SUMMARY

If we assume continued escalation of diesel fuel prices and of freight growth, electrification, which has a positive return on investment, is becoming more attractive than ever. For rail routes that carry heavy traffic, rail electrification provides a technologically available system that is extremely competitive with petroleum costs.

Since more than 200 000 miles of track are in use, the railroads will continue to rely on liquid fuels for their medium-density and low-density operation. With freight growth, electrification of high-density lines will be necessary if the railroads wish to maintain their present level of diesel fuel use. Detailed questions of cost, appropriate financing, and industry profitability remain to be answered; segments to be electrified will need to be rationalized and utility interface issues resolved.

Since it saves liquid fuel at a competitive or lower cost than supplying the equivalent synthetic fuel and since it is an existing technology, electrification should receive priority as a national investment equal to that given to synthetic fuels and other conservation options.

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REFERENCES

1. An Evaluation of the Costs and Benefits of Railroad Electrification. Federal Railroad Administration, U.S. Department of Transportation, July 1977.
2. C.H. Spenny. An Update of the Costs and Benefits of Railroad Electrification. Federal Railroad Administration, U.S. Department of Transportation, Rept. PM-742-C-14-83, April 8, 1980.
3. J. Fraser and others. Developing a Methodology for Evaluation Alternatives for Reducing Petroleum Use in Transportation. Automotive Transportation Center, Purdue Univ., West Lafayette, IN, May 1980.
4. C.G. Swanson, V.D. Nene, R. Martin, and M. Lenard. The Energy and Environmental Impact of Railroad Electrification. Mitre Corporation, McLean, VA, Tech. Rept. MTR-7594, Sept. 1977.
5. A Prospectus for Change in the Freight Railroad Industry. U.S. Department of Transportation, Oct. 1978.
6. F.L. Raposa and C.H. Spenny. Cost Effectiveness of Research and Development Related to Railroad Electrification in the United States. Federal Railroad Administration, U.S. Department of Transportation, Rept. FRA-ORD-77-62, Dec. 1977.
7. National Transportation Policies Through the Year 2000. National Transportation Policy Study Commission, Washington, DC, Final Rept., June 1979.
8. E.G. Schwarm. Engineering Cost Data Analysis for Railroad Electrification. Arthur D. Little, Inc., Cambridge, MA, Final Rept., Oct. 1976.
9. Intermodal Freight Program: Phase II--Demonstration Management. Federal Railroad Administration, U.S. Department of Transportation, Rept. FRA/ORD/69, July 1980.
10. R.K. White and others. Railroad Electrification in America's Future: An Assessment of Prospects and Impacts. SRI International, Menlo Park, CA, Center for Resource and Environmental System Studies Rept. 97, July 1979.
11. R.H. Shackson and H.J. Leach. Maintaining Automotive Mobility: Using Fuel Economy and Synthetic Fuels to Compete with OPEC Oil. Energy Productivity Center, Mellon Institute, Arlington, VA, Aug. 18, 1980.
12. G.A. Backus, J.R. Greene, and A. Masevice. FOSSIL79: Documentation. Resource Policy Center, Dartmouth College, Hanover, NH, Rept. DSD 166, Vol. 3, Aug. 1979.
13. R.E. Goodson and others. A Discussion Paper on Shale Oil and Coal Liquids and Their Use as Transportation Fuels. Automotive Transportation Center, Purdue Univ., West Lafayette, IN, Sept. 15, 1979.
14. J. Fraser and others. An Overview of Selected Alternatives for Reducing Transportation's Dependence on Imported Petroleum. Automotive Transportation Center, Purdue Univ., West Lafayette, IN, Rept. DOT-ATC-80-10, Nov. 12, 1980.
15. Monthly Energy Review. U.S. Department of Energy, Sept. 1980.
16. R.K. Whitford. Railroad Electrification: An Option for Petroleum Savings. Automotive Transportation Center, Purdue Univ., West Lafayette, IN, Aug. 1980.
17. J.E. Pastaret and R.A. Uher. Energy Savings of Regeneration on a Proposed Electrified Railroad between Harrisburg and Pittsburgh. Carnegie-Mellon Univ., Pittsburgh, PA, June 1977.

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Energy Considerations for Railroad Electrification in the United States

HAL B.H. COOPER, JR., AND CATHERINE A. WEBB

Minimum, medium, and maximum railroad electrification networks that consist of 10 000, 26 000, and 42 000 route miles, respectively, have been proposed for the nation. These systems are based on projected future levels of freight traffic, which will be sufficient to justify future railroad-electrification projects. Energy and environmental impacts plus an economic analysis are presented that relate to both costs and benefits of national railroad electrifica-

tion. The previous guidelines of break-even traffic densities of 20-40 million gross tons/year will be too high for basing future decisions regarding railroad electrification. Break-even freight-traffic densities to justify railroad electrification will be reduced to 10 million gross tons/year by 1990 because of the greater rate of increase of diesel oil prices as compared with that of electricity in the future. Synthetic fuels produced from coal will not be economically competitive with electricity produced from coal for railroad propulsion in this century. Net energy savings from railroad electrification will range from 75 to 168 trillion Btu/year by 2000. Petroleum savings from national railroad electrification will gradually increase from 22 to 193 million bbl/year between 1985 and 2000. Electricity consumption requirements for railroad electrification will range from 19 to 42 million kW·h/year by 2000; needed generating capacities will be 7916-17 701 MW or about 1 percent of the expected national total.

The United States is facing an increasingly serious problem of decreasing availability and increasing cost of energy supplies. The problem is particularly serious for petroleum; the United States imported as much as 8.0-8.5 million bbl/day during 1979. Oil imports have been reduced to between 6.5 and 7.0 million bbl/day during 1980 by the combined effects of extensive consumer conservation and by the nation's economic recession. The oil import level is expected to increase in the future in the absence of stringent conservation measures and alternative energy resource development (1).

The implications for national security of foreign oil importation will become increasingly apparent in the near future because of the possible change of the Soviet Union from a net petroleum exporter to a net petroleum importer. The Soviet Union will no longer be self-sufficient in oil production after 1983-1984, according to recent estimates by the U.S. Central Intelligence Agency, and by 1987-1988, according to its own estimates, as shown in Figure 1 (2,3). The petroleum needs of the Soviet Union create further pressures on world oil supplies and prices through economic (and perhaps noneconomic) means.

A temporary glut developed during 1980 because of purposeful overproduction by Saudi Arabia of 1.0-1.5 million bbl/day in an attempt to recover the Organization of Petroleum Exporting Countries (OPEC) price stability. However, the long-term policy of OPEC recommended by Saudi Arabia is to peg future oil price increases to a combination index based on the inflation rates of the consuming countries and the equivalent replacement costs of alternative energy sources (4). OPEC oil production is expected to peak by about 1990; future exports will become progressively reduced as internal demands for industrial expansion become greater, according to testimony by John M. Sullivan of the Federal Railroad Administration (FRA) to a U.S. Senate committee in September 1980.

The possibility that the oil supply will be disrupted will grow more serious in the future. This threat of disruption will occur at the same time that crude-oil prices are expected to increase rapidly. These estimates of future OPEC world crude-oil prices are shown in Figure 2; they indicate that oil prices are estimated to reach more than $100/bbl as early as 1990 and $300/bbl by 2000, according to trends projected by the Saudi Arabian Oil Ministry.

The result of the need to import foreign oil is a growing deficit in terms of the national balance of payments, as shown in Figure 3. The national balance-of-payments deficit is estimated to reach $80 million in 1980 and could grow to between $150 and $450 billion/year by 1990. This growing drain on the national balance-of-payments deficit from oil importation aggravates the nation's increasingly serious inflation and unemployment problems by capital exportation outside the country to transfer economic sovereignty to foreign nations.

The United States has a serious imbalance between domestic energy demand and supply. This imbalance is nowhere greater than in the transportation sector, which now uses nearly half of the nation's total petroleum. More than 95 percent of the transportation sector's energy is supplied by petroleum, whereas conventional petroleum constitutes less than 1 percent of the nation's total energy reserves.

In contrast, coal supplies only 0.1 percent of the total national transportation energy requirement but constitutes more than 90 percent of the nation's total energy reserves. The only sector in which energy supply and demand even begin to coincide is in the area of electric-generating capacity, of which approximately 55 percent is now being supplied by coal. Transportation electrification will allow such alternative energy sources to be used as coal and nuclear, geothermal, and solar power in place of petroleum.

Railroads are perhaps the most immediate candidates for transportation electrification. Railroads are now more than 99 percent dependent on petroleum as their energy source; the main exception is the Northeast Corridor. Railroad electrification is applicable to both freight and passenger movement and is both technically and commercially feasible at the present time. The rapid recent increases in the price of railroad diesel fuel (Figure 4) will force increasing consideration to be given to use of alternative fuel through electrification.

The cost of diesel fuel is expected to increase in absolute terms relative to the cost of electricity, as shown in Figure 5. The result is that the economics of operating-cost savings will increasingly favor railroad electrification in the future as compared with continued diesel locomotive operation. These economic trends will continue in spite of the significant capital cost associated with construction of electrified railroad operation. These data also show that synthetic fuels derived from coal are not expected to be competitive with electricity for railroad propulsion in this century.

NETWORKS

There are now approximately 1100 route miles of electrified main-line railroad in the United States, largely confined to the Northeast Corridor, as shown in Figure 6. There are some additional electrified commuter lines in the Chicago area plus four electrified coal-hauling lines from mines to power plants--one in Ohio, one in Arizona, and two in Texas. Two additional electrified coal-hauling lines are being planned for Texas and Utah, respectively. Four main-line railroad electrification lines are also being proposed or planned as shown in Table 1.

Route Selection

Three candidate networks for railroad electrification have been proposed for the nation based on differing criteria for route selection, as shown below:

Network	Route Distance (mile 000s)	Density (10^6 gross tons/year)	Year
Minimum	10	40	1980
Medium	26	30	1985
Maximum	42	30	1990

The minimum-sized network of 10 000 route miles is essentially designed to serve those routes that already meet the minimum criteria of freight traffic densities of 40 million gross tons/year or more. These data are based on 1974 traffic data.

The medium network of 26 000 route miles is based on those lines that already have the needed traffic density plus those for which freight traffic is expected to exceed 30 million gross tons/year by 1985. The maximum network of 42 000 route miles is expected to serve routes on which the freight traffic density is expected to exceed 30 million gross tons/year by 1990 plus those lines that had already met this criterion. The national networks were selected from testimony by Sullivan (5) and from a

Figure 1. Estimated petroleum production and consumption trends in Soviet Union, 1975-1990.

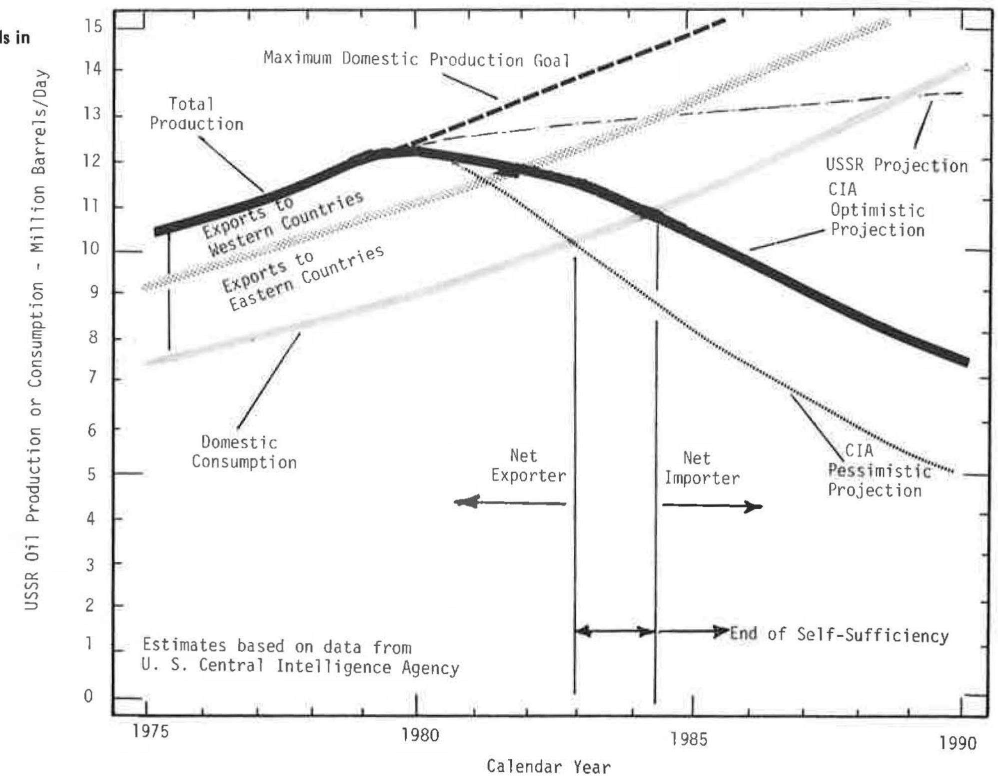
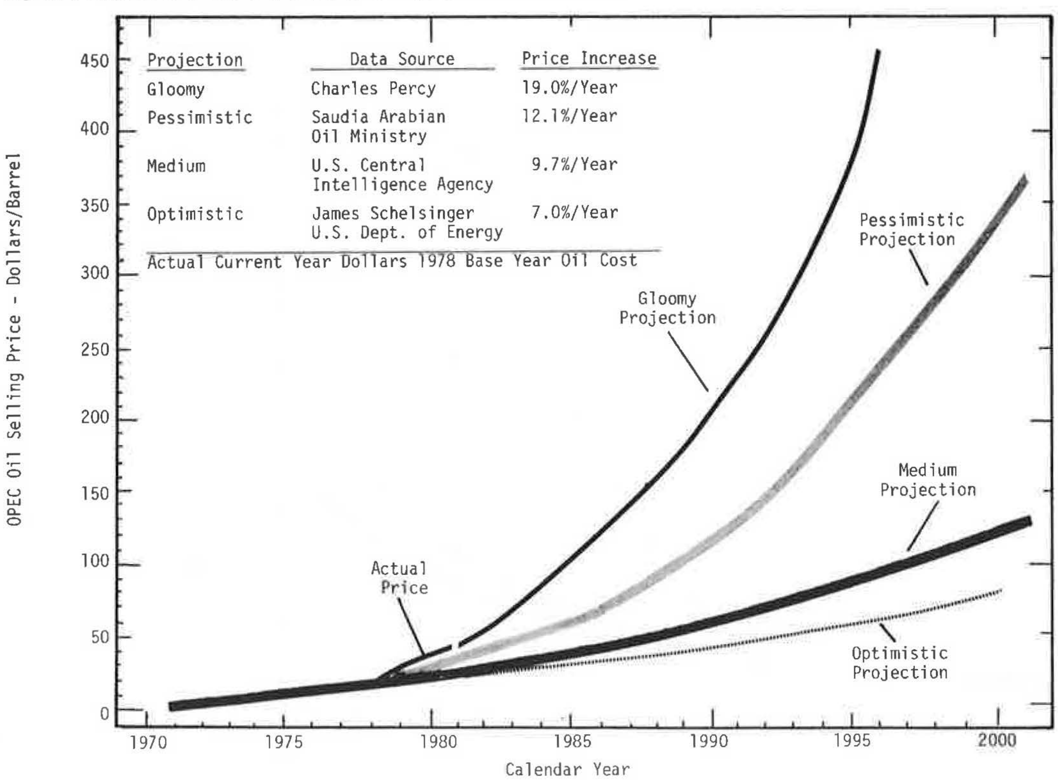


Figure 2. Projected increases in average price of imported oil from OPEC.



previous report by Buck and others (6).

The minimum network for the nation is based on those most heavily traveled lines whose traffic densities already exceed 40 million gross tons/year based on 1974 traffic data (7). These lines include some of the major East-West transcontinental lines plus the proposed electrified Southern Railway--Louisville and Nashville line, the Norfolk and Western main line from Norfolk to Columbus, and the two Consolidated Rail Corporation (Conrail) East-West main lines plus the Northeast Corridor (Figure 7).

The medium network is based on those lines that already meet the present minimum traffic density level plus those lines that are expected to meet this minimum density because of projected increases

Figure 3. Projected increases in national balance-of-payments deficit from petroleum importation, 1960-2000.

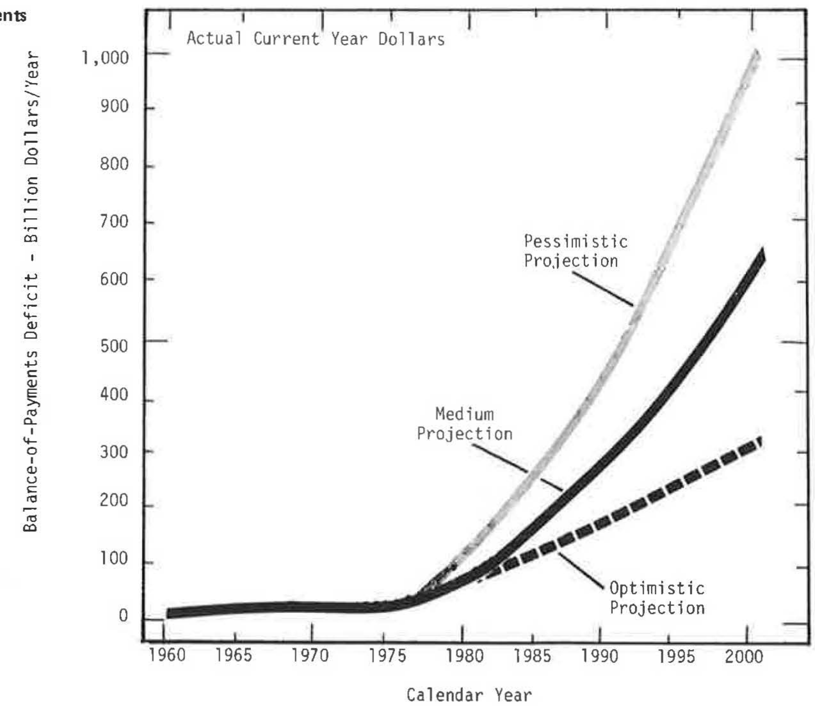


Figure 4. Projected increases in average price of railroad diesel locomotive fuel, 1956-2000.

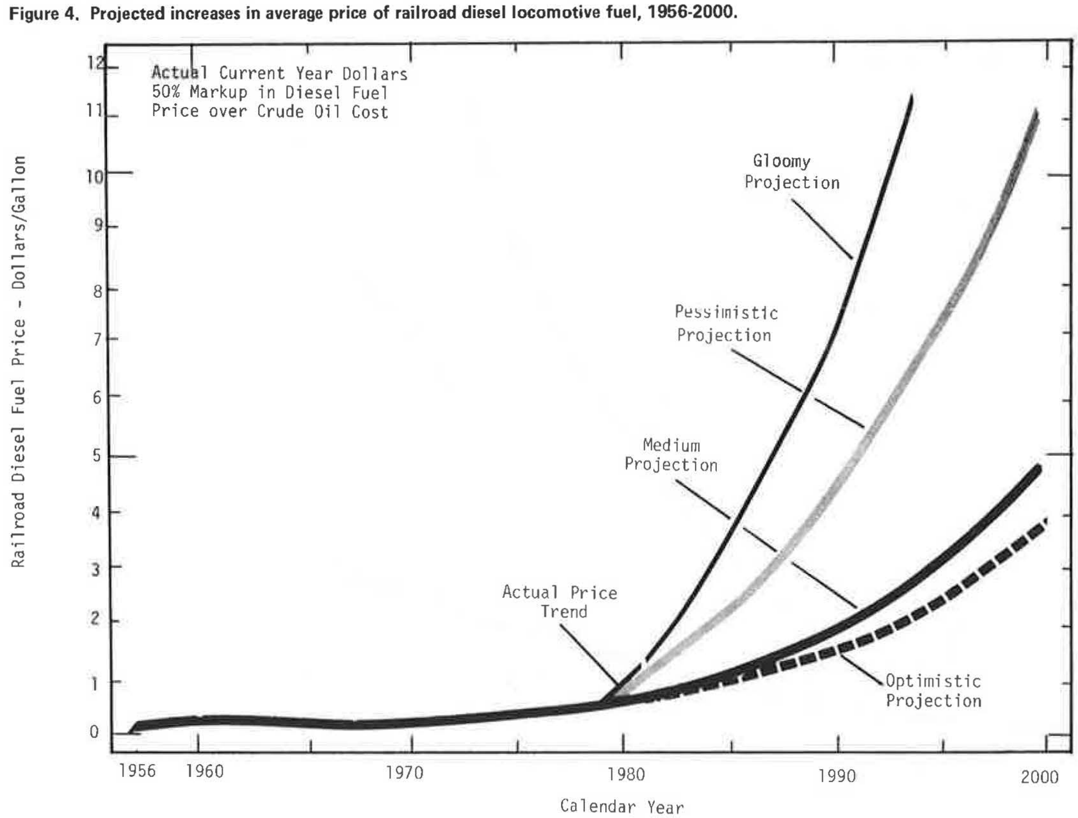


Figure 5. Estimates of projected OPEC oil, synthetic fuel, and electricity prices as railroad locomotive fuels.

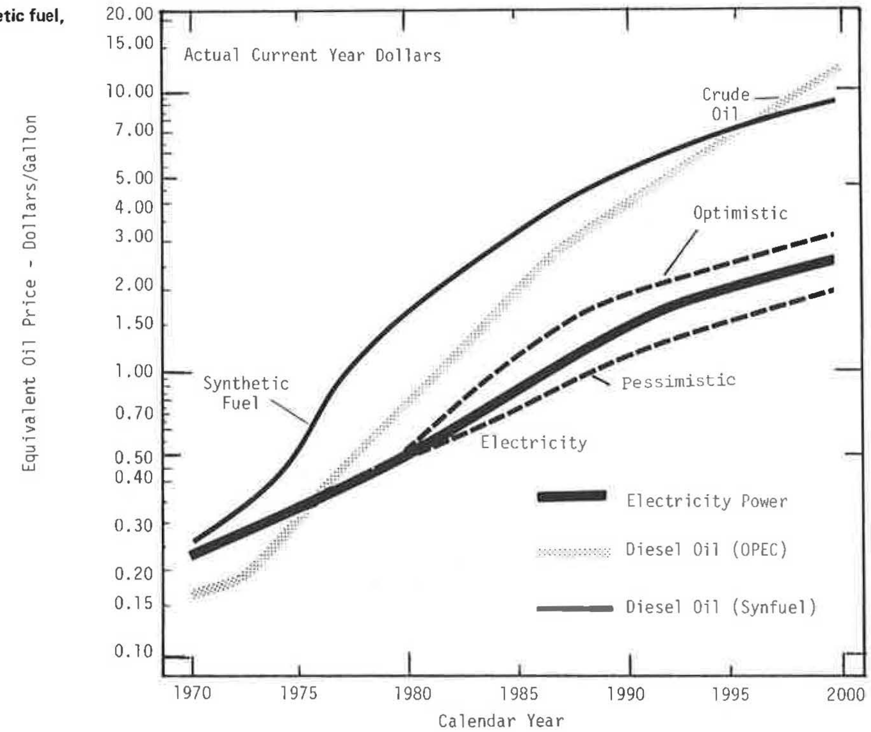


Figure 6. Present locations of railroad electrification in United States.

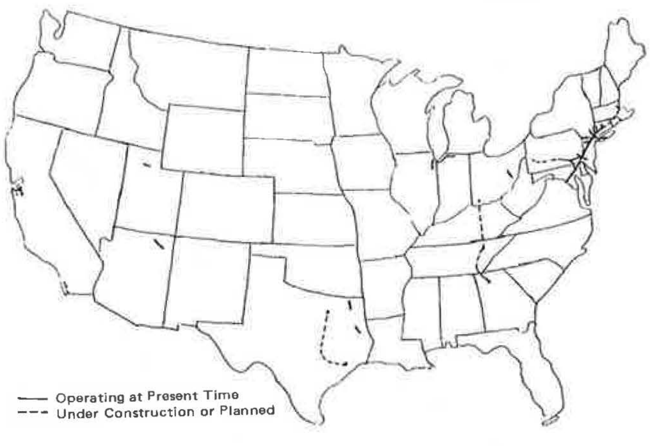


Figure 7. Proposed minimum national railroad electrification network (10 000 route miles).

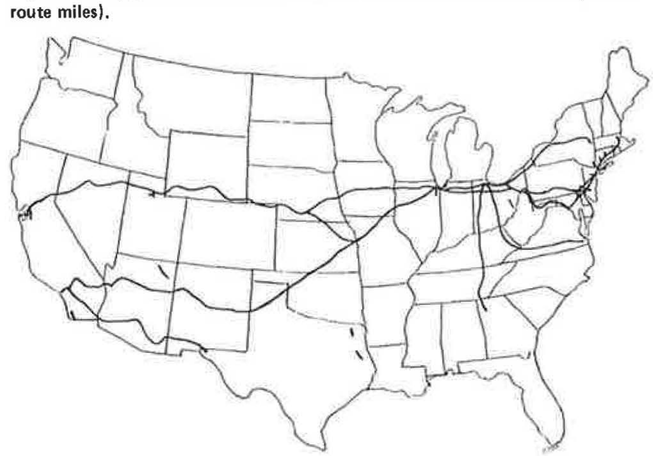


Table 1. Planned or proposed main-line railroad electrification projects.

Railroad	Origin	Destination	Distance (miles)	Density (10^6 gross tons/year)
Amtrak	New Haven, CT	Boston, MA	162	-[a]
Conrail	Harrisburg, PA	Pittsburgh, PA	325	100
Missouri-Kansas-Texas (Katy)	Fort Worth, TX	Houston, TX	323	30
Southern	Cincinnati, OH	Atlanta, GA	478	75

[a] Passenger line.

in freight traffic. The medium national network proposed is 26 000 route miles (Figure 8). The network includes the 10 000 route miles from the minimum network that have densities of 40 million gross tons or more plus those lines that already do exceed or will exceed freight traffic density levels of 30 million gross tons/year by 1985. The result is that a number of transcontinental and North-South connecting lines in the Midwest and East are added to the system. This system is basically the same as that proposed by the U.S. Department of Transportation in October 1980 (5).

The maximum network is based on those lines that are expected to meet the minimum traffic criterion of 30 million gross tons/year by 1990 in addition to those lines that already meet it. The maximum network at the national level is 42 000 route miles in length (Figure 9). This network is based on previous studies by Buck and others (6), in which lines that had freight traffic densities of 20 million gross tons/year or more in 1974 are considered candidate lines for electrification by 1990.

Traffic Growth

Freight traffic growth rate is a major factor in determining the future economic viability of railroad electrification projects. Rail freight traffic in the United States has grown at rates between 2.5 and 4.7 percent per year, although this value varied considerably by region of the country. Trends in total and rail freight traffic levels are presented in Figure 10 based on data from Oak Ridge National Laboratory shown in Table 2 (8). If an average intermediate growth rate of 3.5 percent per year is assumed, the expected future freight levels for the minimum, medium, and maximum networks will reach 1.5-3.3 trillion gross ton miles in 2000.

These results assume that the relative proportions of total freight traffic remain essentially constant with time. Of the total rail freight traffic, the 10 000-mile network carries about 30 percent, the 26 000-mile network carries about 55 percent, and the 42 000-mile network carries about 67 percent. The base freight traffic level is assumed to be 925 million net ton miles in 1980. Projected freight traffic densities for the alternative national railroad electrification networks are presented in Figure 11.

Figure 8. Proposed medium national railroad electrification network (26 000 route miles).

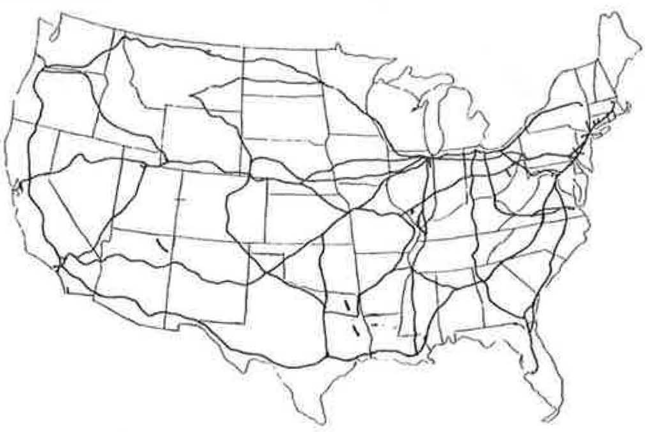


Figure 9. Proposed maximum national railroad electrification network (42 000 route miles).

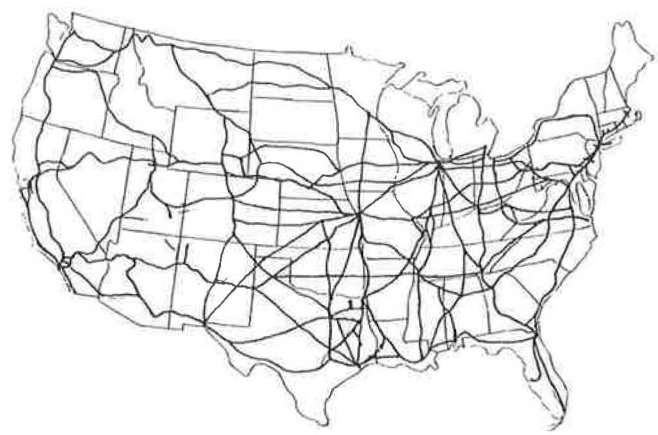


Figure 10. Trends in intercity railroad and total freight movement in United States, 1925-2000.

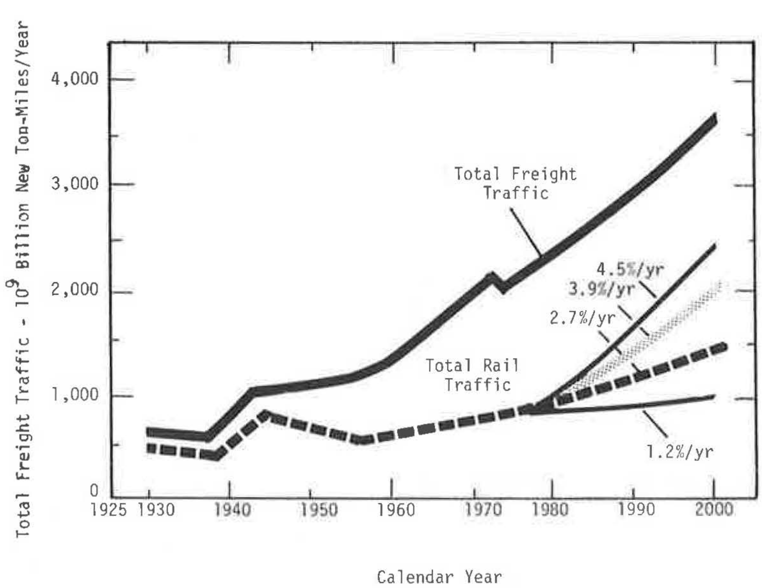


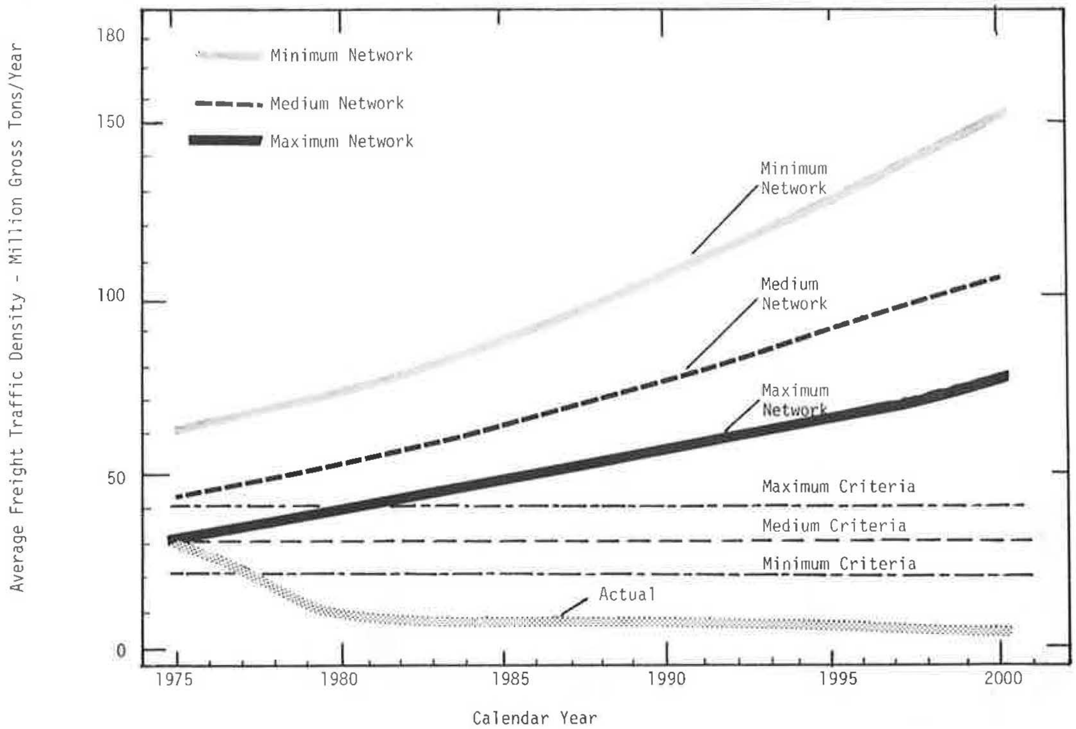
Table 2. Projected trends in freight traffic movement in United States: 1975-2000.

	Freight Traffic Level (10^9 net ton miles/year)		
Transportation Mode	1975	1985	2000
Railroad	759	900	1500
Truck	454	630	1050
Aircraft	4	6	8
Waterway	334	457	626
Pipeline	506	564	531
Total	2057	2557	3715

ENERGY

The major benefit of electrified railroad operation is the fact that alternative fuels can be substituted for petroleum as a transportation energy source. There is no major net energy benefit from electrified railroad operation as compared with diesel railroad operation, although some savings can occur from reduced refining requirements. Potential diesel-fuel shortages could be minimized by the implementation of railroad electrification in the future.

Figure 11. Projected increases in freight traffic density for the alternative candidate national railroad electrification networks.



Net Energy Consumption

The comparative direct energy requirements for alternative freight transportation modes in shipping coal are shown in Table 3. The direct energy consumption of diesel-powered and electric-powered railroads is about 300 Btu/gross ton mile. Coal transport and processing adds 3-8 percent to the direct energy use for electrified railroad operation, depending on haul distance and coal heating value. Based on 1978 data from the American Petroleum Institute, the indirect energy consumption for oil refining is 8-15 percent of the heating value of the inlet crude oil plus 1-3 percent for production and transport. The comparative energy impacts for alternative national railroad electrification networks compared with those for continued diesel locomotive operation in 2000 are given in Figure 12.

Net energy savings from railroad electrification range between 30 and 50 Btu/gross ton mile. In 1990, net energy savings would range between 32 and 119 trillion Btu/year for the respective minimum and maximum networks. In 2000, the net energy savings would range from 45 to 168 trillion Btu/year for the three national railroad electrification networks.

Table 3. Unit direct energy and petroleum consumption requirements of alternative transportation modes for coal shipment.

Transportation Mode	Energy Consumption[a] (Btu/NTM)	Petroleum Consumption[b] (bbl/10^6 NTM)
Diesel railroad	450-690	80-122
Electric railroad	500-700	0
One-way slurry pipeline	450-500	0
Two-way slurry pipeline	1050-1200	0
Barge	500-1100	88-194
Truck	1400-2400	256-440

[a]Measured in Btu per net ton miles moved (NTM).
[b]Based on a heating value of 5 670 000 Btu/bbl of diesel oil.

Petroleum Savings

Total direct petroleum consumption for electrified railroad operation would be zero if alternative sources such as coal are available. Projections of future petroleum savings for the nation as a whole for the three candidate railroad electrification networks are presented in Figure 13. These petroleum savings would range from 52 to 115 million bbl/year between the three networks in 1985. The projected petroleum savings would increase to 61-137 million bbl/year by 1990 and to 86-193 million bbl/year by 2000.

The most likely future projection of potential petroleum savings is based on construction of the network over a 20-year period in which 5000 route miles would be finished by 1985, 10 000 route miles by 1990, 26 000 route miles by 1995, and 42 000 route miles by 2000. This program of construction would result in potential petroleum savings of 26 million bbl/year by 1985, 61 million bbl/year by 1990, 134 million bbl/year by 1995, and 193 million bbl/year by 2000. Actual petroleum savings would be somewhat less than these values because a portion of the nation's electricity is supplied by burning fuel oil on the West and East Coasts. This contribution of oil to electricity generation will decrease in the future because of the Power Plant and Industrial Fuel Use Act (P.L. 95-620, July 18, 1978).

Coal Consumption

Coal will be the primary fuel used to provide the energy to propel electrified railroads in the future. Coal provided about 42 percent of the nation's electricity in 1975, which, it is estimated, will increase to 47-50 percent by 1985 and to as much as 60-65 percent by 2000. The coal burned across the country will be about equally split between Western subbituminous and Eastern bituminous coal, whereas low-grade lignite coal is the major fuel burned in Texas. Prediction of the maximum en-

Figure 12. Comparative energy impacts for alternative national railroad electrification networks compared with continued diesel locomotive operation in 2000.

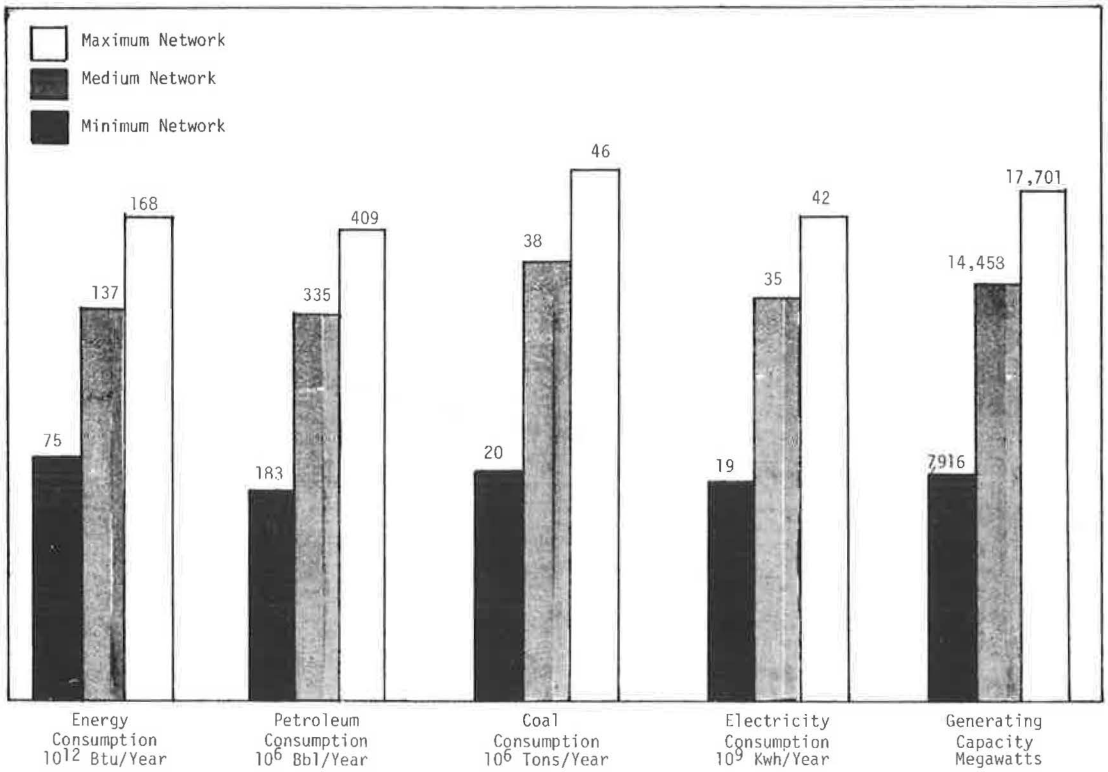
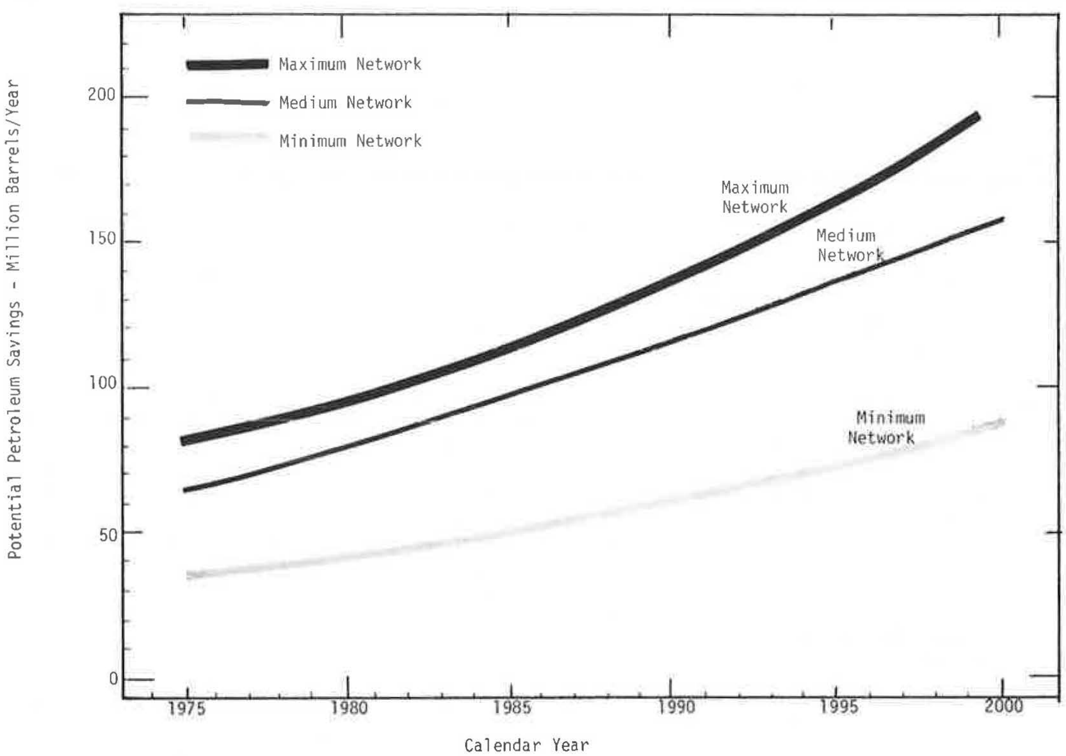


Figure 13. Projected petroleum savings by conversion from diesel to electric locomotives for railroad freight movement in United States.



vironmental impacts will justify the assumption of complete coal use to power electrified railroads.

Projected coal consumption for national railroad electrification for the different networks is presented in Table 4. The most probable values for coal consumption per year to power electrified railroad operation are 6 million tons in 1985, 15 million tons in 1990, 32 million tons in 1995, and 46 million tons in 2000. These values of increased coal combustion represent 1-2 percent of the national total coal production for these years. In actuality, coal consumption will probably not exceed 30-35 million tons/year to power electrified railroads because an estimated maximum of 70 percent of the nation's electricity will be supplied by coal.

The impacts of railroad electrification on the national electricity grid system can be expressed in terms of both electricity consumption and generating capacity. Electricity consumption requirements for the national network are shown in Table 5. The most probable electricity consumption rate per year for railroad electrification will increase from 5 billion kW•h in 1985 to 39 billion kW•h in 1995 to 42 billion kW•h in 2000. These levels of electricity consumption for railroad electrification represent a maximum of 1-2 percent of the total national use. This electricity consumption does represent the potential for substantial increase in utility revenues that result from railroad electrification.

There will be a need for additional electric generating capacity to supply intercity railroad electrification, as shown in Table 6. These values represent the maximum requirements for additional generating capacity because they assume no integration of the existing system. The estimated generating capacity needs will increase from 1000 MW in 1985 to 2350 MW in 1990 to 5100 MW in 1995 to 7500 MW in 2000. These values of increased generating capacity represent a maximum increase of 1-2 percent in the present and future national totals.

Table 4. Projected increases in coal consumption for supplying national railroad electrification: 1975-2000.

	Total Network Coal Consumption (10^6 tons/year)			
Year	Minimum	Medium	Maximum	National
1975	9	16	19	650
1980	10	19	23	800
1985	12	22	27	1020
1990	15	27	32	1450
1995	17	32	39	1730
2000	20	38	46	2220

Table 5. Projected increases in electricity consumption for candidate national railroad electrification networks.

	Network Electricity Consumption (10^9 kW·h/year)		
Year	Minimum	Medium	Maximum
1975	7.9	14.4	17.6
1980	9.4	17.2	20.9
1985	11.2	20.5	24.9
1990	13.3	24.4	29.7
1995	15.9	29.1	35.4
2000	18.8	34.4	41.9

Table 6. Projected maximum increases in electric generating capacity requirements for national railroad electrification.

	Network Electric Generating Capacity (MW)		
Year	Minimum	Medium	Maximum
1975	3328	6 036	7 455
1980	3956	7 270	8 874
1985	4725	8 621	10 311
1990	5618	10 253	12 546
1995	6703	12 257	14 982
2000	7916	14 458	17 701

CONCLUSIONS

Three railroad electrification networks of 10 000, 26 000, and 42 000 route miles have been proposed for the nation. Projected freight densities of these lines are expected to be well above the minimum levels required by 1990. Electrification would be expected to reduce net energy consumption by approximately 4 percent as compared with hauling the equivalent freight traffic by diesel locomotive. These savings would result largely from the reductions of 75-168 trillion Btu/year in the need for processing oil at the refineries by 2000 and constitute 0.1-0.3 percent of the national total.

Potential petroleum savings from the proposed national railroad electrification networks are expected to increase from 22 million bbl/year in 1985 to 61 million bbl/year by 1990. After 1990, petroleum savings are expected to increase to 134 million bbl/year in 1985 and 193 million bbl/year in 2000. Actual petroleum savings will probably be between 65 and 70 percent of these values. Petroleum savings from railroad electrification make up 1-6 percent of the present national import levels.

Coal consumption to provide power for railroad electrification is expected to range from 20 to 46 million tons/year by 2000. This coal-use level makes up 2-6 percent of the 1980 national total coal consumption rate of about 800 million tons. The year-2000 levels of coal consumption for railroad electrification are expected to constitute 1-3 percent of the national total of about 2 billion tons/year.

Increased electricity consumption for railroad electrification will reach 19-42 billion kW•h/year by 2000, or 1-2 percent of the present national total. Increased electricity generating capacity requirements for railroad electrification will constitute 1-3 percent of the present national total, or less than 2 percent of the year-2000 total. This level of electricity consumption can be readily served from the present national utility grid system.

ACKNOWLEDGMENT

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REFERENCES

1. U.S. Oil Appetite: 5 Years of Failure. Los Angeles Times, Part 1, Sunday, June 24, 1980, pp. 1, 12-16.
2. H.E. Meyer. Why We Should Worry About the Soviet Energy Crunch. Fortune, Vol. 101, No. 4, Feb. 25, 1980, pp. 82-88.
3. D. Wolfberg. A Soviet View of Energy. Wall Street Journal, Friday, March 6, 1981, p. 14.
4. OPEC's Intended Strategy; Report of the Ministerial Committee on Long-Term Strategy: Read It and Weep. Forbes, Vol. 127, No. 2, Jan. 19, 1981, pp. 32-34.
5. Electrification Talk Is Getting More Serious. Railway Age, Vol. 181, No. 24, Nov. 24, 1980, pp. 26-28.
6. R.J. Buck, H.B.H. Cooper, P. Elliott, J.N. Martin, and A. Purcell. A Report of U.S. Railroad Electrification. Unified Industries, Inc., Springfield, VA; Federal Railroad Administration, Rept. FRA/ORD-77-67, Oct. 1977.
7. Transportation Zone Maps. U.S. Government Printing Office, 1975.
8. D.B. Shonka, A.S. Loebl, and P.D. Patterson. Transportation Energy Conservation Data Book, 2d ed. Energy Division, Oak Ridge National Laboratory, Oak Ridge, TN, Rept. ORNL-5320, Oct. 1977.

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