by Territory (1,2)									
	Total RR Orginated Tons (5)	Official %	Official Tons	Southern %	Southern Tons	Western Trunk Lines %	Western Trunk Lines Tons	Southwestern %	Southwestern Tons	Mountain-Pacific %	Mountain-Pacific Tons
1973	45.3	26.3	11.9	38.6	17.5	8.9	4.0	12.8	5.8	13.4	6.1
1975	47.7	24.4	11.6	39.0	18.6	8.5	4.1	14.3	6.8	13.7	6.5
1980	58.9	23.2	13.7	40.8	24.0	6.3	3.7	15.6	9.2	13.3	7.8
1985	71.4	21.1	15.1	42.5	30.3	4.7	3.4	17.4	12.4	13.3	9.5
CHANGE IN TONS											
1973-1980			1.8		6.5		-.3		3.4		1.7
1980-1985			1.4		6.3		-.3		3.2		1.7
TOTAL CHANGE			3.2		12.8		-.6		6.6		3.4

Data Source: Reference 38, 39

TABLE XXXII

CHEMICALS (STCC 28)
TONNAGE ORIGINATED BY TERRITORY
(MILLIONS OF TONS)

	Total RR Originated Tons(5)	Market Share by Territory(1,2) Official		Southern		Western Trunk Lines		Southwestern		Mountain-Pacific	
		%	Tons	%	Tons	%	Tons	%	Tons	%	Tons
1973	99.7	23.4	23.3	28.4	28.3	7.1	7.1	30.4	30.3	10.7	10.7
1975	104.4	21.3	22.2	29.2	30.5	8.2	8.6	28.9	30.2	12.5	13.0
1980	124.6	14.3	17.8	32.3	40.2	8.3	10.3	32.9	41.1	12.3	15.3
1985	144.7	7.7	11.1	35.4	51.2	8.5	12.3	35.5	51.4	13.0	18.8
CHANGE IN TONS											
1973-1980			-5.5		11.9		3.2		10.8		4.6
1980-1985			-6.7		11.0		2.0		10.8		3.5
TOTAL CHANGES			-12.2		22.9		5.2		21.1		8.1

Data Source: Reference 38, 39

TABLE XXXIII

STONE CLAY & GLASS (STCC 32)

TONNAGE ORIGINATED BY TERRITORY

(MILLIONS OF TONS)

	Total RR Originated Tons (5)	Market Share by Territory (1,2)									
		Official		Southern		Western Trunk Lines		Southwestern		Mountain-Pacific	
		%	Tons	%	Tons	%	Tons	%	Tons	%	Tons
1973	72.6	30.1	21.9	34.7	25.2	12.1	8.8	10.8	7.8	12.3	8.9
1975	74.1	28.6	21.2	32.2	23.9	12.5	9.3	12.4	9.2	14.4	10.7
1980	81.0	25.7	20.8	37.4	30.3	11.2	9.1	11.1	9.0	14.7	11.9
1985	89.8	22.3	20.0	40.3	36.2	10.6	9.5	10.6	9.5	15.9	14.3
CHANGE IN TONS											
1973-1980			-1.1		5.1		.3		1.2		3.0
1980-1985			- .8		5.9		.4		.5		2.4
TOTAL CHANGE			- 1.9		11.0		.7		1.7		5.4

Data Source: Reference 38, 39

TABLE XXXIV

PRIMARY METALS (STCC 33)
TONNAGE ORIGINATED BY TERRITORY
(MILLIONS OF TONS)

	Total RR Originated Tons(5)	Market Share by Territory (1,2)									
		Official		Southern		Western Trunk Lines		Southwestern		Mountain-Pacific	
		%	Tons	%	Tons	%	Tons	%	Tons	%	Tons
1973	71.4	71.9	51.3	9.2	6.6	4.6	3.3	4.9	3.5	9.4	6.7
1975	72.5	69.7	50.5	9.6	7.0	4.2	3.0	5.5	4.0	10.9	7.9
1980	84.6	70.3	59.5	10.3	8.7	3.4	2.9	5.3	4.5	10.7	9.1
1985	96.6	70.1	67.9	10.7	10.3	2.7	2.6	5.2	5.0	11.1	10.7
CHANGE IN TONS											
1973-1980			8.2		2.1		- .4		1.0		2.4
1980-1985			8.4		1.6		- .3		.5		1.6
TOTAL CHANGE			16.6		3.7		- .7		1.5		4.0

Data Source: Reference 38, 39

TABLE XXXV

FORECASTS OF RAILROAD TRAFFIC GROWTH FROM 1975 TO 1985 BY TERRITORY

	Offical Million Tons	%	Southern Million Tons	%	Western Trunk Lines Million Tons	%	Southern Million Tons	%	Mountain-Pacific Million Tons	%
Forecast I (no coal)	1.3	2.1%	126.8	36.7%	67.2	33.4%	59.7	40.1%	38.5	20.2%
Forecast II (trends)	-28.0	.6%	274.6	79.6%	79.6	39.5%	64.6	43.3%	94.8	49.7%
Forecast III (adjusted for energy crisis)	39.2	8.5%	199.9	58.1%	81.0	40.3%	62.7	43.2%	124.0	65.2%

from 6% a year to almost 8%. The Southern Territory should enjoy substantial coal growth.

The Western Trunk Lines benefit little from increased coal traffic. Almost all traffic growth is due to farm products and iron ore. While farm products are important to all carriers in the territory, iron ore is important only on two, the BN and the DM&IR, in northern Minnesota. While the region shows about a 4% annual growth, subtracting ore growth leaves an annual growth rate of only 2%.

The Southwestern Territory will enjoy a higher growth rate than the national average with large increases in chemical and pump and paper traffic. The region should achieve a 4% annual growth rate, even though coal traffic will not add significant tonnage.

The Mountain-Pacific Territory shows slow growth, about 2%, except for coal traffic. However, coal traffic should grow considerably, although this will benefit only a few roads in the territory. Depending on which coal projection is used, total territorial growth should be between 5 and 6.5%.

APPENDIX III

PREDICTION OF FREIGHT TRAIN ENERGY CONSUMPTION

BACKGROUND

Although general information on the fuel consumption characteristics of railroad freight service is available, more specific route-by-route predictions of fuel and energy consumption for all the candidate segments for electrification were desired for this railroad electrification study. The prediction of fuel consumption was hampered by a scarcity of data. There has been little need to develop this type of information in detail previously, and any existing pertinent information generally had a restricted availability. Consequently, procedures for generating the fuel consumption estimates were developed, as reported in Reference 18.

General Considerations Pertaining to Fuel Consumption

The flow chart of Figure 22 provides a starting point for a discussion of the conversion of diesel fuel into the movement of freight in a railroad system. The conversion from fuel energy to productive work is shown in eight numbered sequential steps; each step also indicates a diversion of energy. Some of the uncertainties regarding fuel consumption will be discussed by presenting available information in terms of specific pairs of these steps.

Steps (1-2) The amount of fuel consumed in transporting and distributing the fuel to the railroad supply points is a minor factor; it has been estimated in order to provide a self-consistent comparison with losses in an electrified system; an estimate of 2% was adopted.

Step (2) The characteristics of diesel fuel are variable, both in terms of heating value and density. (The latter is significant because both the volume and the weight of fuel are sometimes used as

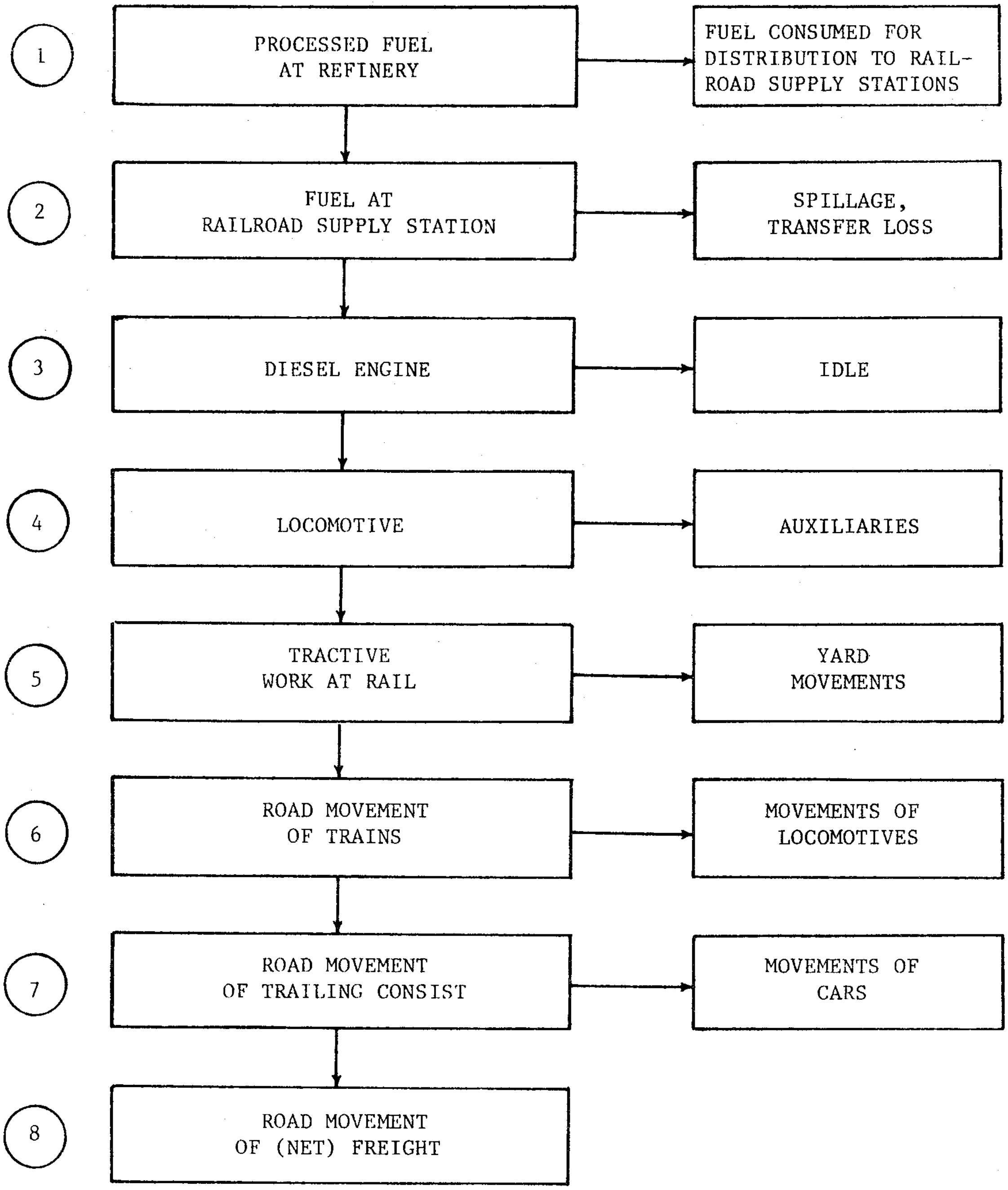


FIGURE 22
THE CONVERSION OF FUEL AT POINT OF ORIGIN INTO FREIGHT MOVEMENT IN A RAILROAD SYSTEM

a reference to define fuel consumption.) The range of heating values has been quoted as 130,000 - 140,000 BTU/gallon;[40] densities have been given as 7.1[41] and 7.3 - 8.0[42] lbs/gallon.

Steps (2-3) Brake specific fuel consumption (BSFC) is the most frequently used method of relating engine shaft output to fuel input. This is a variable depending on engine operating condition. Average values for locomotives have been quoted as 0.34[41] and 0.35 - 0.43[42] lbs/BHP-hr. Since the engines in locomotives operate at 8 distinct notch settings, each of which corresponds to a specific engine speed and nominal (constant) HP, it is possible to derive the average BSFC for a locomotive by combining duty cycle information, such as provided in Reference 43 and in Table 2.3 of Reference 44, with the nominal HP (Table 2.1 ibid) and fuel consumption rate data.[45]

Steps 3-5 Losses are inevitable in the electrical transmission and control system that transmits the power from the engine shaft to the wheels; operating auxiliary equipment such as fans, air brake pumps, etc., are further sources of loss. For example, the manufacturer's maintenance manual for the SD-45 road locomotive quotes 0.82 for transmission efficiency, while allotting 300 HP for auxiliaries in addition to the rated 3600 traction HP.[46] This indicates an efficiency accounting for transmission and auxiliary losses in the range of 0.77 - 0.82. Similar values can be easily confirmed from the published tractive effort characteristics of other locomotives, the transmission efficiency generally decreasing from 82 - 87% at full speed to lower values (65 - 80%) near the low speed, high tractive effort operating conditions,[47] with auxiliary losses not included. Reference 41 quotes an average transmission efficiency of 0.8

Steps (2-5) Combining engine and transmission system losses, one arrives at the effectiveness of converting fuel into useful tractive work at the wheels. The most frequently quoted value is E. C. Poole's 0.0324 gallons/10^6 ft-lbs, a value which was intended to represent typical operating cycles for road locomotives and is based on a large number of measurements. The result obtained by combining the average BSFC and transmission efficiency quoted in Reference 41 differs from this frequently quoted value by less than 1%. An informal estimate of one railroad for an overall thermal efficiency for their main line road service was 28%.[49] This is exactly equivalent to the foregoing (Reference 48) average if diesel fuel of 141700 BTU/gallon is assumed. Another railroad[50] combined the previously quoted characteristics of the SD-45 locomotive ($0.82 \times \frac{3600}{3900}$) with engine efficiencies of 0.35[51] and 0.37[52] for overall efficiencies of 26.5 and 28.1% respectively. The comparison of these various sources indicates that there is good agreement on the effectiveness of diesel electric locomotives in converting fuel to tractive work for road (i.e., long-haul freight) service.

Steps (5-6) How the tractive effort at the rail is converted into train movement is governed by many factors. These include the makeup of the train, including the trailing load and the locomotives, the tractive characteristics of the locomotives, the physical layout of the track with its grades and curves, and any restrictions and requirements of the travel, such as speed limits and stops. Train performance computer (TPC) programs are the most frequently used means of predicting the train's movement from its tractive characteristics and from the other pertinent data. Train movement itself (distance vs. time) is generally the desired output of these TPC predictions; fuel consumption is calculated as a secondary output. Efforts are underway currently to relate the fuel consumption predictions of TPC programs to actual measurements; preliminary results have been reported.[53] Depending on the assumptions made in the TPC model, fuel consumption is frequently under-predicted by these programs. Two railroads recommended 8 and 15% increases over their respective TPC predicted fuel consumption rates.[54,55]

Steps (6-7), (6-8) The effectiveness of trains as freight carriers can be expressed by considering the net freight and trailing load as fractions of the total train weight. This is not of direct concern in the present investigation, which is concerned with predicting the amount of fuel consumed on selected routes on the basis of overall traffic density (i.e., gross ton-miles per mile). However, the selection of the basis (gross, trailing or net weight) of expressing specific fuel consumption is often not identified, leading to possible misinterpretations of existing data.

Other Diversions Considering now the remaining diversions of fuel energy from its intended goal of moving freight, some information has been published on most of the categories shown in Figure 22. Reference 40 quotes 2-3% for spillage and transfer losses, 3-5% for idling and 10% for the auxiliaries. Using the duty cycles for road locomotives quoted earlier[43,44] and the fuel consumption rates at idle,[45] the 3-5% for idling can easily be confirmed. The use of fuel in yard switching duty is a separate topic, of interest only because it may or may not be included in operating statistics that could be used for the interpretation or prediction of fuel consumption.

Comparison of Diesel Electric and Electric Fuel Consumption Rates

For an electrified rail network, which is the intended replacement of the present system, the sequence of converting fuel into freight movement is modified, as shown in Figure 23. In an analogy to Figure 22, the sequence of steps have again been labeled by numbers designated with the "e" post-script. Only the sequence up to step (5) is shown; starting with step (6) the sequence is the same as in Figure 22.

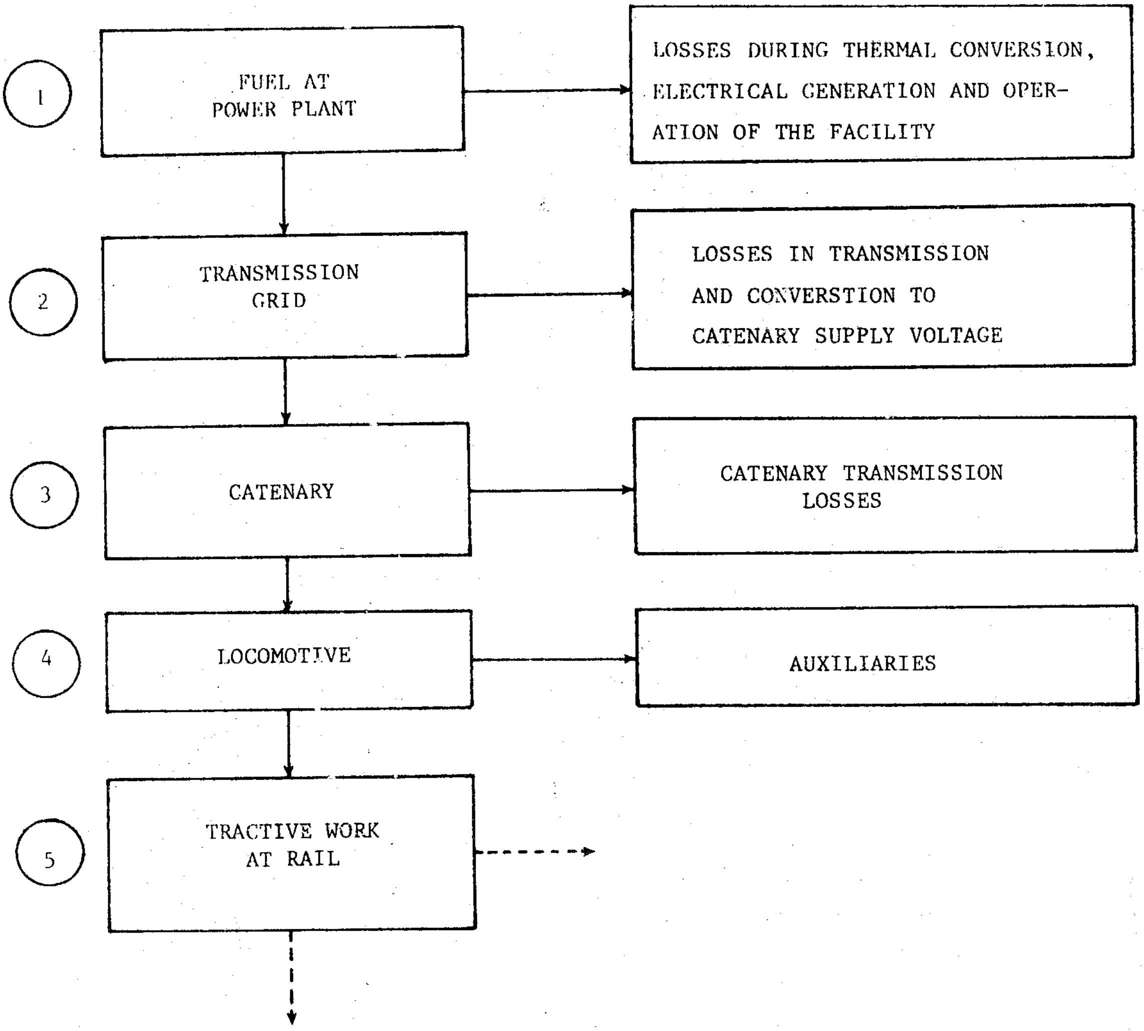


FIGURE 23
CONVERSION OF FUEL INTO FREIGHT MOVEMENT IN AN ELECTRIFIED RAILROAD SYSTEM

Available information pertaining to the conversion process will again be discussed by referring to specific pairs of steps.

Steps (1e - 2e) Reference 50 quotes boiler, turbine, generator and step-up transformers efficiencies of 0.88, 0.47, 0.99 and 0.995 respectively for an overall efficiency indicator of 0.41 for modern steam turbine installations. The same reference compares this with an average overall power plant efficiency under existing conditions of 0.33; reference 56 quotes 35% as the comparable average value.

Steps (2e - 3e) The same two sources (References 50 and 56) quote .96 and .995 efficiencies for the transmission line and the step-down transformer respectively. The inherent impedance of the catenary-rail configuration and the lagging power factor of locomotives has led to a belief that the effective power available at the locomotive will be less than indicated by these efficiencies. A transmission line of efficiency of .95 and an overall step-down/catenary efficiency of .95 are considered more appropriate.

Steps (4e - 5e) Reference 50 quotes 0.86 as the conversion efficiency of an electric locomotive; 85% is an informal quote from a manufacturer. Reference 56 details the losses inside the locomotive on the basis of transformer, thyristors, traction motors, auxiliaries and gearboxes (99, 99, 92, 98 and 96% respectively) for an overall 85% efficiency.

The foregoing paragraphs indicate that, in spite of minor differences in detail, the sources quoted above are in good agreement as to the overall effectiveness of an electrified rail system. The average power plant quoted in Reference 52 results in a 26% overall efficiency, the "modern steam turbine" plant is 32%. The corresponding value from Reference 56 is 27%; an informal quote from locomotive manufacturer suggests that the overall fuel to tractive work conversion capabilities of the electric and conventional railroad systems are the same. Considering the range of values just presented, this seems to be a valid assumption.

A Framework for Fuel Consumption Predictions

To accomplish the objective of this investigation the fuel consumed for train movements, measured in gross ton-miles, needs to be determined. This is the relation covering steps (2-6) in the sequence of steps shown in Figures 22 and 23. The approach taken concentrates on the relation between work performed at the locomotive wheels and the resulting train movement (Step (5-6), because this is where the principal differences between the various routes under consideration can be identified. The remaining uncertainties, both as to what happens inside the locomotives, and as to the various losses and diversions of motive power from actually moving the trains, as shown in Figures 22 and 23, will be treated on the basis of available data, as discussed above.

The dynamics of train movement provide a good start for analyzing the conversion of tractive effort into train movement. Resistance requiring tractive effort can be ascribed to four causes: (1) accelerating the train, (2) ascending grade, (3) friction and drag on tangent level track and (4) curves, where resistance is often expressed in "equivalent grade." The sum of these four causes results in a total tractive effort requirement at the wheels. One approach to determine the total work done at the wheels is then to calculate the point to point variation of each of these four quantities and accumulate their sum as the train moves over the route. This is what the TPC programs do as they calculate (in the computer) the movement of the train under prescribed limits. Fuel consumption is then derived by means of a specified locomotive operating schedule that relates engine notch setting to tractive effort and train speed and integrates the resulting fuel consumption rate.

An alternative approach to analyzing tractive work at the wheels takes advantage of the fact that the first two causes of train resistance can be ascribed to an increase in the convertible mechanical energy of the train. This energy is stored in the moving train, and is later dissipated. To the extent that this reconversion of stored mechanical energy is complete, the first two causes of resistance to tractive effort could be ignored and tractive work be described entirely by (dissipative) train resistance and curves. Adopting such an approach for a route would err on the following three counts:

- Some of the train's energy is dissipated by the brakes when decelerating for speed changes or stops.
- Braking dissipation will also occur on a downgrade.
- There might be a net change in elevation between end-points, combined with a significant imbalance of traffic.

The amount of energy dissipated by braking would have to be added to compensate for the first two errors. No published information was found to indicate the amount of energy dissipated by braking. Some unpublished data indicate that it could be as high as 25% for braking due to speed changes and 15% for braking due to downgrades, but they will be generally no more than half to a quarter of these amounts.

Finally, even if the direct effect of grades is not considered, their presence must be accounted for in the prediction of fuel consumption. The reason for this is that freight train operation is generally HP-limited, so that the train's speed is most often determined by grade rather than by the speed limit. Speed, in turn, is a vital ingredient in determining train resistance, which is affected both by the first and second power of speed.

METHODOLOGY

The methodology developed to predict fuel consumption follows the approach of calculating the dissipative energy due to train and curve resistance over the length of the route. The speed of the train over the various portions of the route is established by the speed limit or by the HP-limit overcoming grade and train resistance. By aggregating the route into typical sections and establishing a maximum speed directly, the amount of calculation to determine fuel consumption is greatly reduced compared to using a TPC in which the speed history is calculated sequentially over the entire route.

Description of Predictive Method

Figure 24 shows a flowchart for the predictive method that was adopted. The prediction is accomplished in two sequential steps by two computer programs, MATRIX, and FUEL. In addition to the two track chart tables, the input to MATRIX includes a table that defines selected subdivisions for both grade and speed limit. MATRIX then processes the two track charts and categorizes each consecutive segment of track on the basis of the combination of grade and speed limit into the appropriate subdivision. (The grade referred to is the sum of the actual grade and of the grade representing track curvature.) Track lengths are accumulated in each subdivision; the values of grade and speed limit are averaged within each subdivision as the program proceeds. At the end, the fraction of route length in each subdivision is identified, together with the corresponding average values of grade and speed limit. The number of subdivisions

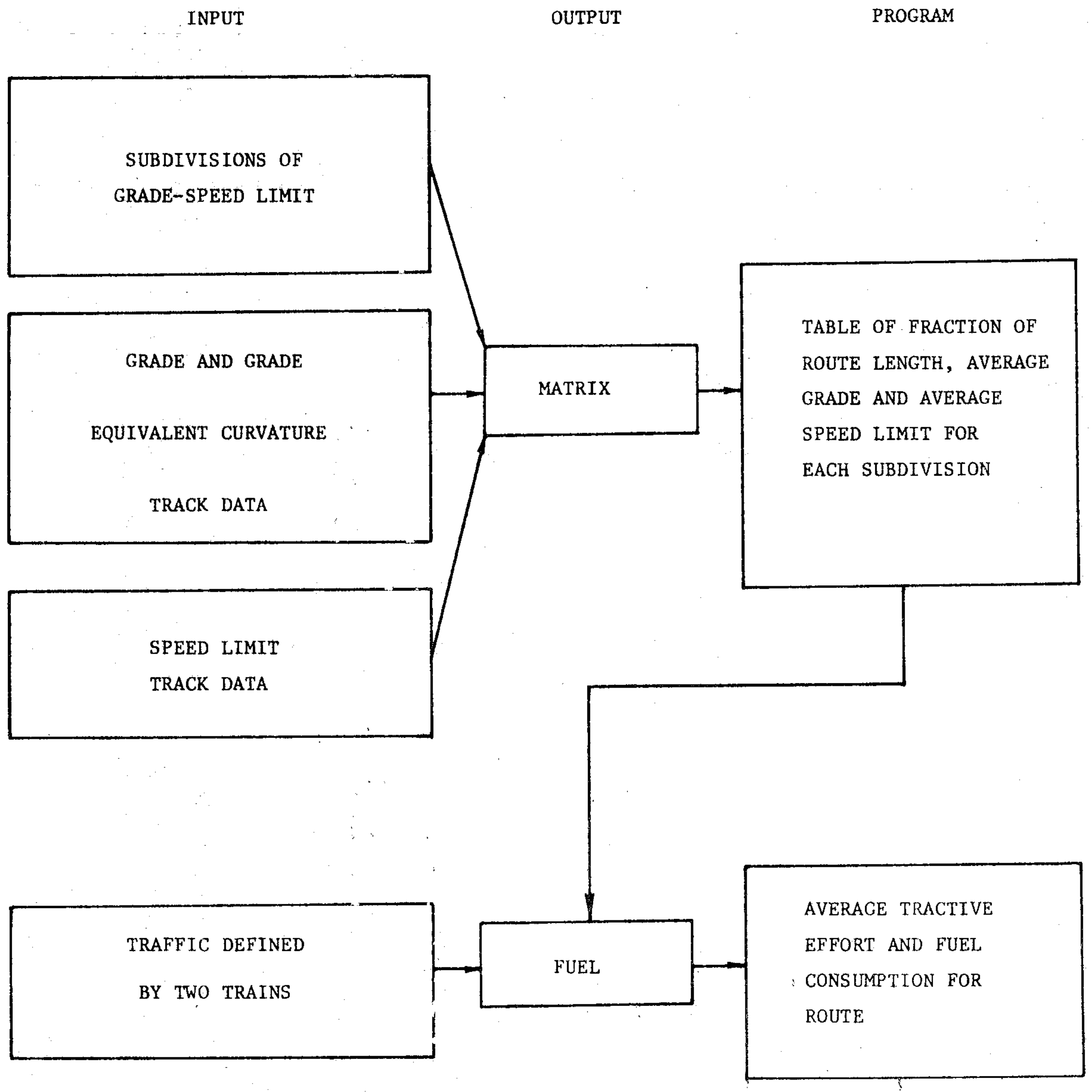


FIGURE 24
FLOW CHART FOR PREDICTIVE METHOD

utilized in MATRIX was selected on the basis of a lack of sensitivity of the predictions to finer subdivisions of both grade and speed limits.

In the second step the table generated by MATRIX is combined with a simplified representation of traffic. The simplest approach would represent the available information on traffic by a train with characteristics that match the appropriate averages for the route under consideration. Because of the large differences in the performance and fuel consumption characteristics of manifest and drag freight trains, traffic can be represented by a combination of two kinds of freight trains instead. The description of the trains, and their proportion, are so chosen as to best represent the available information on traffic.

The FUEL program calculates the speed and then tractive work (if any) for each of the two trains and for each of the conditions identified by MATRIX, and then properly averages the result to define an overall number for tractive work per unit of gross weight for the entire route. This number is converted into fuel consumption by using a constant multiplier, based on Poole's[48] recommended average of 0.0324 gallons/10^6 ft-lb, as discussed above.

The calculation of tractive work is based on the formulation of an expression generally accepted to be quadratic in train speed:

$$P(V) = A + BW + CVW + DV + EV^2$$

where

P, resistance, lbs

V, speed, mph

W, weight, tons

The values of the coefficients A through E were taken from Hopkins'[41] formulation of using the traditional Davis equation at low speeds and using another set of coefficients for high speeds. The latter were devised by Hopkins by curve-fitting Tuthill's corrections to the Davis equation. These coefficients, applicable to freight trains, are reproduced below, directly from Reference 41, Table 2-1.

Vehicle	A	B	C	D	E
Freight car, caboose (low speed)	116	1.3	.045	0	.045
Freight car, caboose (high speed)	195	3.48	0.	-14.9	.362
First Locomotive	116	1.3	.03	0	.264
Additional Locomotives	116	1.3	.03	0	.045

The transition from low speed to high speed occurs where the two curves intersect. At unusually high axle loadings the two curves do not intersect; special provisions were made in the computer program for this possibility.

Comparing FUEL to a train performance program the following simplifications and omissions have been made.

- The energy required for repeatedly accelerating the train after stops and changes in speed limits is not considered at all. Some of this energy is recovered by decelerating trains, some of it is dissipated by braking. The latter portion is neglected, thus FUEL will underpredict TPC programs to the extent of this omission.

- Trains operating at their HP limit and changing from a lower to a higher (more positive) grade on the track will not change speed instantly to their new equilibrium speed but will instead use up some of their kinetic energy to move through the initial sections faster. To the extent that this happens FUEL will overpredict fuel consumption compared to TPC programs. On the other hand, in the opposite situation (changing from a higher to a lower up-grade), the opposite is true. The effects will tend to cancel each other.
- The losses that can be ascribed to down-hill braking are accounted for in FUEL by explicitly including the effect of grade in the fuel consumption prediction.
- FUEL represents the train as a point mass, thus the fact that a long train will tend to mitigate the effect of rapidly changing sections of grade, is not represented. This shortcoming can be equally true for some of the less sophisticated TPC programs as well. The result can be fairly significant over-prediction of fuel consumption, as high as an estimated 10-20% for a mile long train operating in a terrain where grade changes occur 1 or 2 times per mile. Also, short sections of sharp up-grades can create problems in the point mass representation of long drag freight trains because of an apparent violation of the adhesion limits.

The approach that has been taken to cope with these shortcomings was a calibration of the simplified model by means of the available fuel consumption data (both measured and predicted) for a number of cases where both the fuel consumption data and the track chart data were available. Also, the most appropriate representation of traffic was developed by a similar comparison with results where more detailed information on the traffic was available.

Calibration of Fuel Consumption Prediction

It had been anticipated from the start that the simplified model will underpredict fuel consumption because it did not include the energy required to accelerate the trains, a significant portion of which is dissipated by braking. In addition, the model had no provision to account for the detailed tractive effort characteristics of specific locomotives; locomotives were represented as constant tractive HP devices instead. The calibration procedure was then based on the assumption that in order to compensate for the unaccounted energy consumption, locomotives may be represented by tractive HP that exceeds their actual capability. The comparisons described below indicated that the simple expedient of assuming nominal (rated) locomotive HP available at the wheels provided adequate correlation with the more accurate measurements and predictions. Fuel consumption measurements from Reference 53 were compared to the predictions of the MATRIX-FUEL models. A similar comparison between the fuel consumption predictions of the Southern Railway train performance model and those of the MATRIX-FUEL models was also made. Results of extensive parametric studies of train performance by the Union Pacific Railroad on three segments of a principal east-west route (Council Bluffs to North Platte to Rawlins to Ogden) were compared in a similar manner. Based on experience with their respective TPC models, actual fuel consumption is expected to be higher by 15% (Southern) and by 8% (UP) respectively. In comparing the prediction of fuel consumption by the approximate method adopted in this study, the simplifying assumptions have clearly caused some distortion. Additional distortion is likely, compared to TPC predictions, due to the difference in train resistance equations adopted by TPC models and the simplified method. In spite of these shortcomings and uncertainties it was felt that a sufficiently wide range of combinations of terrain speed limit and train configuration were explored to give reasonably credible predictions by the chosen method, without changes or the introduction of additional refinements. The effect of the difference between actual speed limits under the influence of train interference, track repairs and equipment limitations, and the nominal speed limits recorded on the track charts could be as serious as any flaw in the method itself.

Effects of the Representation of Traffic

The only available significant data on train dispatchings on a major route (Ref. 54) were used as a basis of testing the effects of various simplifying assumptions. The traffic shown was represented by various groups of trains, with five distinct sets of assumptions adopted, representing increasing levels of simplification and decreasing levels of dependence on information indicating the nature of the traffic. (Only the most and least detailed representation are discussed below; Reference 18 gives additional details.)

In the most detailed breakdown, trains were grouped into the following four types:

1) Coal trains (both empty and loaded condition) over two portions of the route.
2) General freight trains with average loaded car gross weights between 60 and 90 tons.
3) General freight trains with light average loads (less than 60 gross ton per loaded car, less than 2.2 HP/gross ton for train)
4) Manifest freights (HP/gross ton in excess of 2.6).

The coal trains were treated separately for each of the routes and the corresponding empty trains were dispatched on the respective reverse routes. Average train configurations were developed for the other three categories; fuel consumption for each category was determined by having each of these three average trains traverse the entire route in both directions. The resulting four fuel consumptions were then averaged on a gross ton mile basis.

For the least detailed representation of traffic, two trains are combined in a proportion to meet the requirement of the proper average HP per gross ton for the entire sample (1.708). The characteristics of the two trains have been defined arbitrarily to provide general prototypes of two distinctly different freight trains, as follows:

	Drag	Manifest
Locomotives/train	6	3
Loaded car weight (gross tons/car)	105	60
HP/gross ton	1.4	3

The number of cars per train is defined on the basis of these requirements as 41 and 112 for the manifest and drag trains respectively. It was assumed that no information is available on the nature of the traffic. The two trains are combined on the basis of equal gross ton miles of traffic for the two kinds of trains.

For the entire sample of the representations of traffic, the difference between the most detailed calculation and the prediction based on minimal information is less than 7%. This latter method was then used as the basis of defining traffic for railroads and routes where no information was available.

FUEL CONSUMPTION PREDICTIONS

Routes Selected for Prediction

Track chart data were available for only a fraction of the routes selected as candidates for electrification. Detailed information on traffic was limited to one route; less than half a dozen routes had any information available on traffic at all. These facts, and the additional uncertainties due to the assumptions and approximations required to develop the predictive method, led to the decision not to attempt any precise prediction of fuel consumption for all the routes under consideration. Rather, a representative sample of routes was chosen to include a wide variety of conditions of terrain, speed capability, operating policy and traffic as a basis of estimating fuel consumption for the remaining routes.

A list of the routes chosen for the sample, a description of the type of traffic on each route, and a quantification of the terrain characteristics in % grade or equivalent are given in Table XXXVI The longer routes have all been split into their principal segments, on the basis of operational considerations (junctions, yards) or differences in geographic characteristics. The first column of numerical information shows the mileage, the second the net average grade in the forward direction, the third the average curvature, described in grade equivalent terms. The average resistance based on the absolute value of the combined grade and curve resistance is probably the best indicator of the roughness of the terrain (4th and 5th columns in the respective directions). Finally, the last two columns show the maximum combined grade and curve resistance as compiled by the MATRIX program in the respective directions. This can be identical to the ruling grade, but is frequently somewhat less because of the averaging process performed by MATRIX. This maximum effective grade is significant because in the absence of other information, it determines the configuration of the drag trains on the basis of the HP/GT requirement discussed earlier.

The characteristics of each of the routes, including any information pertaining to the traffic, will be discussed in the next section. Some general comments can be made on the various types of terrain represented in Table XXXVI. The impact of curvature on train resistance is significantly less than that of grade. Although Cincinnati to Atlanta route of the Southern Railway has the most curved right of way in the chosen sample, average curve resistances are less than 10% of the respective resistance due to the average absolute values of grades. This route, while showing little net rise in elevation between the end points, is also one of the most hilly routes, as indicated by the average absolute value of grade.

The NW coal route passes through terrain with similar curvature and grade characteristics, differing from the previous route only by its strong downhill character from the West Virginia coalfields to the Atlantic Coast. At the opposite extreme of terrain characteristics, compared to the Southern route, is the UP route through Nebraska, with very few curves and hills, but a plateau that rises steadily in the westbound direction. The terrain for the ICG route southbound from Chicago and the Florida-bound SCL route along the Atlantic Coast are similarly flat and straight, but there is an absence of any net change in elevation between end points for these routes.

The steepest steady grades among the chosen routes occurs in a short section where the El Paso to Los Angeles SP route crosses a ridge in Southwest California. (A similar but shorter steep section was eliminated from the UP route in the sample because of the inability to represent effectively the use of helper locomotives over a short segment of route, and the expectation of only minor changes in the resulting average fuel consumption rate.) In addition to the foregoing differences in terrain, the selected sample also represents

TABLE XXXVI

SAMPLE ROUTES, INCLUDING TRAFFIC AND TERRAIN CHARACTERISTICS

Railroad and Route	Route Miles	% GRADE Average Forward	Average Curvature Equivalent	Average Absolute* Forward	Average Absolute* Reverse	Maximum* Forward	Maximum* Reverse
ATSF							
Corwith-Argentine	449.9	.01	.02	.29	.29	1.01	1.03
Argentine-Clovis	636.0	.11	.01	.29	.28	.99	.58
Clovis-Barstow	971.5	-.03	.02	.61	.61	1.24	1.05
Barstow-Los Angeles	146.4	-.01	.03	.49	.49	1.26	1.24
Barstow-Richmond	440.1	-.02	.02	.19	.19	1.03	1.03
Purcell-Houston	513.1	-.04	.02	.40	.40	.92	.96
BN							
Clyde Yd.-North Yd.	434.7	.02	.01	.17	.16	1.22	.80
North Yd.-Gavin	463.3	.03	.00	.13	.13	.66	.60
Gavin-Havre	436.5	.03	.01	.14	.13	.63	.59
Galesburg-Lincoln	372.6	.02	.02	.25	.25	1.03	1.21
Lincoln-Sheridan	698.5	.07	.02	.39	.39	.99	1.10
ICG							
Markham-Edgewood	192.7	.00	.00	.15	.15	.57	.55
Edgewood-Fulton	158.9	-.02	.00	.22	.22	.28	.28
Fulton-Memphis	128.4	-.02	.01	.30	.30	.52	.51
NW							
Norfolk-Bluefield	353.2	.14	.04	.35	.35	1.20	.99
BLE							
Albion-N. Bessemer	124.0	-.04	.00	.41	.41	.59	.80
RFP							
Washington-Richmond	103.5	.05	.00	.33	.33	.80	.54
SCL							
Richmond-Jacksonville	649.5	.00	.00	.15	.15	.57	.54
Southern							
Cincinnati-Danville	115.4	.06	.03	.38	.37	1.17	.82
Danville-Chattanooga	218.2	-.02	.05	.56	.56	.96	1.09
Chattanooga-Atlanta	145.6	.02	.04	.63	.62	1.02	1.02
SP							
El Paso-Indio	685.3	.11	.01	.34	.33	1.00	.96
Indio-Colton	72.0	-.26	.02	1.13	1.11	1.45	1.50
Colton-Los Angeles	59.3	.14	.01	.43	.44	.97	1.08
UP							
Council Bluffs-N. Platte	286.1	.11	.00	.15	.15	.59	.51
N. Platte-Rawlins	396.7	.18	.01	.41	.41	.86	.86
Rawlins-Ogden	309.8	-.15	.02	.44	.46	.82	1.07

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*Includes Equivalent for Curvature.

various combinations of primarily high speed manifest trains vs. low speed drag freights, a preponderance of one way traffic vs. balanced traffic in the two directions, and speed limits geared to high speed vs. low speed service as well.

Results of Fuel Consumption Prediction

Table XXXVII shows the results of the fuel consumption predictions for the routes and route segments under consideration. For those routes where there was a complete absence of any information on the nature of traffic, the gross tonnage was split evenly between manifest and drag trains. Only the HP per gross ton for drag trains varied from route to route in this case, because of its definition as 1.2 times the respective maximum grade on each route. Traffic for all routes was assumed to be completely symmetrical, unless specific information was available to the contrary. Among the routes described in Table XXXVI this "standard" method of describing traffic was applied to the ICG, RFP, SCL and UP routes (eight altogether).

The traffic on each of the remaining routes will now be described; the information used came either from the railroads themselves or from general information pertaining to the nature of traffic on the route. Traffic on the ATSF route from Chicago (Corwith) to Los Angeles, with a branch to Richmond, California (5 segments altogether) was defined as all manifest traffic. Loaded cars, which constitute 55% of the traffic, were assembled into separate trains from the empties. Unlike loaded-car trains, empty-car trains are subject to a 55 mph maximum speed limit everywhere. Both types of trains are described by 3600 trailing tons and a locomotive consist resulting in 3 HP/trailing ton. This information resulted in selecting three SD-45 locomotives for each type of train with 60 loaded and 120 empty cars in the respective trailing consists. In the absence of information on the directions of the loaded and empty traffic they were assumed evenly divided in the two directions. Numerical checks on two of the five route segments indicated that the maximum error due to this assumption is less than 5%.

Traffic on the remaining ATSF route (Purcell-Houston) was characterized as 60% (by weight) grain traffic with 8000 ton trailing consists. HP per gross ton for the Houston-bound grain trains was selected as 1.2 on the basis of a maximum grade slightly less than 1% in that direction. Three 3600 HP locomotives were capable of providing this; the same locomotives were the basis of defining the 3 HP/GT, 60 GT/car manifest traffic, assumed uniform in both directions.

Traffic on three segments of the BN's Chicago (Clyde Yard) - Seattle route was defined as all manifest traffic, on the basis of the sample of trains given in Reference 53. The other BN route, defined by two segments, was characterized as 100% east-bound coal traffic. The trains are pulled by five U30 locomotives, with cars weighing 23 tons empty and 130 tons loaded. The performance of a "standard" manifest train, on this route, directionally balanced, is also provided in Table XXXVII for reference. Two other routes in the sample were characterized by similar directional traffic of unit trains of heavy material as the preceding BN route; they are the NW east-bound coal traffic from West Virginia, and the BLE ore traffic from the Lake Erie port area to the Allegheny River Basin near Pittsburgh. This type of traffic, though extremely efficient in the principal direction, consumes additional fuel by having to return unused equipment.

For the three route segments of the Southern Railway's Cincinnati to Atlanta route the sample of trains provided in Reference 54 served as the basis of prediction. Traffic on the El Paso to Los Angeles route of the SP was described as 2/3 manifest trains by weight with 3.5 HP/Gross Ton characteristics; drag trains were characterized by 1.0 HP/GT. The Indio to Colton section of this route presented a special problem because the train here crosses a mountain with grades of 1.5%. Three extra locomotives were added to the drag trains in this section to cope with these high grades. Using the same assumptions describing cars and locomotives as for the "standard" trains, the resulting train configurations were 45 60-ton cars and 4 locomotives for the manifest trains, 150 105-ton cars and 6 locomotives for the drag trains, except in the mountainous second section of the route, where the number of locomotives for the drag trains was increased from 6 to 9.

Concluding Discussion

This completes the presentation of the method for, and the results of predicting diesel fuel consumption rates for a varied sample of 27 routes. The accuracy of the method is adequate for the intended purpose of providing reasonable estimates for the selected candidate routes, and is consistent with the lack of availability of data on the route by route variations in the detailed makeup of freight traffic. Further details of how this informatin was applied all candidate segments and how electrical energy for electrified traffic was calculated are given in Appendix IV.

APPENDIX IV

ESTIMATION OF ENERGY AND FUEL CONSUMPTION

BACKGROUND

Assessing the energy impact of railroad electrification requires a prediction of the future diesel fuel requirements of continuing the present mode of operations and a prediction of the electricity requirements, and the fuels required to generate this electricity, if a conversion to electrified operations is made.

The fuel consumed by locomotive motive power in moving the train over the route is a function of the speed of the train and the terrain of the route. These factors have been evaluated and a methodology for estimating fuel consumption developed, as summarized in Appendix III. The method was used to calculate the fuel consumption for a number of routes for which route (track chart and speed limit) data and traffic characteristics (size of trains, amount of motive power, operating speed limit) were available. This sample of calculated fuel consumptions was reduced to a specific fuel consumption (SFC) in gallons of diesel fuel per 1000 gross ton-miles, and then used to estimate SFC on the remaining candidate segments, based on similarity of traffic and terrain. The detailed estimates, on a route-by-route basis, have been presented for project use in Reference 18.

In tracing the fuel source associated with railroad electrification, it must be remembered that the electric utilities use a variety of fuels, as well as other energy sources, for the generation of electricity. The largest portion of electricity comes from generating stations that burn fossil fuels (coal, oil, natural gas), while in suitable areas hydro-electric generating facilities tap a renewable energy source. Nuclear power has been a rapidly increasing factor in electricity generation, and new technologies might expand the list of significant sources. The mix of the current energy sources for electricity generation varies throughout the nation and will continue on a changing course as the utilities build new generating stations to meet the growth of electrical energy demand. These factors have been considered in estimating fuel data, as reported in Reference 19.

METHODOLOGY

Overall Efficiencies

The motive work for a particular route and traffic condition should be calculated using the best available data concerning performance and fuel consumption. Thus it has to be based on the presently used diesel-electric motive power. The different characteristics of an all-electric locomotive (lighter weight for a given horse power rating, overload capability) would tend to alter the operating conditions from that of a diesel-electric pulling the same train over the same route. The extent of this variation is subject to discussion, however. Lighter weight locomotives would lower the gross tonnage, reducing the fuel consumption, while more power availability would increase the speed and fuel consumption. For this study, it was assumed that the motive work requirements would remain constant with a switch from diesel to electric locomotives.

Figure 25 summarizes the factors used to convert the motive power back to diesel fuel and to electrical energy requirements. The diesel fuel consumption was calculated on the basis of 0.0324 gallon of fuel consumed by the locomotive per 10^6 ft-lb of motive work. At a nominal heat content of 138,000 BTU/gal for diesel fuel, this is equivalent to a 36% efficiency for the diesel engine (including duty cycle) and 80% of efficiency for the drive train. To trace the fuel to its source, a 2% loss for transportation and spillage was assumed between the refinery and the locomotive. For the electric locomotive, 85% efficiency was assumed. This is equivalent to 0.4431 KWH of electrical

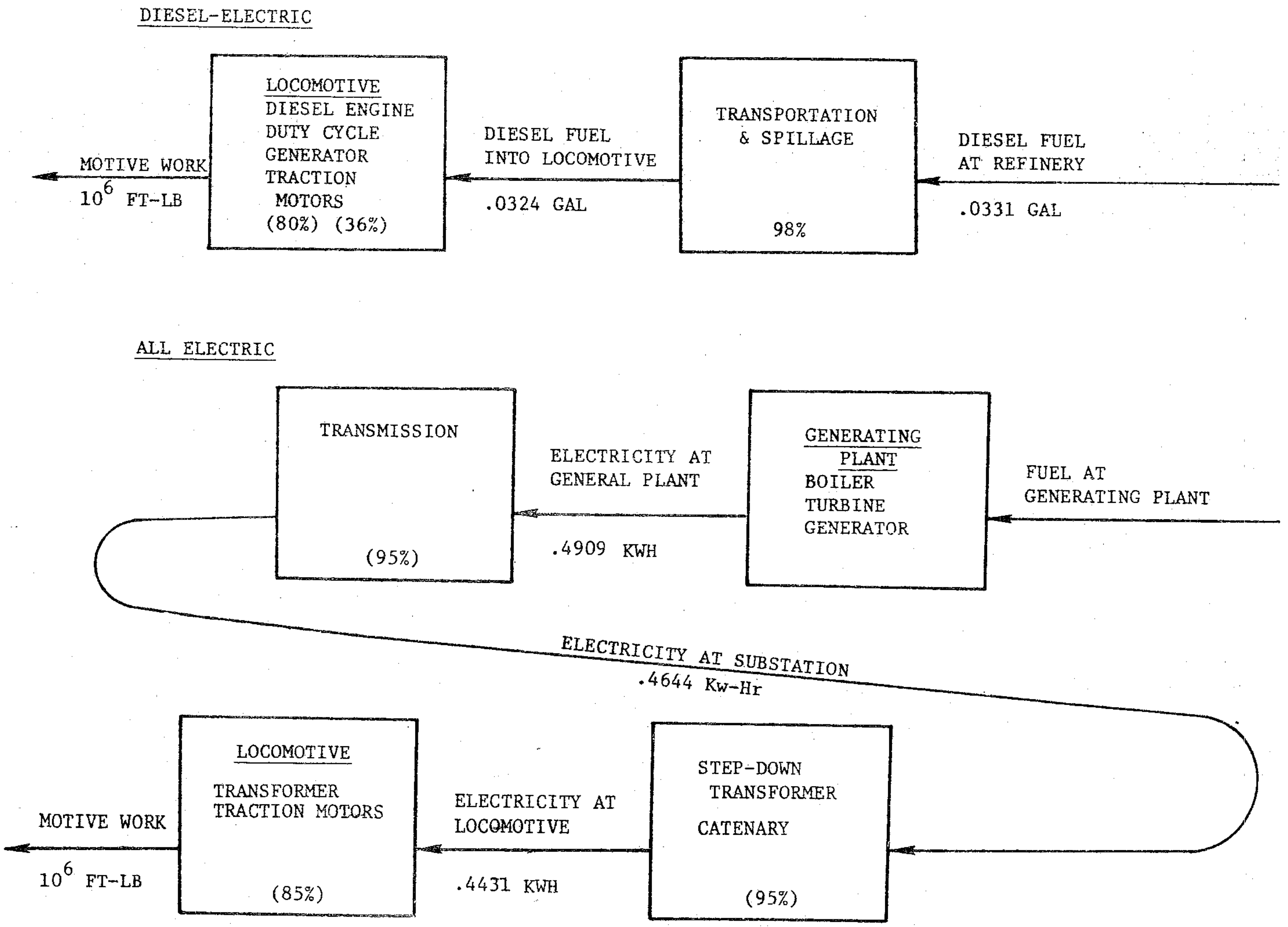

FIGURE 25
ENERGY CONVERSION FACTORS

energy at the locomotive per 10^6 ft-lb of motive work. Again tracing the energy back to its source, a 95% efficiency for the wayside distribution system and 95% efficiency for the transmission system were assumed. The motive power requirement at the generating station is then .4909 KWH per 10^6 ft-lb.

Energy Requirements

Tables XXXVIII and XXXIX present the data used to calculate the diesel fuel requirements for the candidate segments for electrification. The numbers marked with an asterisk in the specific fuel consumption column are calculated values (Appendix III), increased by 2% to establish the requirements for refined fuel (rather than fuel at the locomotive fueling station). The growth factors, based on Reference 13 and summarized previously in Table V, provide the fuel estimates for 1980, 1985 and 1990. The electrical energy requirements, representing power at the generating station, were calculated directly from the diesel fuel requirements on the basis of 14.85 KWH/gal.

Fuels for the Generation of Electricity

The data source for the fuels currently used in electricity generation are Federal Power Commission Statistics.[21] For the future projections of electricity, the data source is the National Energy Outlook[20] and supporting data[22] developed by the Federal Energy Administration (FEA). The FEA projections come from the Project Independence Evaluation System (PIES) that forecasts the state of the energy system for a 15 year planning horizon. Various economic forecasts and supply and demand options are used to develop scenarios of future activity that produce a range of estimates of energy usage. The evaluation system relies on balancing supply models and demand models for the future U.S. energy situation. Railroad electrification presents an alteration of two demand curves (lowering oil, raising electricity). Such an

TABLE XXXVII

FUEL CONSUMPTION PREDICTIONS FOR SAMPLE ROUTES

		DRAG			MANIFEST			Manifest as % of Total Traffic			
Railroad and Route	Maximum Speed Limit	Principal Direction (if any)	HP/GT (Average)	Gal/ 10^3 GTM (Average)	Principal Direction (if any)	HP/GT (Average)	Gal/ 10^3 GTM (Average)	By Train	By GTM	Average HP/GT	Average Gal/ 10^3 GTM
ATSF											
Corwith-Argentine	70	-	-	-	-	2.60	2.41	100.0	100.0	2.60	2.41
Argentine-Clovis	70	-	-	-	-	2.60	2.47	100.0	100.0	2.60	2.47
Clovis-Barstow	70	-	-	-	-	2.60	2.44	100.0	100.0	2.60	2.44
Barstow-Los Angeles	70	-	-	-	-	2.60	2.30	100.0	100.0	2.60	2.30
Barstow-Richmond	70	-	-	-	-	2.60	2.58	100.0	100.0	2.60	2.58
Purcell-Houston	60	Forward	1.86	1.88	-	3.00	1.93	44.6	40.0	2.31	1.90
BN											
Clyde Yd.-North Yd.	60	-	-	-	-	4.00	1.69	100.0	100.0	4.09	1.69
North Yd.-Gavin	70	-	-	-	-	4.00	2.12	100.0	100.0	4.09	2.12
Gavin-Havre	60	-	-	-	-	4.00	1.79	100.0	100.0	4.09	1.79
Galesburg-Lincoln	60	Reverse	2.02	1.59	-	3.00	1.87	0.0	0.0	2.02	1.59
Lincoln-Sheridan	60	Reverse	2.02	1.72	-	3.00	2.11	0.0	0.0	2.02	1.72
ICG											
Markham-Edgewood	60	-	1.00	1.19	-	3.00	2.01	85.7	50.0	2.00	1.60
Edgewood-Fulton	45	-	1.00	.94	-	3.00	1.24	85.7	50.0	2.00	1.09
Fulton-Memphis	45	-	1.00	1.04	-	3.00	1.28	85.7	50.0	2.00	1.16
NW											
Norfolk-Bluefield	45	Reverse	1.75	1.25	-	-	-	0.0	0.0	1.75	1.25
BLE											
Albion-N. Bessemer	45	Forward	1.75	1.24	-	-	-	0.0	0.0	1.75	1.24
RFP											
Washington-Richmond	80	-	1.00	1.38	-	3.00	2.61	85.7	50.0	2.00	1.99
SCL											
Richmond-Jacksonville	80	-	1.00	1.29	-	3.00	2.73	85.7	50.0	2.00	2.01
Southern											
Cincinnati-Danville	60	-	1.40	1.51	-	3.00	2.05	42.0	14.5	1.63	1.62
Danville-Chattanooga	60	-	1.40	1.68	-	3.00	2.03	42.0	14.5	1.63	1.75
Chattanooga-Atlanta	60	-	1.40	1.67	-	3.00	1.98	42.0	14.5	1.63	1.75
SP											
El Paso-Indio	65	-	1.07	1.38	-	3.50	2.27	90.1	66.7	2.69	1.98
Indio-Colton	65	-	1.60	2.29	-	3.50	2.48	90.1	66.7	2.87	2.42
Colton-Los Angeles	65	-	1.07	1.33	-	3.50	2.01	90.1	66.7	2.69	1.78
UP											
Council Bluffs-N. Platte	70	-	1.20	1.37	-	3.00	2.57	83.2	50.0	2.10	1.97
N. Platte-Rawlins	70	-	1.20	1.38	-	3.00	2.06	83.2	50.0	2.10	1.72
Rawlins-Ogden	70	-	1.20	1.49	-	3.00	2.19	83.2	50.0	2.10	1.84

TABLE XXXVIII – FUEL CONSUMPTION FACTORS SERVICE LEVEL 1

RAILROAD	ROUTE	LOCATION	NON-ELE.	TERRAIN CHARACTERISTICS	TRAFFIC CHARACTERISTICS	SFC	GROWTH FACTOR 1980	1985	1990
AT&SF	CHICAGO, IL - LOS ANGELES, CA	CHICAGO	1	GREAT PLAINS	100% HIGH-SPEED MANIFEST SERVICE, 2.6 HP/GT	2.46*	1.100	1.210	1.33
		KANSAS CITY	1	GREAT PLAINS	100% HIGH-SPEED MANIFEST SERVICE, 2.6 HP/GT	2.52*	1.100	1.210	1.33
		CLOVIS	1	SOUTHERN ROCKY MTS	100% HIGH-SPEED MANIFEST SERVICE, 2.6 HP/GT	2.49*	1.100	1.210	1.33
		BARSTOW	2	CALIFORNIA HILLS	100% HIGH-SPEED MANIFEST SERVICE, 2.6 HP/GT				
CHESSIE SYSTEM	CHICAGO, IL - WASHINGTON, DC - BALTIMORE, MD	CHICAGO	2	GENTLE ROLLING	MIXED, HEAVY COAL TRAFFIC	1.8	1.150	1.323	1.521
		YOUNGSTOWN	2	EASTERN MOUNTAINS	MIXED, HEAVY COAL TRAFFIC	1.5	1.150	1.323	1.521
		WASHINGTON	2	COASTAL PLAIN	MIXED, HEAVY COAL TRAFFIC	2.0	1.150	1.323	1.521
	TOLEDO, OH - CINCINNATI, OH	ROUTE	2	GENTLE ROLLING	MIXED, LARGE MANIFEST SERVICE	1.8	1.00	1.00	1.00
CHICAGO & NORTHWESTERN	CHICAGO, IL - COUNCIL BLUFFS, IA	ROUTE	1	GREAT PLAINS	MIXED	2.0	1.100	1.210	1.331
	CALIFORNIA JCT. IA - FREMONT, NB	ROUTE	1	GREAT PLAINS	MIXED	2.0	1.100	1.210	1.331
CONRAIL	CHICAGO, IL - SELKIRK, NY	CHICAGO	2	GENTLE ROLLING	MIXED	1.8	1.150	1.323	1.581
		BUFFALO	2	ROLLING	MIXED	1.6	1.150	1.323	1.581
	CLEVELAND, OH - NEWARK, NJ	CLEVELAND	2	GENTLE ROLLING	MIXED, HEAVY COAL TRAFFIC	1.6	1.150	1.323	1.581
		HARRISBURG	3	EAS MTS-COASTAL PLN	MIXED, HEAVY COAL TRAFFIC	1.8	1.150	1.323	1.581
	PITTSBURGH, PA - JOHNSTOWN, PA	ROUTE	0	EASTERN MOUNTAINS	MIXED, HEAVY COAL TRAFFIC	1.6	1.150	1.323	1.581
	HARRISBURG, PA - DOWNINGTON, PA	ROUTE	0	ROLLING	MIXED, HEAVY COAL TRAFFIC	1.8	1.150	1.323	1.581
NORFOLK & WESTERN	BELLEVUE, OH - NORFOLK, VA	BELLEVUE	1	ROLLING	UNIT COAL	1.3	1.150	1.323	1.581
		BLUEFIELD	1	EAS MTS-COASTAL PLN	100% UNIT COAL, 1.75 HP/GT LOADED	1.28*	1.150	1.323	1.581
	NARROWS, VA - ROANOKE, VA	ROUTE	0		100% UNIT COAL, 1.75 HP/GT LOADED	1.28*	1.150	1.323	1.581
	ROANOKE, VA - BURKEVILLE, VA	ROUTE	0		100% UNIT COAL, 1.75 HP/GT LOADED	1.28*	1.150	1.323	1.581

TABLE XXXVIII - FUEL CONSUMPTION FACTORS SERVICE LEVEL 1 (concluded)

RAILROAD	ROUTE	LOCATION	NON-ELE.	TERRAIN CHARACTERISTICS	TRAFFIC CHARACTERISTICS	SFC	GROWTH FACTOR		
							1980	1985	1990
SOUTHERN	CINCINNATI, OH - ATLANTA, GA	CINCINNATI	1	ROLLING	20% MANIFEST, 3.0 HP/GT; 80% DRAG, 1.4 HP/GT	1.65*	1.175	1.266	1.424
		DANVILLE	1	EASTERN MOUNTAINS	20% MANIFEST, 3.0 HP/GT; 80% DRAG, 1.4 HP/GT	1.79*	1.175	1.266	1.424
		CHATTANOOGA	1	ROLLING	20% MANIFEST, 3.0 HP/GT; 80% DRAG, 1.4 HP/GT	1.79*	1.175	1.266	1.424
SOUTHERN PACIFIC	EL PASO, TX - LOS ANGELES, CA	EL PASO	1	SOUTHERN ROCKY MTS	66.7% MANI, 3.5 HP/GT: 33 1/3% DRAG,1.1HP/GT	2.02*	1.05	1.103	1.158
		INDIO	1	BEAUMOUNT HILL	66.7% MANI, 3.5 HP/GT: 33 1/3% DRAG,1.6HP/GT	2.47*	1.05	1.103	1.158
		COLTON	1	CALIFORNIA HILLS	66.7% MANI, 3.5 HP/GT: 33 1/3% DRAG,1.1HP.GT	1.82*	1.05	1.103	1.158
	OGDEN, UT - ROSEVILLE, CA	OGDEN	0	WESTERN ROCKY MTS	MIXED	2.5	1.05	1.103	1.158
		RENO	0	SIERRA MOUNTAINS	MIXED	2.3	1.05	1.103	1.158
UNION PACIFIC	COUNCIL BLUFFS, IA - SALT LAKE CITY, UT	COUNCIL BLUFFS	1	GREAT PLAINS	50% DRAG, 1.2 HP/GT; 50% MANIFEST 3.0 HP/GT	2.01*	1.125	1.266	1.424
		N. PLATT	1	GRT PLNS-ROCKY MTS	50% DRAG, 1.2 HP/GT; 50% MANIFEST 3.0 HP/GT	1.75*	1.125	1.266	1.424
		RAWLINGS	1	ROCKY MOUNTAINS	50% DRAG, 1.2 HP/GT; 50% MANIFEST 3.0 HP/GT	1.88*	1.125	1.266	1.424
	GIBBONS, NB - KANSAS CITY, MO	ROUTE	1	GREAT PLAINS	50% DRAG, 1.2 HP/GT; 50% MANIFEST 3.0 HP/GT	2.0	1.125	1.266	1.424
	GRANGER, WY - POCATELLO, ID	ROUTE	1	ROCKY MOUNTAINS	50% DRAG, 1.2 HP/GT; 50% MANIFEST 3.0 HP/GT	1.9	1.125	1.266	1.424

TABLE XXXIX

FUEL CONSUMPTION FACTORS SERVICE LEVEL 2

RAILROAD	ROUTE	LOCATION	NON-ELE.	TERRAIN CHARACTERISTICS	TRAFFIC CHARACTERISTICS	SFC	GROWTH FACTOR 1980	1985	1990
AT&SF	CLOVIS, NM - TEMPLE, TX	ROUTE	1	GENTLE	MIXED	2.5	1.100	1.210	1.331
	BARSTOW, CA - RICHMOND, CA	ROUTE	2	VALLEY	100% MANIFEST 2.5 HP/GT	2.63*	1.100	1.210	1.331
	KANSAS CITY, KS - HOUSTON, TX	ROUTE	1	FLAT TO ROLLING	MIXED	2.5	1.100	1.210	1.331
B&LE	CONNEANT, OH - UNITY JCT, PA	ROUTE	0	EASTERN MOUNTAINS	100% DRAG, 1.1 HP/GT LOADED	1.26*	1.0	1.0	1.0
BN	CHICAGO, IL - LAUREL, MT	CHICAGO	1	GREAT PLAINS	DRAG, 2 HP/GT	1.62*	1.075	1.156	1.242
		LINCOLN	1	ROLLING	DRAG, 2 HP/GT	1.75*	1.075	1.156	1.242
	CHICAGO, IL - VANCOUVER, WA - PORTLAND, OR	CHICAGO	1	GREAT PLAINS	MANIFEST 4 HP/GT	1.72*	1.0	1.0	1.0
		ST. PAUL	1	GREAT PLAINS	MANIFEST 4 HP/GT	2.16*	1.0	1.0	1.0
		MINOT	1	GREAT PLAINS	MANIFEST 4 HP/GT	1.83*	1.0	1.0	1.0
		HAVRE	1	ROCKY MOUNTAINS	MANIFEST 4 HP/GT	1.9	1.0	1.0	1.0
		SPOKANE	1	ROLL-RIVER VALLEY	MANIFEST 4 HP/GT	1.7	1.0	1.0	1.0
	CHERRY, WA - PASCO, WA	ROUTE	1	ROLLING	MANIFEST 4 HP/GT	1.7	1.0	1.0	1.0
	FARGO, ND - LAUREL, MT	ROUTE	1	PLAINS	DRAG	1.6	1.075	1.156	1.242
	MINNEAPOLIS, MN - CASSELTON, ND - NOLAN, ND	ROUTE	1	PLAINS	MIXED	2.1	1.075	1.156	1.242
	DULUTH, MN - FARGO, ND	ROUTE	0	GENTLE	100% UNIT COAL TRAINS	1.6	1.5	2.0	2.5
	LINCOLN, NB - KANSAS CITY, MO	ROUTE	0	GREAT PLAINS	100% UNIT COAL TRAINS	1.6	1.5	2.0	2.5
	ALLIANCE, NB - FT. WORTH, TX	ROUTE	0	ROLLING	100% UNIT COAL TRAINS	1.6	1.5	2.0	2.5

TABLE XXXIX
(continued)

RAILROAD	ROUTE	LOCATION	NON-ELE.	TERRAIN CHARACTERISTICS	TRAFFIC CHARACTERISTICS	SFC	GROWTH FACTOR 1980	1985	1990
BN (cont.)	DENVER, CO - WALENSBURG, CO	ROUTE	0	ROLLING	100% UNIT COAL TRAINS	1.6	1.5	2.0	2.5
CHESSIE (B&O)	BALTIMORE, MD - PHILADELPHIA, PA	ROUTE	2	COASTAL	MANIFEST	1.8	1.0	1.0	1.0
	CUMBERLAND, MD - GRAFTON, WV	ROUTE	0	EASTERN MOUNTAINS	DRAG	1.3	1.15	1.323	1.5
CHESSIE (C&O)	TOLEDO, OH - NEWPORT NEWS, VA	ROUTE	1	GENTLE-EAST MTS	COAL	1.3	1.150	1.323	1.15
	CATLETTSBURG, KY - ELKHORN CITY, KY	ROUTE	0	EASTERN MOUNTAINS	COAL	1.3	1.150	1.323	1.15
	CHICAGO, IL - DETROIT, MI	ROUTE	2	GENTLE	MERCHANDISE	1.8	1.0	1.0	1.0
	TOLEDO, OH - SAGINAW, MI	ROUTE	2	GENTLE	MERCHANDISE	1.8	1.0	1.0	1.0
C&NW	NELSON, IL - E. ST. LOUIS, IL	ROUTE	1	GREAT PLAINS	MIXED	2.0	1.1	1.21	1.331
CONRAIL	NEWARK, NJ - SELKIRK, NY	ROUTE	2	ROLLING	MIXED	1.8	1.15	1.323	1.521
	E. ST. LOUIS, IL - CONWAY, PA	ROUTE	2	ROLLING	MIXED	1.8	1.15	1.323	1.521
	DETROIT, MI - CINCINNATI, OH	ROUTE	2	GENTLE	MIXED	1.8	1.15	1.323	1.521
	UNION CITY - CLEVELAND, OH	ROUTE	2	GENTLE	MIXED	1.8	1.15	1.323	1.521
	- COLUMBUS - DAYTON, OH	ROUTE	2	GENTLE	MIXED	1.8	1.15	1.323	1.521
	NEWARK, NJ - ALEXANDRIA, VA	ROUTE	2	COASTAL	MIXED, LARGE MERCHANDISE	1.8	1.15	1.323	1.521

TABLE XXXIX
(continued)

RAILROAD	ROUTE	LOCATION	NON-ELE.	TERRAIN CHARACTERISTICS	TRAFFIC CHARACTERISTICS	SFC	GROWTH FACTOR		
							1980	1985	1990
CONRAIL (continued)	PHILADELPHIA - DOWNINGTON PA	ROUTE	2	COASTAL	MIXED, LARGE MERCHANDISE	1.8	1.15	1.323	1.521
	PERRYVILLE, MD - HARRISBURG, PA	ROUTE	2	COASTAL	MIXED, LARGE MERCHANDISE	1.8	↓	↓	↓
	BOSTON, MA - SELKIRK, NY	ROUTE	2	COASTAL	MIXED, LARGE MERCHANDISE	1.8	↓	↓	↓
	HARRISBURG & RENOVO, PA	ROUTE	1	EASTERN MOUTAINS	DRAG	1.3	↓	↓	↓
	ASHTABULA, OH - PITTSBURGH, PA	ROUTE	1	EASTERN MOUNTAINS	DRAG	1.3	↓	↓	↓
DM & IR	DULUTH, MT - IRON, MN	ROUTE	0		100% DRAG	1.3	1.1	1.21	1.331
D & RGW	SALT LAKE CITY, UT - DENVER, CO	ROUTE	1	ROCKY MOUNTAINS	MIXED	1.8	1.1	1.21	1.331
	DOTSERO - PUEBLO, CO	ROUTE	1	" "		1	1	1	1
FAMILY (CLIN)	ELKHORN CITY, KY - GREENWOOD, SC	ROUTE	0	EASTERN MOUNTAINS	100% COAL	1.3	1.15	1.323	1.521
(L & N)	CHICAGO, IL - NASHVILLE, TN	CHICAGO	1	GENTLE	MIXED	1.6	1.15	1.323	1.521
		EVANSVILLE	1	EASTERN MOUNTAINS	MIXED	1.8	↓	↓	↓
	NASHVILLE, TN - NEW ORLEANS, LA	NASHVILLE	1	EASTERN MOUNTAINS	MIXED	1.8	↓	↓	↓
		BIRMINGHAM	1	ROLLING-FLAT	MIXED	1.6	↓	↓	↓
	LOUISVILLE, KY - NASHVILLE, TN	ROUTE	1	EASTERN MOUNTAINS	MIXED	1.8	↓	↓	↓
	CINCINNATI, OH - ATLANTA, GA	ROUTE	1	EASTERN MOUNTAINS	MIXED	1.8	↓	↓	↓
	WINCHESTER - HAZARD, KY	ROUTE	0	" "	100% COAL	1.3	↓	↓	↓
(SCL)	RICHMOND, VA - TAMPA, FL	ROUTE	1	COASTAL PLAIN	50% MANIFEST, 2 HP/GT; 50% DRAG 1 HP/GT	2.05*	1.05	1.103	1.158
	HAMLET, NC - DILLON, SC	ROUTE	0	" "	" " " " " "	2.05*	↓	↓	↓
	SAVANNAH - WAYCROSS, GA	ROUTE	0	" "	" " " " " "	2.05*	↓	↓	↓

TABLE XXXIX
(continued)

RAILROAD	ROUTE	LOCATION	NON ELE.	TERRAIN CHARACTERISTICS	TRAFFIC CHARACTERISTICS	SFC	GROWTH FACTOR		
							1980	1985	1990
FAMILY (SCL con)	RICHMOND, VA - ATLANTA, GA	ROUTE	1	ROLLING	MIXED	1.8	1.05	1.103	1.158
	JACKSONVILLE, FL - ATLANTA, GA	ROUTE	1	FLAT TO ROLLING	MIXED	1.8	1.05	1.103	1.158
GTW	CHICAGO, IL - PORT HURON, MI	ROUTE	2	GENTLE	MERCHANDISE	2.0	1.05	1.103	1.158
	DURAND - DETROIT, MI	ROUTE	2	GENTLE	MERCHANDISE				
ICG	CHICAGO, IL - NEW ORLEANS, LA	CHICAGO	1	FLAT	50% MANIFEST, 3 HP/GT; 50% DRAG, 1 HP/GT	1.63*	1.05	1.103	1.158
		EDGEWOOD	1	ROLLING	" " " " "	1.11*			
		FULTON	1	RIVER VALLEY	" " " " "	1.18*			
		MEMPHIS	1	FLAT TO ROLLING	" " " " "	1.6			
	EDGEWOOD, IL - FULTON, KY	ROUTE	0	ROLLING	" " " " "	1.18*			
MILW	CHICAGO, IL - ST. PAUL, MN	ROUTE	1	ROLLING	MIXED	1.7	1.0	1.0	1.0
MP	ST. LOUIS, MO - FORT WORTH, TX	ROUTE	1	ROLLING - FLAT	MIXED	2.0	1.15	1.323	1.521
	BALD KNOB, AR - MEMPHIS, TN	ROUTE	0	ROLLING	MIXED	1.8	1.15	1.323	1.521
	KANSAS CITY - ST. LOUIS, MO	ROUTE	1	GENTLE	MIXED	2.0	1.15	1.323	1.521
	CHICAGO, IL - E. ST. LOUIS, MO	ROUTE	1	GENTLE	MIXED	2.0	1.15	1.323	1.521
N&W	KANSAS CITY, MO - BUFFALO, NY	ROUTE	2	FLAT	MIXED, LARGELY DRAG	1.6	1.15	1.323	1.521
	CHICAGO, IL - FORT WAYNE, IN	ROUTE	2	FLAT	MIXED, LARGELY DRAG	1.6	1.15	1.323	1.521
	BELLEVUE, OH - PITTSBURGH, PA	ROUTE	2	FLAT-EASTERN MTS.	MIXED, LARGELY DRAG	1.6			
	NORTON - BLUEFIELD, VA	ROUTE	0	EASTERN MOUNTAINS	COAL	1.3	1.15	1.323	1.521
P&LE	ASHTABULA, OH - RIVERTON, PA	ROUTE	0	EASTERN MOUNTAINS	DRAG	1.3	1.0	1.0	1.0
RF&P	RICHMOND - ALEXANDRIA, VA	ROUTE	1	COASTAL PLAIN	50% MANIFEST, 3 HP/GT; 50% DRAG, 1.2 HP/GT	2.03*	1.05	1.103	1.158
SL-SF	MEMPHIS, TN - KANSAS CITY, MO	ROUTE	1	GENTLE	MIXED	2.0	1.10	1.21	1.331
	MEMPHIS, TN - BIRMINGHAM, AL	ROUTE	1	ROLLING	MIXED	2.0	1.10	1.21	1.331

action should alter the equilibrium established by PIES and a rigorous evaluation would involve evaluating new cases with the model. The changes in demand, however, are very small in comparison to both regional and national demands, and so this study has used the original PIES projections without modification.

The FEA data[22] present estimates of fossil fuel consumption for electricity generation, broken out in categories of coal (high and low sulfur), gas, and oil (distillate and residual). These data for the nation are compiled on a regional basis, with United States Census Regions being used to aggregate electricity supply and demand. The normalized utility fuel requirements were calculated for various scenarios used in the study (Reference Cases with \$13/barrel and \$16/barrel for imported petroleum plus a variety of cases for 1985 to indicate a possible range from different supply and demand situations.) The utility fuel requirements are presented in Table XL for 1975 historical data from Reference 21 Tables XLI-1 through XLI-18 for future projections from Reference 22. The coefficients in these tables, when multiplied by the electricity consumption in a region (or in the nation), will provide the mix of fuels required to generate that electricity. (The units used in these tables reflects those used in the original sources - electricity is in 1000 GWH/yr; fuel usage is the daily rate; the coefficient M represents 10^3).

One further assumption was made to determine the fuels for electricity generation attributable to the railroads. The philosophy used was that since the new electrical load is a relatively small addition to the existing load, the fuels attributable to rail will be apportioned on the basis of the overall electrical generation fuel mix. In other words, on the average, the railroad load would draw equally from all fuels used in the generation of electricity in a given region. It can be argued that since the railroad electricity

TABLE XL

FUEL CONSUMPTION FACTORS

1975 STATISTICS

FUEL USED BY CENSUS REGION PER 1000 GWH/YR

REGION	COAL MT/D	OIL MB/D	GAS MMCF/D
NE	.0702	2.726	.0988
MA	.5168	1.5004	.2688
SA	.6033	1.1040	1.5858
ENC	1.0582	.2583	.9109
ESC	.9561	.1834	.6026
WSC	.1059	.1418	23.9118
MTN	.7886	.3002	4.0725
PAC	.0447	.9295	3.0851
USA	.5798	.7243	4.4948

TABLE XLI-1

UTILITY FUEL CONSUMPTION FACTORS

1980 REFERENCE CASE
IMPORTS........................ $13
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.01924	0.07911	0.88839	0.0	2.67586
MA	0.24052	0.23970	1.66975	0.51377	0.79492
SA	0.51443	0.18342	0.64564	0.00443	0.55160
ENC	0.32215	0.55371	0.91105	0.20224	0.15075
ESC	0.50286	0.26641	1.20142	0.06430	0.15417
WNC	0.55675	0.33168	1.65671	0.05472	0.00733
WSC	0.12811	0.02293	21.49680	0.08662	0.0
MTN	0.22175	0.59721	3.96966	0.00504	0.0
PAC	0.01935	0.0	4.19269	0.05804	0.30955
USA	0.30707	0.25609	3.86310	0.14113	0.39864

TABLE XLI-2

UTILITY FUEL CONSUMPTION FACTORS

1985 REFERENCE CASE
IMPORTS......................... $13
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.35387	0.07077	0.66787	0.02592	1.64576
MA	0.35402	0.24947	1.25562	0.00059	0.44794
SA	0.40302	0.25327	0.54998	0.00444	0.40302
ENC	0.45676	0.37227	0.68448	0.06661	0.11189
ESC	0.35376	0.27995	0.94675	0.07444	0.00255
WNC	0.41175	0.44403	1.18808	0.06000	0.00497
WSC	0.09938	0.13732	14.72576	0.09230	0.0
MTN	0.22280	0.43213	5.07230	0.02877	0.0
PAC	0.06367	0.0	0.07304	0.18551	0.80569
USA	0.32014	0.25424	2.48320	0.05787	0.30668

TABLE XLI-3

UTILITY FUEL CONSUMPTION FACTORS

1990 REFERENCE CASE
IMPORTS......................... $13
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.27584	0.20111	0.0	0.11532	1.55539
MA	0.30812	0.28483	0.00046	0.06221	0.47268
SA	0.32854	0.29441	0.00335	0.08552	0.32661
ENC	0.29662	0.48832	0.07268	0.10807	0.12998
ESC	0.26766	0.28123	0.0	0.10148	0.10957
WNC	0.31406	0.53014	0.0	0.10820	0.11681
WSC	0.07784	0.35296	0.37676	0.09986	1.43565
MTN	0.32097	0.36386	0.90588	0.11312	0.42419
PAC	0.05002	0.0	0.0	0.56041	0.62450
USA	0.25262	0.32127	0.10169	0.14592	0.46641

TABLE XLI-4

UTILITY FUEL CONSUMPTION FACTORS

1980 REFERENCE CASE
IMPORTS.......................... $16
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS CCAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.01946	0.08002	0.89105	0.0	2.66126
MA	0.24190	0.23916	1.67494	0.52001	0.78083
SA	0.51466	0.18389	0.64560	0.0	0.55232
ENC	0.32132	0.55316	0.90871	0.21060	0.15037
ESC	0.50286	0.26641	1.20142	0.06430	0.15417
WNC	0.55667	0.33332	1.65647	0.05471	0.0
WSC	0.12806	0.02328	21.48560	0.08659	0.0
MTN	0.22183	0.59742	3.96432	0.00504	0.0
PAC	0.01950	0.0	6.04358	0.05747	0.00104
USA	0.30759	0.25667	4.07931	0.14262	0.35842

TABLE XLI-5

UTILITY FUEL CONSUMPTION FACTORS

1985 REFERENCE CASE
IMPORTS........................ $16
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.36311	0.07711	0.65399	0.02733	1.61154
MA	0.35922	0.25153	1.24912	0.0	0.44223
SA	0.40261	0.25829	0.54496	0.00538	0.39935
ENC	0.45400	0.38176	0.66977	0.06759	0.10949
ESC	0.35379	0.28909	0.93009	0.07501	0.00250
WNC	0.40542	0.45472	1.16980	0.06071	0.00489
WSC	0.09840	0.28427	11.36180	0.09251	0.0
MTN	0.23215	0.43054	4.99704	0.03015	0.0
PAC	0.09737	0.0	4.75840	0.05705	0.03099
USA	0.32475	0.27541	2.62045	0.04414	0.21751

TABLE XLI-6

UTILITY FUEL CONSUMPTION FACTORS

1990 REFERENCE CASE
IMPORTS........................ $16
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.29721	0.20990	0.0	0.11465	1.48694
MA	0.31911	0.28786	0.35814	0.00015	0.46132
SA	0.32873	0.30209	0.42059	0.02969	0.30539
ENC	0.27464	0.52640	0.16667	0.07880	0.12491
ESC	0.26983	0.29547	0.74781	0.08250	0.00178
WNC	0.30653	0.54452	0.19999	0.07289	0.11401
WSC	0.07739	0.53595	4.91907	0.09684	0.0
MTN	0.33220	0.36357	3.77324	0.04983	0.0
PAC	0.16953	0.0	0.04871	0.06928	0.62442
USA	0.26474	0.35398	0.97413	0.05754	0.27030

TABLE XLI-7

UTILITY FUEL CONSUMPTION FACTORS

1985 ELECTRIFICATION CASE
IMPORTS......................... $13
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.39653	0.21203	0.49846	0.05952	1.17323
MA	0.34213	0.29710	1.19798	0.00052	0.28872
SA	0.37507	0.25535	0.50645	0.01303	0.37113
ENC	0.41191	0.37498	0.62627	0.07070	0.10238
ESC	0.33819	0.24454	0.92590	0.07529	0.00249
WNC	0.45143	0.42878	1.01727	0.06326	0.00469
WSC	0.09993	0.39600	9.14503	0.09622	0.0
MTN	0.25295	0.38377	4.79686	0.03473	0.0
PAC	0.13413	0.0	4.52731	0.07202	0.02949
USA	0.31502	0.28976	2.38391	0.04990	0.18046

TABLE XLI-8

UTILITY FUEL CONSUMPTION FACTORS

1985 ELECTRIFICATION CASE
IMPORTS......................... 16
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.40799	0.21769	0.48295	0.06127	1.13674
MA	0.35140	0.29949	1.18807	0.00051	0.28242
SA	0.37507	0.25724	0.50482	0.01329	0.36993
ENC	0.41812	0.37535	0.61531	0.07138	0.10058
ESC	0.33815	0.25038	0.91652	0.07576	0.00246
WNC	0.44428	0.43967	1.00117	0.06418	0.00461
WSC	0.09888	0.39964	9.14766	0.09636	0.0
MTN	0.25865	0.38368	4.75270	0.03498	0.0
PAC	0.14009	0.0	4.52383	0.06126	0.02921
USA	0.31860	0.29269	2.37088	0.04913	0.17807

TABLE XXXIX
(continued)

RAILROAD	ROUTE	LOCATION	NON ELE.	TERRAIN CHARACTERISTICS	TRAFFIC CHARACTERISTICS	SFC	GROWTH FACTOR 1980	1985	1990
SL-SF (con)	ST. LOUIS, MO - OKLAHOMA CITY, OK	ROUTE	1	GENTLE	MIXED	2.0	1.10	1.21	1.331
SOUTHERN	E. ST. LOUIS, IL - DANVILLE, KY	ROUTE	1	ROLLING	MIXED, HEAVY COAL	1.7	1.125	1.266	1.424
	HARRIMAN JCT. - KNOX, TN	ROUTE	1	EASTERN MOUNTAINS	MIXED, HEAVY COAL	1.8	1.125	1.266	1.424
	ATLANTA, GA - ALEXANDRIA, VA	ROUTE	1	ROLLING	MIXED, LARGE MERCHANDISE	2.0	1.125	1.266	1.424
	NEW ORLEANS, LA - ATLANTA, GA	ROUTE	1	GENTLE	MIXED, LARGE MERCHANDISE	2.0	1.125	1.266	1.424
	MEMPHIS, TN - BIRMINGHAM, AL	ROUTE	1	ROLLING	MIXED, LARGE MERCHANDISE	1.8	↓	↓	↓
	CHATTANOOGA, TN - SALISBURY, NC	ROUTE	1	EASTERN MOUNTAINS	MIXED, HEAVY COAL	1.8	↓	↓	↓
	ATLANTA - MACON, GA	ROUTE	1	ROLLING	MIXED	1.8	↓	↓	↓
SP	EL PASO, TX - NEW ORLEANS, LA	ROUTE	1	FLAT	MIXED, LARGE MERCHANDISE	2.0	1.050	1.103	1.158
	PORTLAND, OR - ROSEVILLE, CA	ROUTE	2	VALLEY	MIXED	2.0	↓	↓	↓
	SACRAMENTO - COLTON, CA	ROUTE	2	VALLEY	MIXED	2.0	↓	↓	↓
	ROSEVILLE - OAKLAND, CA	ROUTE	2	GENTLE	MIXED	1.6	↓	↓	↓
	E. ST. LOUIS, IL - FLATONIA, TX	ROUTE	1	GENTLE	MIXED	2.0	↓	↓	↓
U.P.	POCATELLO, ID - PORTLAND, OR	ROUTE	1	ROCKY MOUNTAINS	MIXED	1.9	1.125	1.266	1.424

TABLE XXXIX
(continued)

RAILROAD	ROUTE	LOCATION	NON ELE.	TERRAIN CHARACTERISTICS	TRAFFIC CHARACTERISTICS	SFC	GROWTH FACTOR 1980	GROWTH FACTOR 1985	GROWTH FACTOR 1990
U.P. (con)	SALT LAKE CITY, UT - LOS ANGELES, CA	ROUTE	0	WESTERN ROCKY MTS	MIXED, LARGE MERCHANDISE	2.1	1.125	1.266	1.424
W.P.	SALT LAKE CITY, UT - SACRAMENTO, CA	ROUTE	0	WESTERN ROCKY MTS	MIXED, LARGE MERCHANDISE	2.3	1.125	1.266	1.424

*SFC calculated for the routes

TABLE XLI-9

UTILITY FUEL CONSUMPTION FACTORS

1985 REGIONAL LIMITATION
IMPORTS........................... $13
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.01538	0.50075	0.57253	0.07947	1.41081
MA	0.17559	0.24562	1.29055	0.87607	0.47841
SA	0.44028	0.14514	0.56965	0.51086	0.42468
ENC	0.45603	0.27434	0.71713	0.71507	0.11723
ESC	0.51261	0.17985	1.04131	0.66376	0.00280
WNC	0.44263	0.27581	1.27717	1.01648	0.00534
WSC	0.10800	0.22338	16.65207	0.09046	0.0
MTN	0.21854	0.58448	5.31096	0.02499	0.0
PAC	0.01629	0.0	4.91267	0.30221	0.05468
USA	0.29980	0.22547	3.22081	0.54817	0.23539

TABLE XLI-10

UTILITY FUEL CONSUMPTION FACTORS

1985 REGIONAL LIMITATION
IMPORTS......................... $16
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.01518	0.52629	0.56508	0.01181	1.39247
MA	0.17418	0.45329	1.28622	0.00063	0.47456
SA	0.44028	0.27017	0.56965	0.00329	0.42468
ENC	0.43268	0.46091	0.70956	0.06497	0.11599
ESC	0.51420	0.32703	1.03535	0.07062	0.00278
WNC	0.43736	0.52131	1.26196	0.05670	0.00527
WSC	0.10698	0.23559	16.42349	0.09082	0.0
MTN	0.21551	0.59343	5.23722	0.02654	0.0
PAC	0.01619	0.06043	5.01622	0.06679	0.03267
USA	0.29446	0.35733	3.20487	0.04248	0.23121

TABLE XLI-11

UTILITY FUEL CONSUMPTION FACTORS

1985 SUPPLY PESSIMISM CASE
IMPORTS.......................... $13
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.01487	0.08344	0.77577	1.09963	2.02081
MA	0.16943	0.22320	1.27145	0.96282	0.54888
SA	0.42471	0.11977	0.55903	0.61557	0.52006
ENC	0.48213	0.21310	0.70061	0.78054	0.21042
ESC	0.40706	0.23078	0.97694	0.84268	0.10341
WNC	0.42710	0.27815	1.23237	1.10531	0.00515
WSC	0.10226	0.27502	15.53989	0.12702	0.0
MTN	0.21151	0.60415	5.14023	0.02791	0.0
PAC	0.01533	0.0	4.74917	0.39145	0.03093
USA	0.28763	0.20081	3.09663	0.66750	0.30963

TABLE XLI-12

UTILITY FUEL CONSUMPTION FACTORS

1985 SUPPLY PESSIMISM CASE
IMPORTS......................... $16
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.01473	0.51157	0.54840	0.15306	1.35137
MA	0.16846	0.24937	1.26843	0.97649	0.45899
SA	0.42306	0.15296	0.55686	0.62684	0.40807
ENC	0.40908	0.30731	0.69377	0.80751	0.11341
ESC	0.53370	0.13709	0.96907	0.86422	0.00261
WNC	0.42489	0.27842	1.22600	1.11796	0.00512
WSC	0.10227	0.29195	15.37191	0.09178	0.0
MTN	0.21007	0.60804	5.10518	0.02834	0.0
PAC	0.01530	0.0	4.74045	0.39401	0.03088
USA	0.28570	0.23789	3.05408	0.64107	0.22246

TABLE XLI-13

UTILITY FUEL CONSUMPTION FACTORS

1985 REGIONAL LIMITATION W/ BAU DEMAND
IMPORTS........................ $13
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.01469	0.51238	0.54665	0.15747	1.34704
MA	0.16793	0.24958	1.26661	0.98425	0.45753
SA	0.42522	0.15190	0.55971	0.61196	0.41015
ENC	0.40562	0.30922	0.69099	0.81836	0.11296
ESC	0.53455	0.13534	0.96588	0.87306	0.00260
WNC	0.42418	0.27838	1.22394	1.12205	0.00512
WSC	0.10353	0.27697	15.65342	0.09144	0.0
MTN	0.21060	0.60710	5.11807	0.02841	0.0
PAC	0.01537	0.0	0.06176	0.38757	0.80232
USA	0.28591	0.23648	2.53703	0.64337	0.30973

TABLE XLI-14

UTILITY FUEL CONSUMPTION FACTORS

1985 REGIONAL LIMITATION W/ BAU DEMAND
IMPORTS......................... $16
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.01448	0.55676	0.53906	0.01609	1.32835
MA	0.28156	0.37674	1.26144	0.00060	0.45300
SA	0.42529	0.30167	0.55980	0.00570	0.41022
ENC	0.33037	0.57012	0.68368	0.06670	0.11176
ESC	0.53766	0.33371	0.95584	0.07387	0.00257
WNC	0.41829	0.55072	1.20695	0.05928	0.00504
WSC	0.10265	0.28747	15.45593	0.09153	0.0
MTN	0.20742	0.61556	5.04064	0.02980	0.0
PAC	0.01545	0.07697	4.67505	0.06897	0.04938
USA	0.28920	0.38401	3.02761	0.04450	0.22314

TABLE XLI-15

UTILITY FUEL CONSUMPTION FACTORS

1985 ACCEL SUPPLY, BAU DMND W/O LD MGT
IMPORTS.......................... $13
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.20725	0.11376	0.75468	0.03267	1.77631
MA	0.29046	0.28321	1.25423	0.00059	0.32439
SA	0.37806	0.20003	0.55709	0.00300	0.40823
ENC	0.37946	0.37242	0.68386	0.06671	0.11179
ESC	0.42733	0.17285	0.94906	0.07430	0.00255
WNC	0.49393	0.36655	1.09880	0.05947	0.00506
WSC	0.12001	0.10779	14.29404	0.09279	0.0
MTN	0.25579	0.41194	5.03502	0.03038	0.0
PAC	0.11230	0.0	4.87085	0.06907	0.03173
USA	0.30901	0.23130	3.00151	0.04509	0.20046

TABLE XLI-16

UTILITY FUEL CONSUMPTION FACTORS

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            1985 ACCEL SUPPLY, BAU DMND W/O LD MGT
            IMPORTS......................... $16
            FUEL USE BY CENSUS REGION PER 1000 GWH/YR


REGION       HS COAL      LS COAL        GAS         DIST         RES
              MT/D         MT/D        MMCF/D        MB/D         MB/D


  NE        0.21527      0.11873      0.74344      0.03329      1.74986
  MA        0.29608      0.28465      1.24808      0.00058      0.32050
  SA        0.37803      0.20140      0.55582      0.00333      0.40730
  ENC       0.38038      0.37253      0.68227      0.06689      0.11153
  ESC       0.42274      0.17099      0.93886      0.07477      0.0
  WNC       0.49232      0.36914      1.09522      0.05970      0.00505
  WSC       0.11810      0.12931     13.94753      0.09323      0.0
  MTN       0.25447      0.40860      5.00899      0.03083      0.0
  PAC       0.11568      0.0          5.73046      0.05672      0.03173


  USA       0.30961      0.23409      3.06392      0.04400      0.19892
```

TABLE XLI-17

UTILITY FUEL CONSUMPTION FACTORS

1985 BAU SUPPLY,CONSERVATION AND LOAD MG
IMPORTS........................ $13
FUEL USE BY CENSUS REGION PER 1000 GWH/YR

REGION	HS COAL MT/D	LS COAL MT/D	GAS MMCF/D	DIST MB/D	RES MB/D
NE	0.29218	0.08204	0.67876	0.0	2.18350
MA	0.38661	0.21420	1.46369	0.00065	0.64348
SA	0.44659	0.23146	0.26483	0.00449	0.57363
ENC	0.40413	0.49936	0.91493	0.00704	0.15665
ESC	0.43345	0.32642	1.34891	0.01382	0.0
WNC	0.44615	0.48202	1.57924	0.0	0.00673
WSC	0.11104	0.08700	18.21843	0.03796	0.0
MTN	0.22280	0.52989	6.70502	0.0	0.0
PAC	0.02149	0.0	6.71472	0.0	0.04388
USA	0.32865	0.27704	3.74174	0.00760	0.30692

TABLE XLI-18

UTILITY FUEL CONSUMPTION FACTORS

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              1985 BAU SUPPLY, CONSERVATION AND LOAD M
              IMPORTS.......................... $16
              FUEL USE BY CENSUS REGION PER 1000 GWH/YR


REGION          HS COAL        LS COAL         GAS          DIST           RES
                 MT/D           MT/D         MMCF/D         MB/D          MB/D


  NE          0.41051        0.05864        0.48575       0.0           1.88767
  MA          0.39511        0.38342        1.43634       0.0           0.0
  SA          0.44327        0.39241        0.26702       0.0           0.0
  ENC         0.46246        0.48937        0.89663       0.00811       0.0
  ESC         0.42597        0.32541        1.32889       0.01466       0.0
  WNC         0.44169        0.49097        1.56746       0.0           0.0
  WSC         0.10985        0.06760       20.07898       0.03818       0.0
  MTN         0.21918        0.51805        6.60225       0.0           0.0
  PAC         0.02149        0.0            7.86951       0.0           0.04388


  USA         0.34339        0.32939        4.02946       0.00697       0.06118
```

is a new load, the fuel mix of the new generating plants should be used to calculate the fuel use attributable to railroads. This assumption would surely be valid in considering a new electrical use that creates a large and fairly constant load on a system. Within the range of potential electrification projects established by this study, certainly some utilities would have to add additional generating capacity to handle a railroad's demand for power. Considering the size and nature of the new demand created by railroad electrification, however, it appears that the averaging assumption should give a reasonable and accurate estimate of the fuels used by electrified railroads.

APPENDIX V

ESTIMATION OF EMISSIONS

BACKGROUND

One factor in assessing railroad electrification is the changes in air pollutants that would accompany a change in fuel sources. The changes in fuels, from diesel fuel to a mix of fuels for electricity generation, have been calculated in Reference 57. Figure 14, given previously, shows a typical indication of the projected energy sources for railroad electrification. Reference 57 also presents the calculation of emissions associated with the consumption of the fuels for electrification.

METHODOLOGY

The emissions associated from the use of fuel in railroad operations were calculated from factors compiled by the Environmental Protection Agency.[25] Table XLII presents a summary of those factors. The emission factors for high and low sulfur coal represent combustion of pulverized bituminous coal without control equipment in utility boilers (greater than 100 x 10^6 BTU/hr heat input). The 0.7% sulfur represents the upper bound corresponding to the EPA limit of 1.2 lb of SO_2 per 10^6 BTU.[58] The emission factors for natural gas combustion apply to utility power plants without control equipment. The emission factors for diesel-electric locomotives are based on average factors based on typical duty cycle and the nationwide locomotive population.

The control of emissions (air-pollutants) from external combustion sources (stationary power plants) and internal combustion sources (motor vehicles) is a major factor in establishing a satisfactory air quality. The EPA has established various standards of performance for various sources of air pollution; to date no standards have been established for locomotives, but they have been set for new generation

TABLE XLII

FACTORS USED FOR ESTIMATING EMISSIONS

POLLUTANT	HIGH SULFUR(3) COAL (LBS/TON)	LOW SULFUR(3) COAL (LBS/TON)	NATURAL(4) GAS (LBS/MILCFT)	DISTILLATE(5) (LBS/1000 GAL)	RESIDUAL(5) (LBS/1000 GAL)	DIESEL(6) LOCOMOTIVE (LBS/1000 GAL)
PARTICULATES(1)	128	128	5-15	8	8	25
SO_x(2)	114	26.6	0.6	318	318	57
CO	1	1	17	3	3	130
HC	0.3	0.3	1	2	2	94
NO_x	18	18	700	105	105	370
ALDEHYDES	0.005	0.005	0.0	1.0	1.0	5.5

NOTES

(1) Based on 8% Ash Content in Coal

(2) Based on 3% Sulfur in High Sulfur Coal
0.7% Sulfur in Low Sulfur Coal
2% Sulfur in Distillate and Residual

(3) Reference 25, Table 1.1-2

(4) Reference 25, Table 1.4-1

(5) Reference 25, Table 1.3-1

(6) Reference 25, Table 3.2.2-1

facilities.[50] In addition, state governments have established air quality standards, particularly on electrical generating stations. These vary from state to state in both magnitude and manner of specification.[59] In general, however, they are roughly equivalent to the Federal standards. Table XLIII presents a summary of the emission factors used for estimating controlled emissions.

RESULTS

Emissions from railroad operations, for the traffic under consideration, were calculated for the conditions: diesel-electric traction, electric traction with uncontrolled emissions at the utility plant, and electric traction with utilities meeting federal standards for new stationary sources of air pollution. Comparison of the last two values help to establish the size and severity of the control problem. The emissions were calculated on a regional basis for the time frame used throughout the study. The results thus incorporate the regional variation in both utility fuel mix and railroad traffic. Nominal values of emission factors were used, but the variety and range of fuel mix generated by supply and demand scenarios were used to project a range of emissions. The regional estimates are given in Reference 57; the nationwide totals are given in Table XLIV for Level 1 and Table XLV for Level 1 + 2.

TABLE XLIII

FACTORS USED FOR ESTIMATING CONTROLLED EMISSIONS

POLLUTANT	COAL (LBS/TON)	NATURAL GAS (LBS/MIL CFT)	DISTILLATE (LBS/1000 GAL)	RESIDUAL (LBS/1000 GAL)
PARTICULATES	2.25	5-15*	8.0*	8.0*
SO_x	26.6	0.6*	111.0	119.75
NO_x	15.75	206.6	41.6	44.9

*Uncontrolled emissions are less than the maximum permissible.

Data Source: Reference 25

TABLE XLIV

ESTIMATED NATIONWIDE ANNUAL EMISSIONS, LEVEL 1

YEAR	TYPE OF TRACTION	PARTICULATES	SO_x	CO	HC	NO_x	ALDEHYDES
1975	DIESEL	11.8	27.0	61.6	44.5	175.3	2.6
1980	DIESEL	13.2	30.0	68.5	49.5	195.0	2.9
	ELECTRIC						
	Before Control	249.4	140.9-141.8	2.3	0.6	45.5	0.1
	After Control*	4.61	56.3	2.3	0.6	33.8	0.1
1985	DIESEL	14.7	33.4	76.3	55.1	217.1	3.2
	ELECTRIC						
	Before Control	219.4-321.8	132.2-175.4	1.4-2.5	0.5-0.6	42.4-52.0	0.0-0.1
	After Control*	4.4-5.8	51.8-67.9	1.4-2.5	0.5-0.6	31.9-41.6	0.0-0.1
1990	DIESEL	16.3	37.3	85.0	61.5	241.9	3.6
	ELECTRIC						
	Before Control	203.1-292.8	168.8-167.6	2.4	0.6-0.7	46.4	0.0-0.1
	After Control*	5.5	64.8-67.6	2.4	0.6-0.7	38.4-38.7	0.0-0.1

*Based on levels of the federal standards for new stationary sources of air pollution.

TABLE XLV

ESTIMATED NATIONWIDE ANNUAL EMISSIONS, LEVEL 1 + 2

YEAR	TYPE OF TRACTION	PARTICULATES	SO_x	CO	HC	NO_x	ALDEHYDES
1975	DIESEL	29.8	67.9	154.9	112.0	440.9	6.6
1980	DIESEL	32.9	75.0	171.0	123.7	486.8	7.2
	ELECTRIC						
	Before Control	575.2	346.9-349.5	5.3	1.4	112.7	0.2
	After Control*	11.4	129.68-130.68	5.3	1.4	81.26-81.46	0.2
1985	DIESEL	36.4	82.9	189.0	136.7	538.0	8.0
	ELECTRIC						
	Before Control	559.5-767.6	317.4-431.1	5.1-6.5	1.5-2.1	104.0-128.4	0.0-0.3
	After Control*	10.6-14.0	119.9-163.0	5.1-6.5	1.5-2.1	75.6-99.7	0.0-0.3
1990	DIESEL	40.2	91.7	209.1	151.2	595.1	8.8
	ELECTRIC						
	Before Control	670.2-705.3	376.3-404.8	5.9-6.0	1.8	117.6	0.1-0.2
	After Control*	13.2	157.2-163.7	5.9-6.0	1.8	91.7-93.7	0.1-0.2

*Based on levels of the federal standards for new stationary sources of air pollution.

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