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Energy and Environmental Factors In Railroad Electrification

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SEPTEMBER 1975

MITRAE

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FOREWORD

The railroads' role in meeting the nation's demand for transportation services has become a significant public issue because of the current problems and posture of the railroad industry and national concerns in the areas of energy and environmental management. Electrification has a major potential role in the modernization of the rail system in conjunction with petroleum savings and the control of environmental pollution.

This report presents an introduction to railroad electrification with emphasis on energy and environmental aspects. It discusses the nation's energy goals and the position of railroads and transportation in the national energy picture. It presents general estimates on petroleum savings that can be accomplished by railroad electrification and by modal shifts to electrified railroads. Because the use of coal as an energy source is critical in solving the national energy problems, background information on the production and transportation of coal is presented. The environmental aspects of transportation by electrified railroads are also discussed. The report concludes with a discussion of the status of electrified railroads in the U.S.

The information in this report is general in nature and is intended to serve as a mechanism for instituting further discussion and study in the area of railroad electrification.

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INTRODUCTION.

Railroad electrification recently has received attention from both industry and government [1]. For the railroads, any decision to electrify trackage will depend on economic considerations. National interest in other critical areas, however, may give additional impetus to railroad electrification. This presentation concentrates on the impact of railroad electrification on two such areas--energy and the environment--with emphasis on its potential role of alleviating the nation's energy problems.

- Impa

Railroad Electrification

Impact on Energy and Environment -

Today's diesel-electric locomotives use diesel engines to drive on-board generators that supply electrical power to the traction motors. Railroad electrification allows railroad operations to utilize electrical power from stationary power plants in all-electric locomotives. It consists primarily of adding overhead distribution wires (the catenary), with substations to tie into the commercial power grid, and acquiring the all-electric locomotive fleet.

The shift from mobile power to stationary power allows a shift in fuel from oil to coal (or other heat sources). The noxious products of combustion are also shifted from the wayside to the generating site.

COMPONENTS IN ELECTRIFIED RAIL SYSTEMS

POWER GENERATION

ENERGY SOURCE

COAL
URANIUM
PETROLEUM
GAS
HYDRO
GEOTHERMAL

BY-PRODUCTS

NOXIOUS GASSES
PARTICULATES
HEAT
SOLIDS

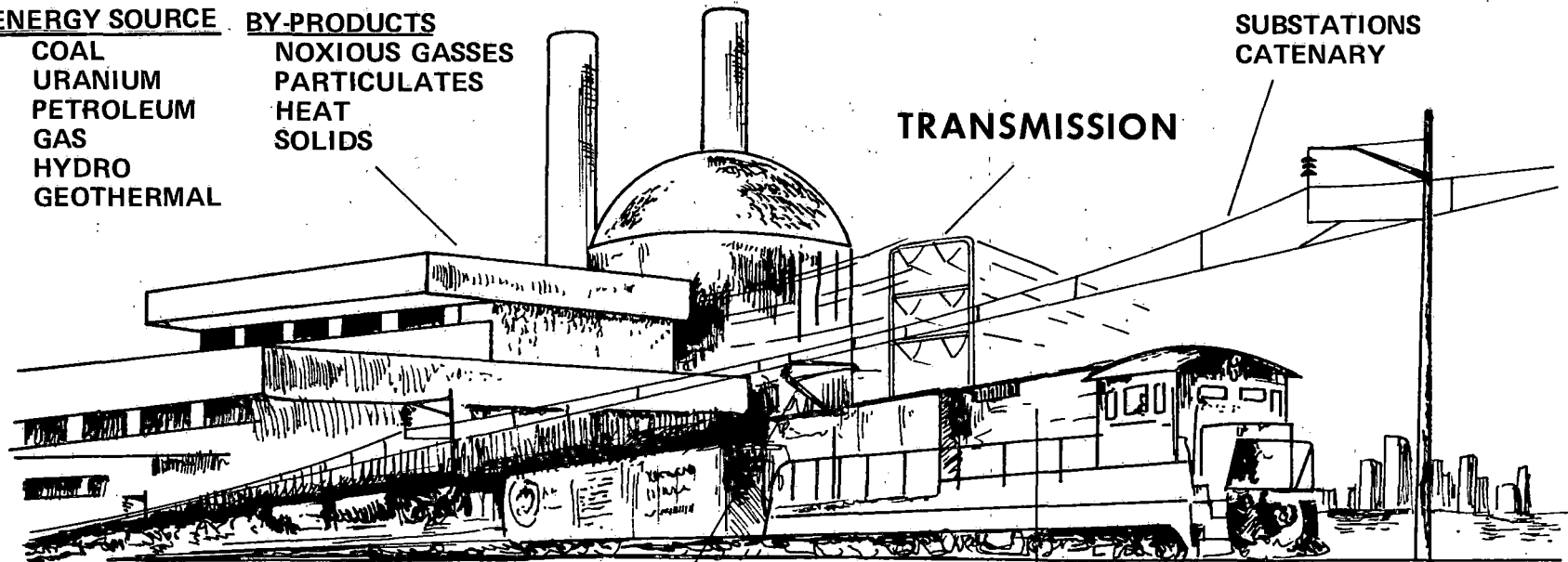
DISTRIBUTION

SUBSTATIONS
CATENARY

TRANSMISSION

MOTIVE POWER

PANTOGRAPH
DRIVE MOTORS
POWER CONVERSION AND CONTROL



The non-economic aspects of electrification have also received recent attention. They are summarized in a statement by Peter K. Høglund, vice president of General Motors and general manager of their Electro Motive Division.

"Electrification is getting a new look because of concern in two important areas, energy availability and ecology Obviously, a wide choice of fuels is one of the principal advantages in any electrification proposal, especially in light of the uncertainty prevailing today in both price and supply of petroleum products. Coal and nuclear sources of energy offer appealing alternatives From the ecology standpoint, the electric has no emission problems, these problems having been transferred to the central generating station supplying its electrical energy, and the electric locomotive ostensibly can make a contribution in reduced noise pollution because of the absence of the individual diesel engine as a prime mover" [2]

**IN ADDITION TO CERTAIN ECONOMIC ADVANTAGES, RAILROAD
ELECTRIFICATION OFFERS OTHER POTENTIAL ATTRACTIONS —**

- **SHIFT OF FUEL FROM PETROLEUM**
- **ELIMINATION OF WAYSIDE EMISSIONS**
- **LOWER NOISE**

ENERGY BACKGROUND

The nation's energy problems are well known. The Federal Energy Administration (FEA) Project Independence Report [3] evaluated the nation's energy problem and contrasted broad strategic options available to the U. S., including conserving and managing energy supply. The President's State of the Union address [4] presented goals in terms of reducing oil imports and ending vulnerability to economic disruption by foreign suppliers. The Energy Research and Development Administration National Plan for Energy RD&D [5] detailed the need to research, develop and implement new energy technologies.

The railroads, and particularly railroad electrification, can play an important role in accomplishing U. S. energy goals.

THE FEDERAL ENERGY GOALS ARE

- **REDUCED GROWTH RATE OF ENERGY CONSUMPTION**
- **REDUCED DEPENDENCE ON PETROLEUM**
- **INCREASED RELIANCE ON COAL AND NUCLEAR POWER**

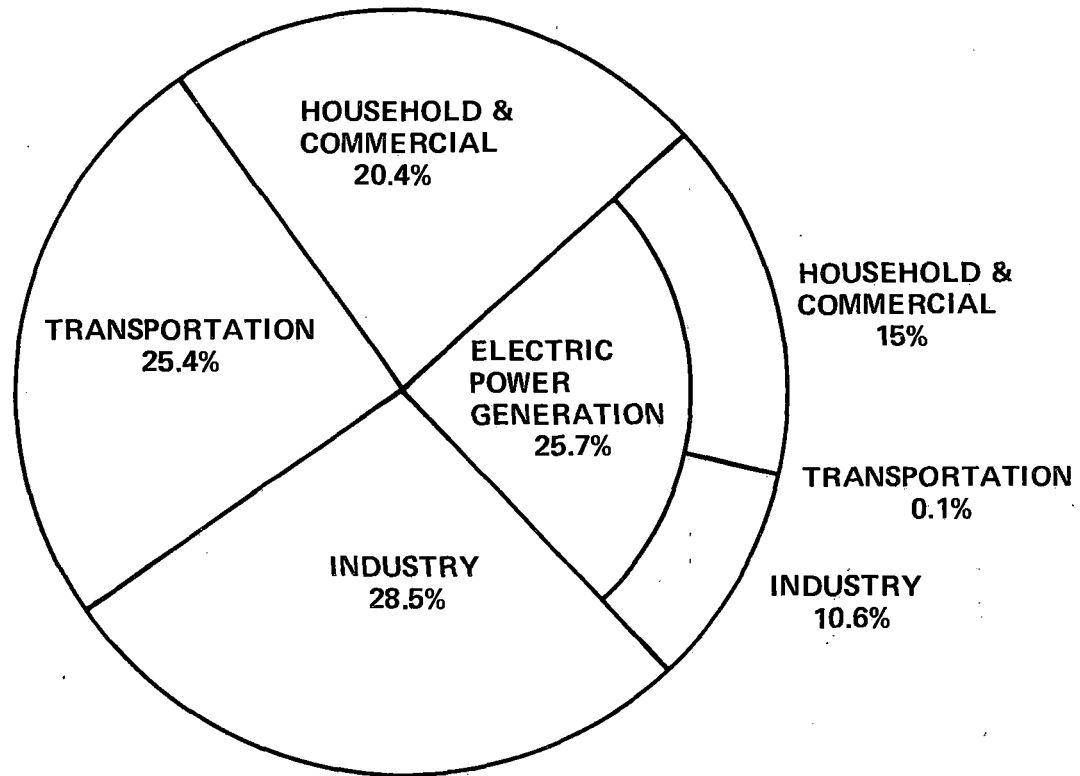
IN TERMS OF THE NATION'S RAILROADS, THE POSSIBLE IMPLICATIONS ARE

- **ELECTRIFICATION**
- **INCREASED COAL HAULAGE**
- **DIVERSION OF FREIGHT FROM TRUCKS TO TRAINS**
- **DIVERSION OF PASSENGERS FROM AUTO AND PLANES TO TRAINS**

The estimated* total U. S. Energy Consumption (1972)
- was 72.1×10^{15} Btu, the equivalent of 34×10^6 Bbl/day
of oil, roughly evenly divided among transportation, direct
household and commercial use, direct industrial use, and
electric power generation. [6]

*The nature of the estimates of energy consumption from
various sources leads to minor inconsistencies in reported
data.

U.S. TOTAL ENERGY BUDGET, 1972



Data Source: FEA [6]

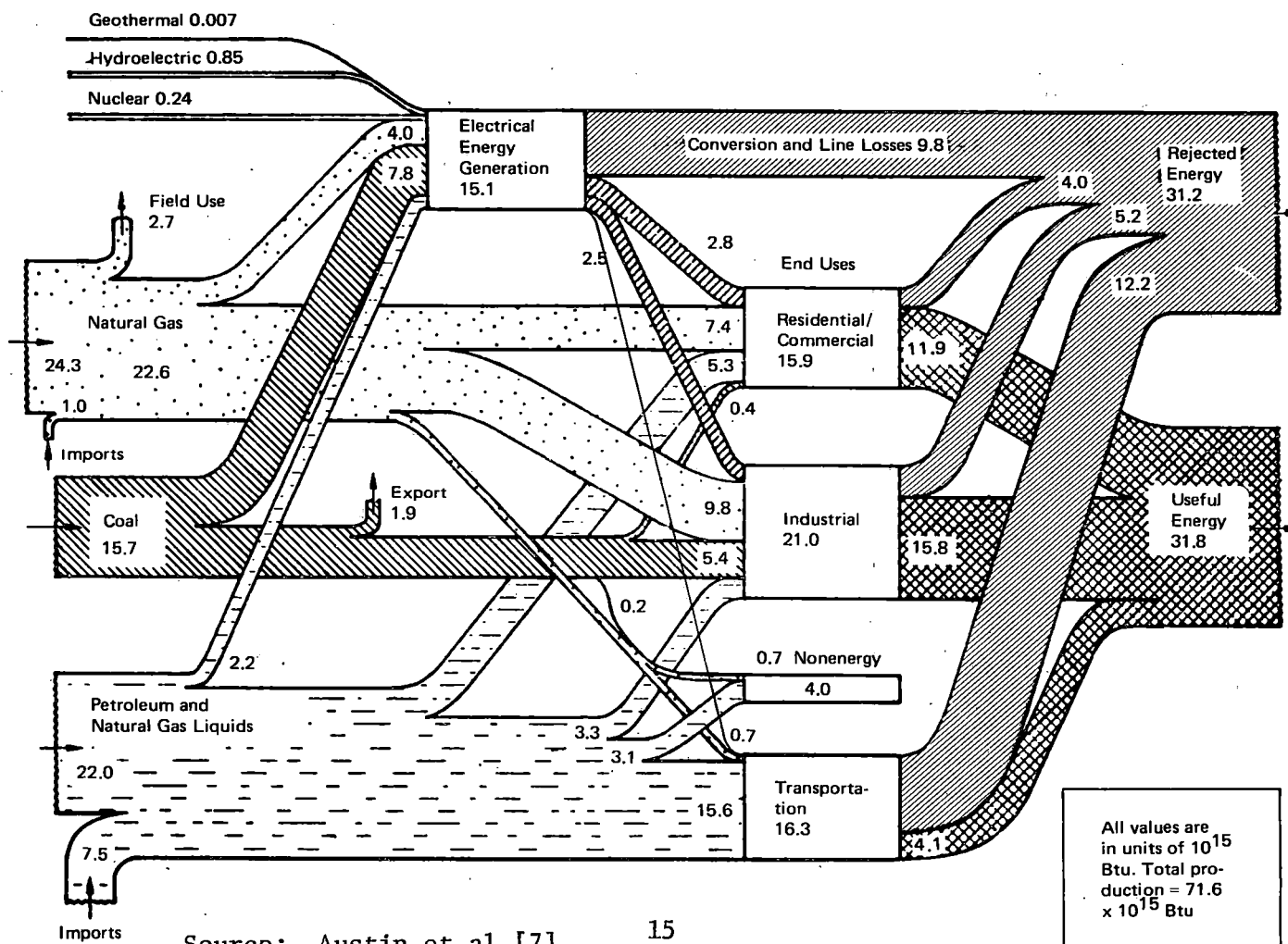
Energy consumption in the U. S. has grown and our energy sources and uses have changed appreciably through the years. This chart, based on 1970 estimates [7], shows the present heavy reliance on petroleum and natural gas.

Petroleum makes up 40% of our energy needs, and imported petroleum in the pre-embargo period is equal to one-third of U. S. production, or 10% of our total energy consumption.

Transportation consumes 52% of our petroleum. Transportation use of electricity is so small it was not included on the original of this figure.

In electrical energy generation, 93% of the energy input comes from fossil fuels. Of the fossil fuels consumed, coal supplied over half the energy. Oil increased its share rapidly from 10% to 20%, at the expense of coal, in the period 1965 to 1974. Also, by 1974 nuclear power had grown to almost 5% of the total capacity. There are also wide differences among U. S. geographical regions in the primary energy source for producing electricity. For example, the East Central regions depend heavily on coal; the West South Central region depends mostly on natural gas, the Pacific region on hydroelectric power, and New England on oil [3].

U.S. ENERGY FLOW PATTERNS - 1970

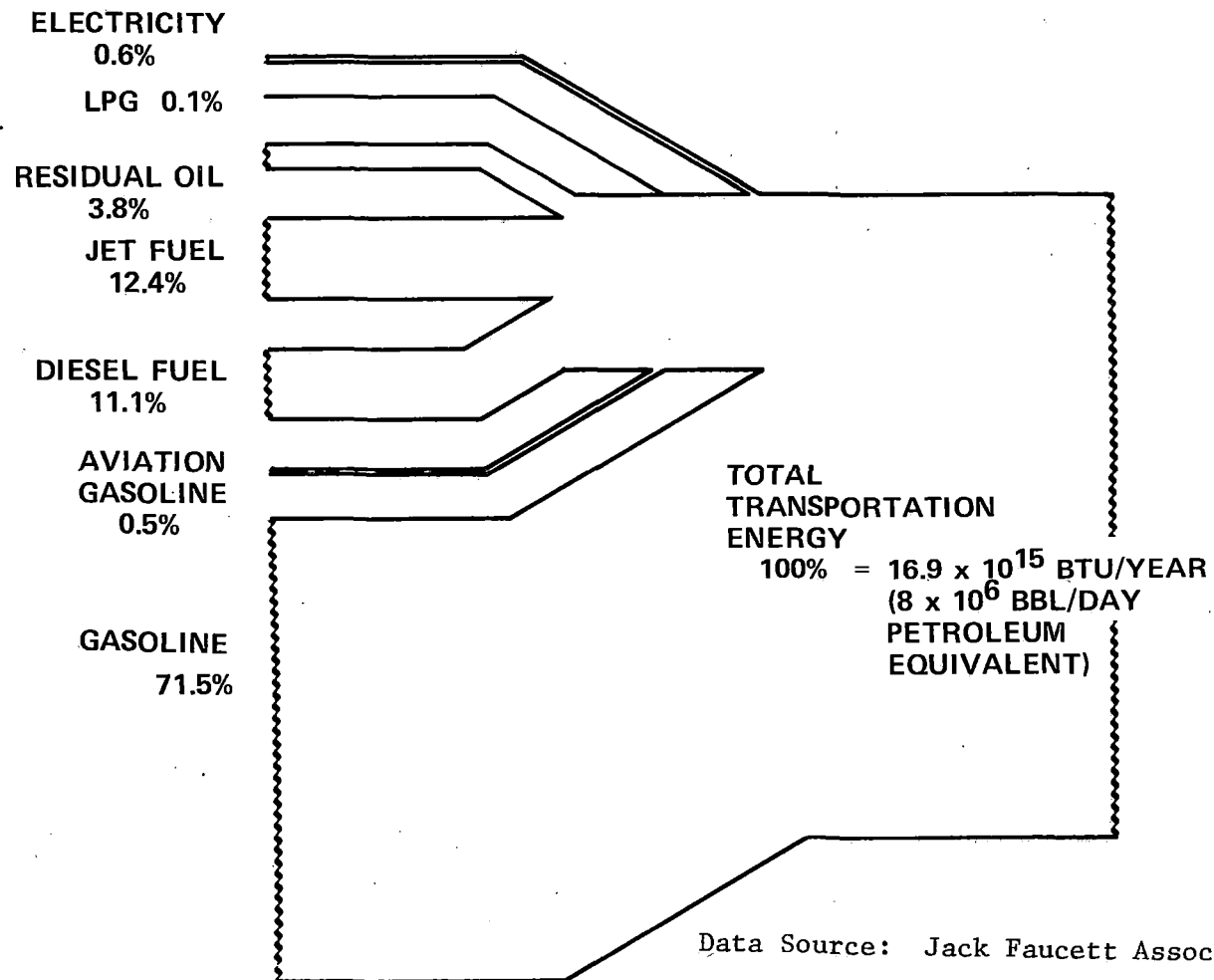


Source: Austin et al [7]

All values are in units of 10¹⁵ Btu. Total production = 71.6 x 10¹⁵ Btu

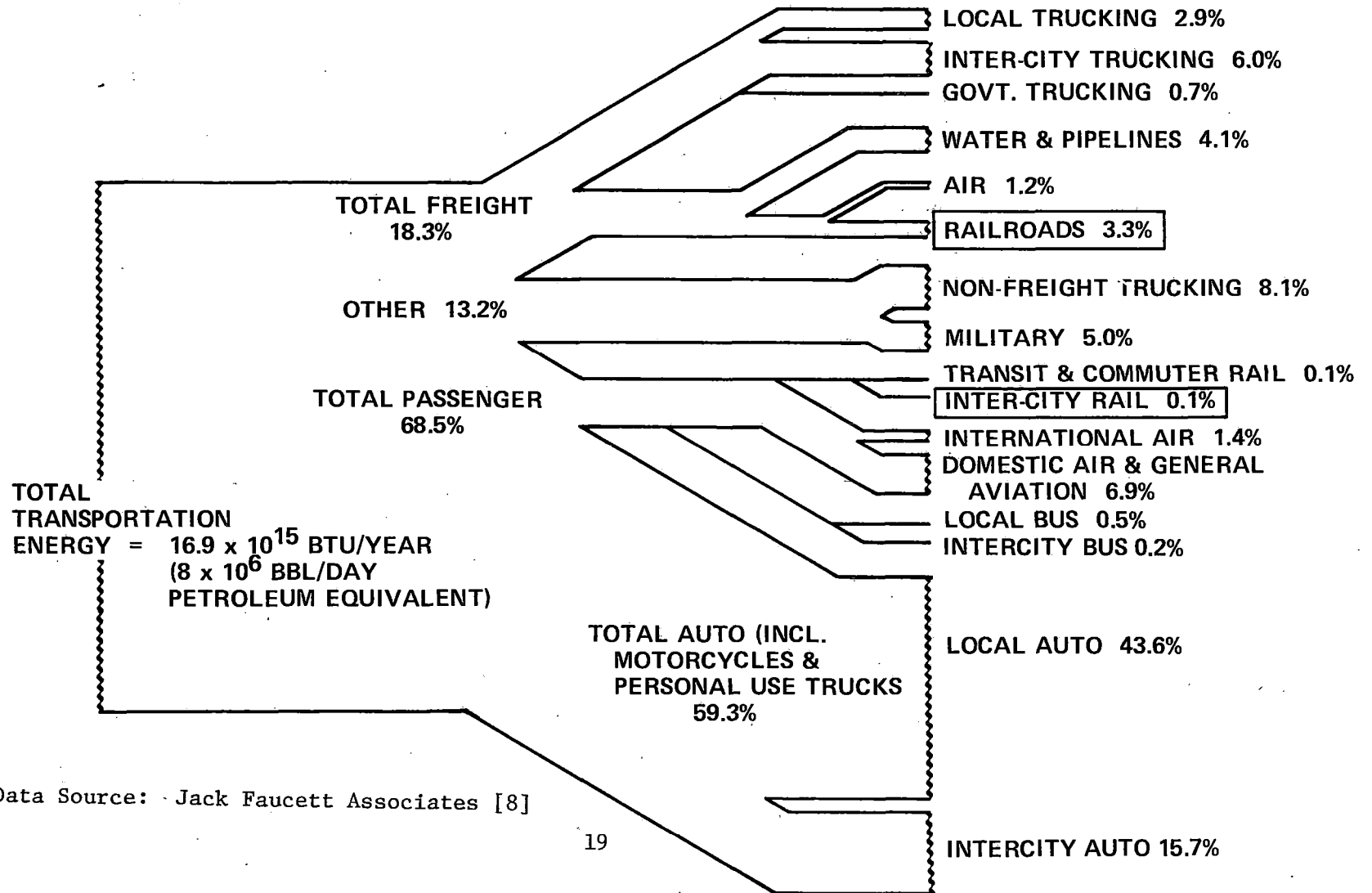
The convenience of using liquid fuels causes U. S. transportation energy to be almost totally petroleum derived. In this estimate the total annual U. S. transportation energy budget is 16.9×10^{15} Btu, (the equivalent of 8 million barrels of petroleum per day) with 99.4% coming directly from petroleum.

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



Automobiles are the overwhelmingly predominate users of transportation energy. This estimate, based on the same source as the previous figure, shows railroads using about 3.5% of the transportation energy, or the equivalent of 280,000 barrels of petroleum per day. This is about 2% of the total petroleum budget and about 0.8% of the total energy budget.

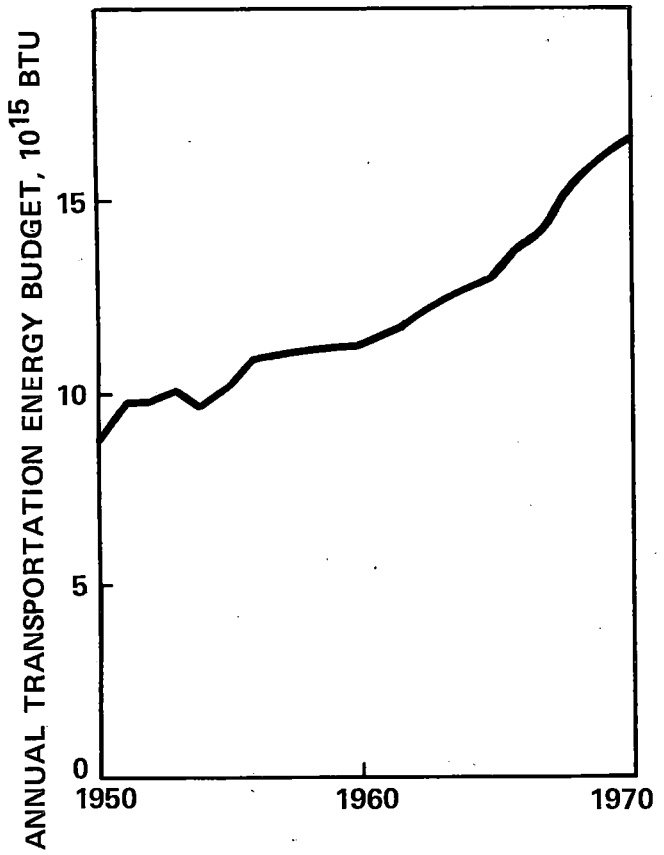
U.S. TRANSPORTATION ENERGY BY MODE, 1972



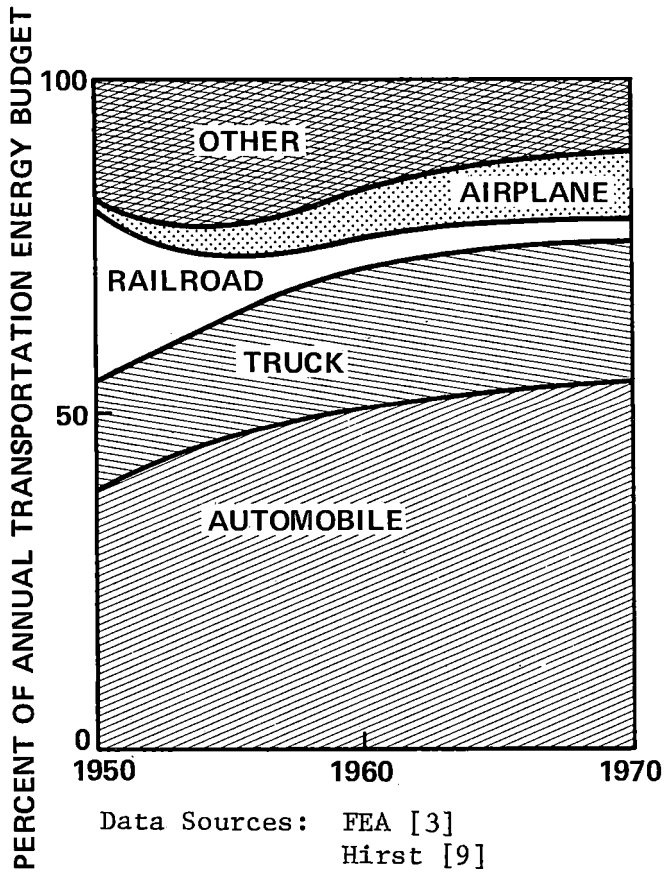
Data Source: Jack Faucett Associates [8]

Total U. S. transportation energy use has been growing at an average rate of over 3% per year. The railroads' share of the transportation energy budget has been shrinking over the past 25 years for two reasons. The railroads' share of both passenger travel and the freight market decreased and the railroads switched from steam power to more efficient diesel-electric power during this time period. (In 1950 steam locomotives outnumbered diesel-electric units.)

HISTORICAL TRENDS IN U.S.



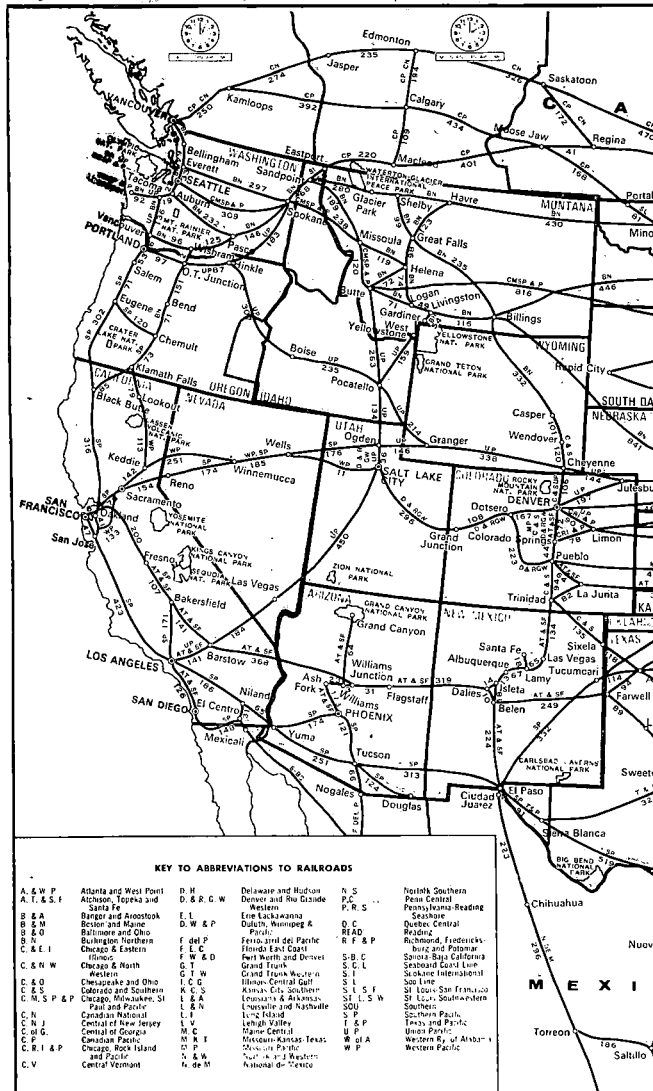
TRANSPORTATION ENERGY



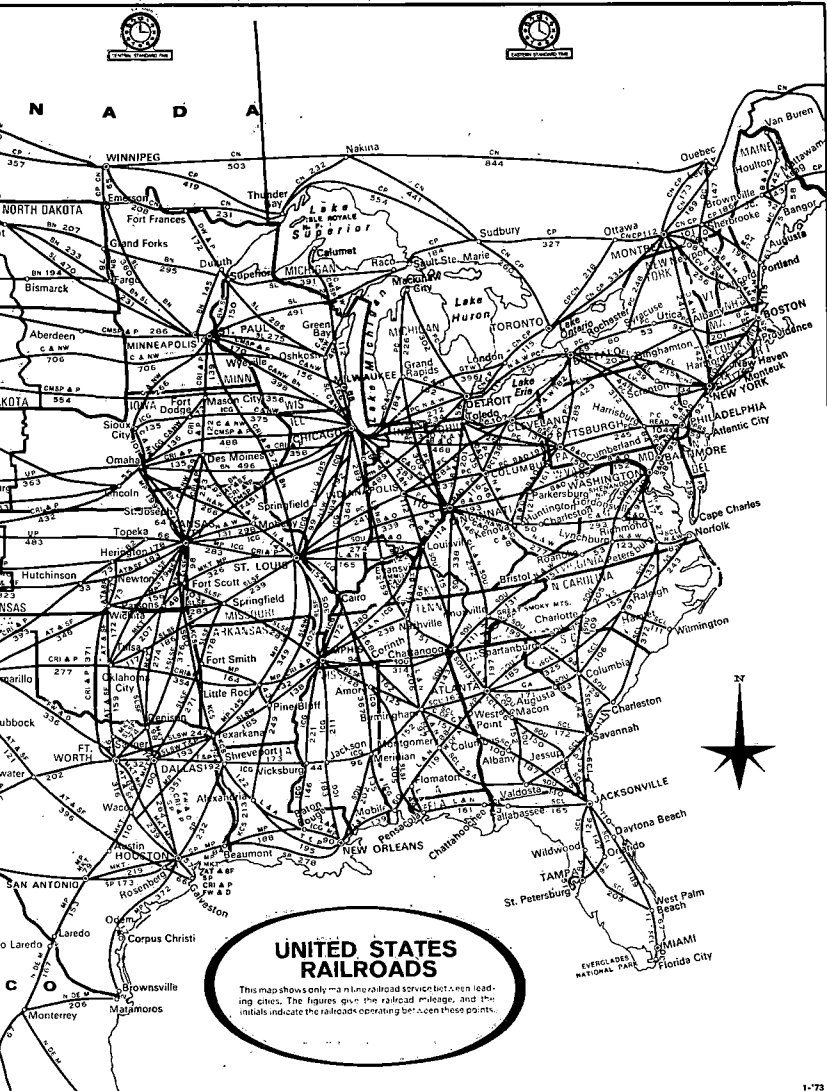
PETROLEUM SAVINGS FROM ELECTRIFICATION

There are approximately 200,000 route miles* of railroad lines in the 48 conterminous states [10]. The total freight traffic handled by Class I railroads (1973) was more than 2 trillion (2×10^{12}) gross ton-miles [11], giving an average traffic density of about 10 million gross ton-miles per route mile. Only the most heavily used routes are candidates for electrification.

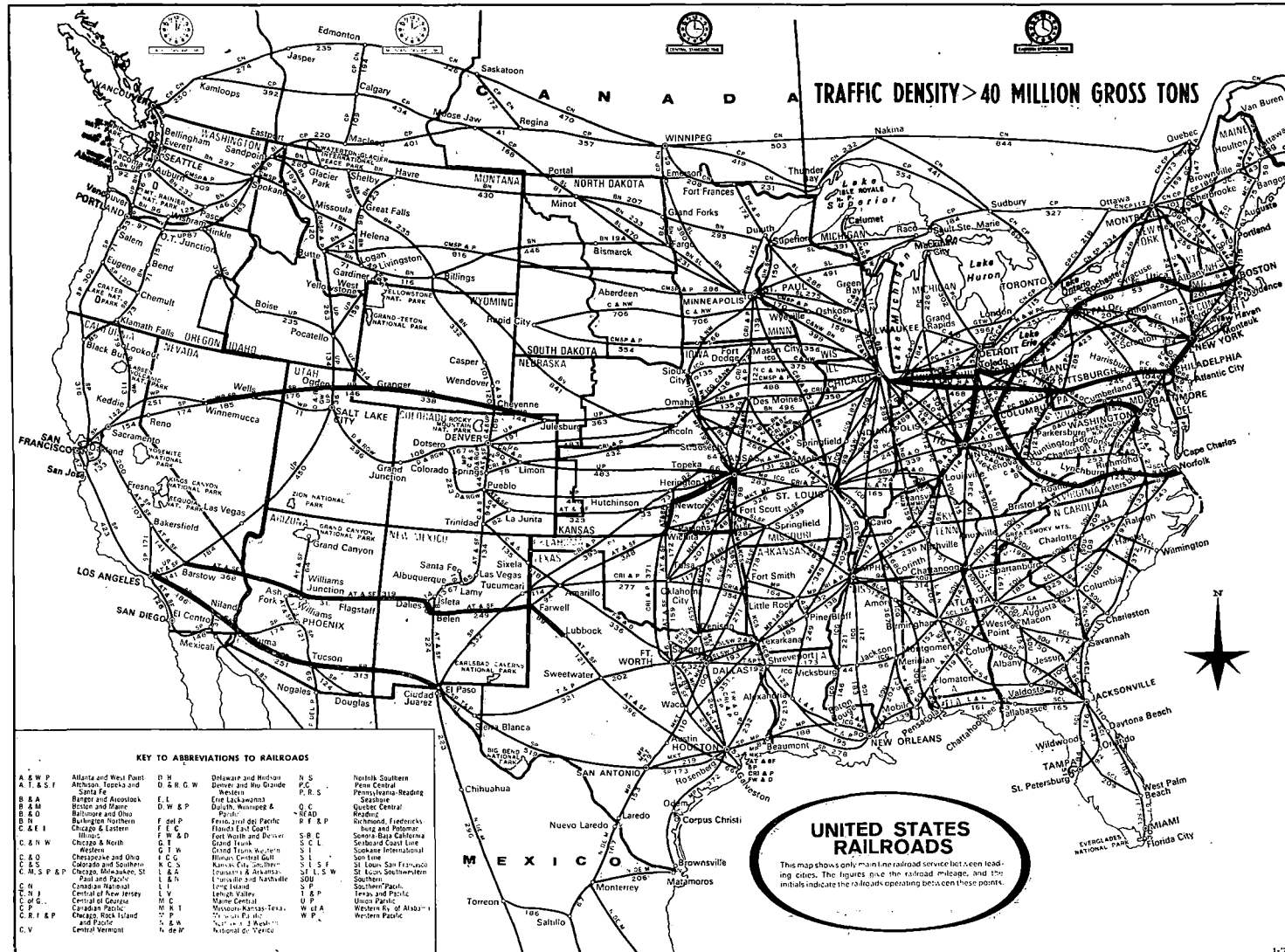
* This chart, showing main line railroad service between leading cities, illustrates only about one-half of the total mileage.



Source: Rand McNally [12]

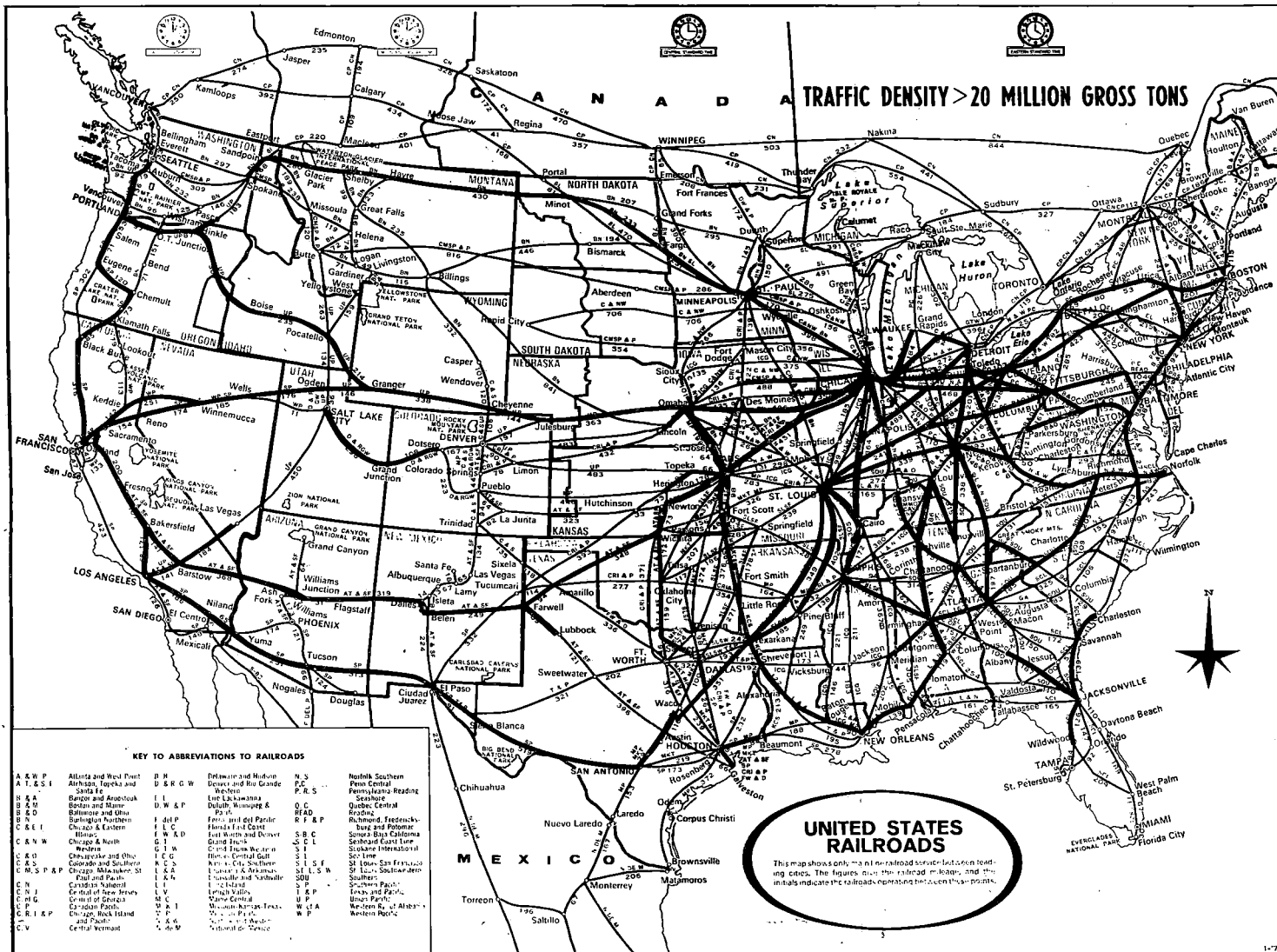


An estimated 8,500 miles of route carry a traffic density greater than 40 million gross tons per year [13]. Thus 4% of the route-miles carry more than 17% of the total traffic.



Data Source: Rand McNally [12]
FRA [13]

8,500 route miles carry from 30 to 40 million gross tons and another 16,000 route miles carry from 20 to 30 million gross tons annually [13]. Thus 33,000 route miles carry a traffic density of over 20 million gross tons, accounting for about one-half the total freight traffic.

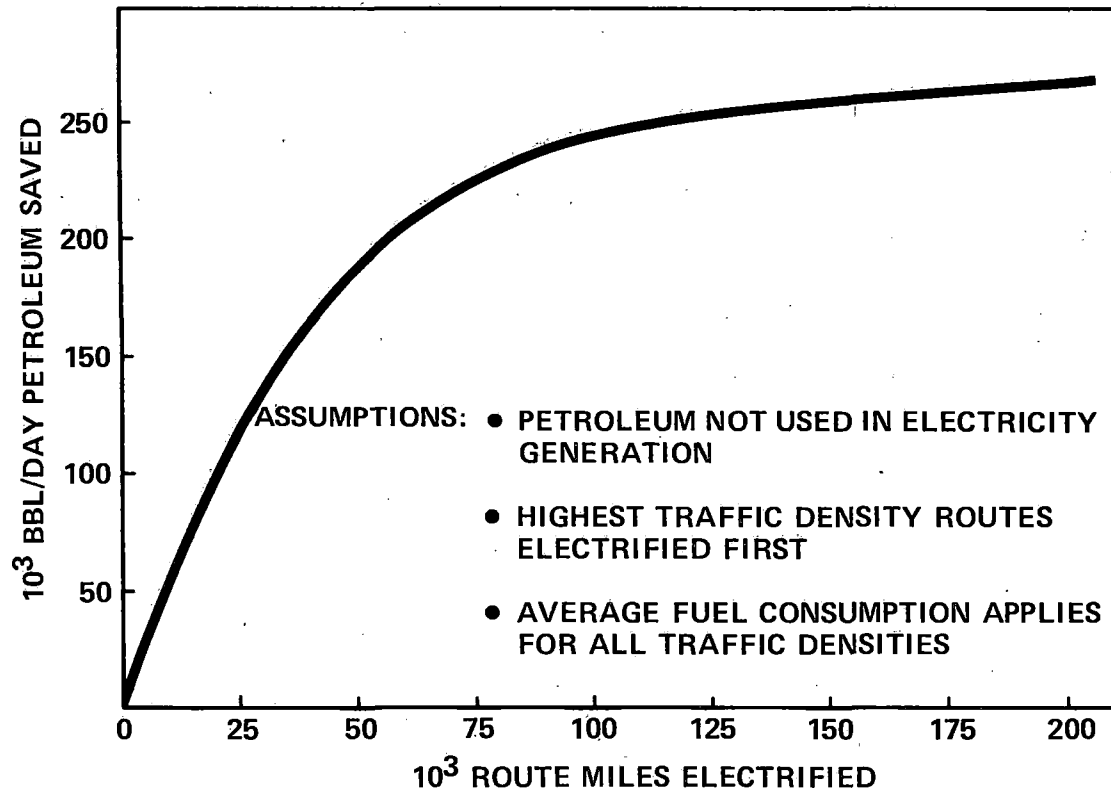


Data Source: Rand McNally [12]
 FRA [13]

Using the traffic density information just presented and an average fuel consumption of 485 gross ton-miles per gallon of fuel (based on overall operating statistics [11]), an initial estimate of potential petroleum savings obtained with electrification has been calculated. It shows that the electrification of 10,000 route miles of high traffic density line can save over 50,000 barrels of petroleum per day and the electrification of 20,000 route miles can save over 100,000 barrels per day.

Although these estimates should be reasonable, more detailed and site-specific investigations are required to establish more accurate assumptions and precise predictions of petroleum savings.

PETROLEUM SAVINGS AS A FUNCTION OF ROUTE MILES ELECTRIFIED

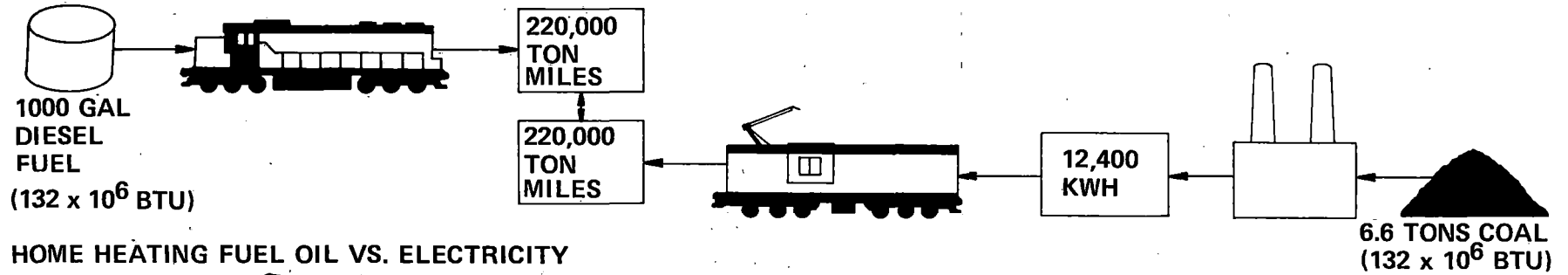


Data Sources: AAR [11]
FRA [13]

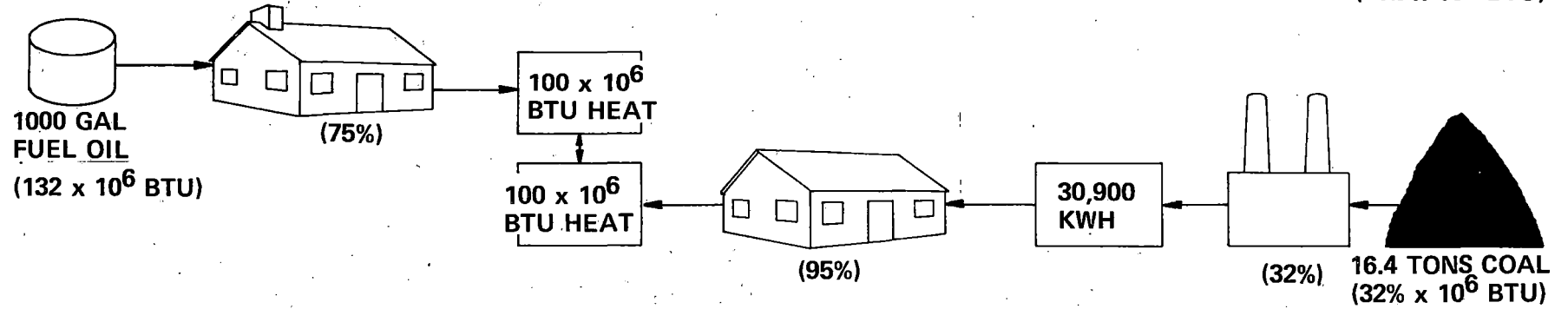
The energy efficiency (the work output for a given fuel input) of a diesel-electric railroad is about equal to that of an all-electric railroad [14]. Railroad electrification thus can result in a petroleum savings for a given amount of work without an increase in energy consumption. On the other hand, a change from an efficient petroleum use to a less efficient electrical application, such as home heating, achieves a petroleum savings at the cost of an increase in overall energy consumption [15]. Electrification can also efficiently accommodate future shifts in fuel if major breakthroughs come about in production techniques.

ENERGY EFFECTIVENESS OF CONVERSIONS

RAILROAD DIESEL-ELECTRIC VS. ALL ELECTRIC



HOME HEATING FUEL OIL VS. ELECTRICITY

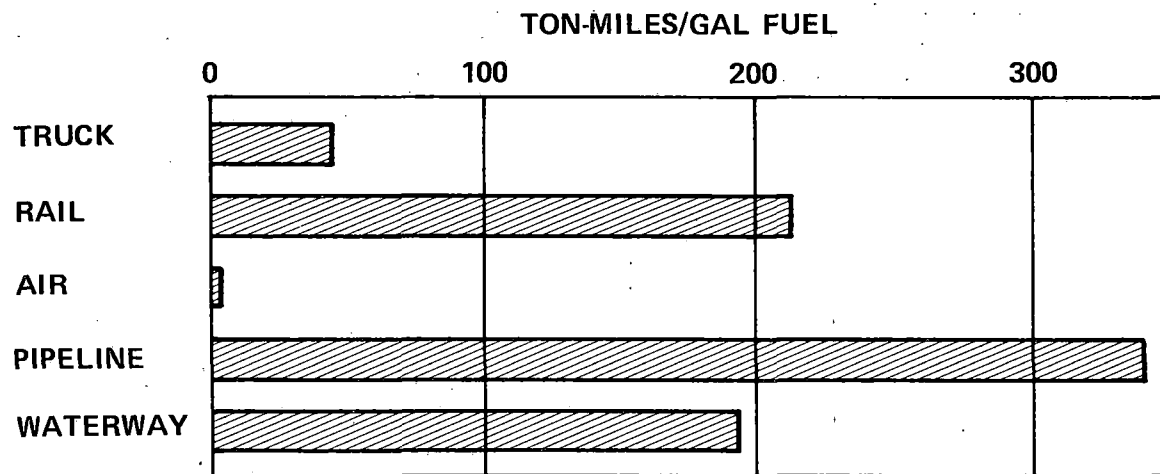


PETROLEUM SAVINGS FROM MODAL SHIFTS

The amount of freight moved by each gallon of fuel consumed varies considerably, depending on what transportation mode is used. The values presented here represent industry averages that show railroads to be 4 times as efficient as trucks and 40 times as efficient as airplanes. Only the pipeline is more efficient.

In comparing the movement of freight by various modes, factors other than average fuel efficiency must be considered. Cost, speed, and level of service all vary widely from mode to mode. Even modal fuel efficiency varies considerably depending on the commodity hauled. For example, since railroads are most efficient in handling high density bulk cargo, an accurate comparison among railroads, trucks, and even airplanes for low density general cargo would show less variation between modes.

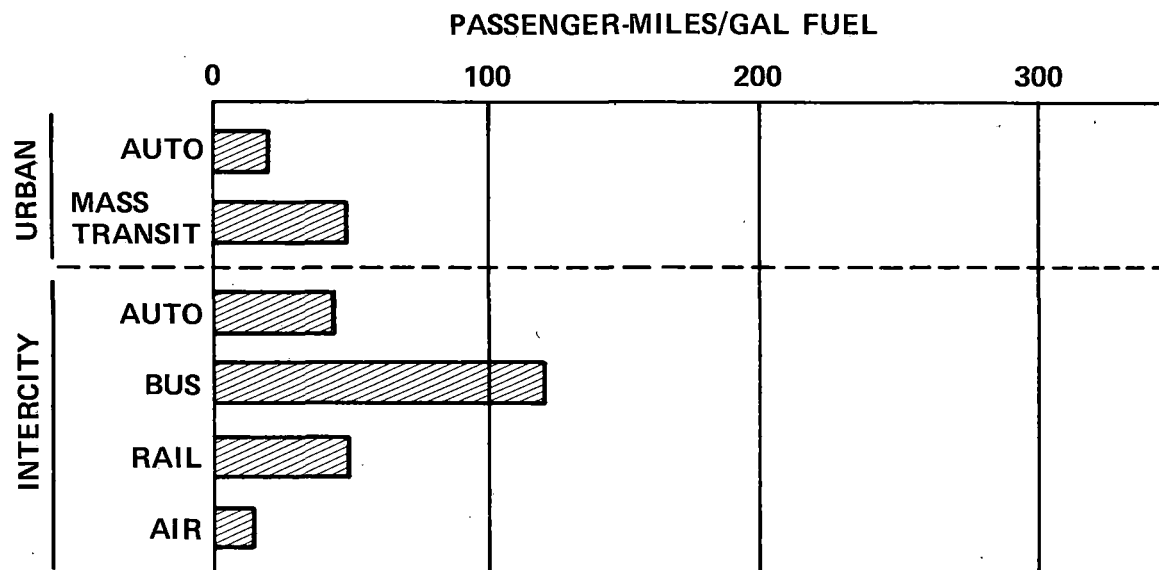
APPROXIMATE MODAL EFFICIENCIES-FREIGHT SERVICE



Data Source: Hirst [9]

Fuel efficiency for passenger travel also varies widely, depending on a number of factors. In general, intercity buses are the most efficient, auto and rail are roughly equal, while air is the least efficient in terms of fuel. While all vary with load factor, the greatest variation in normal usage occurs with the auto. The bus is more efficient than the train partially because the vehicle weight per seat is much less; also the floor area per seat is less. Fuel efficiency for air travel varies with trip length because of the additional fuel burned in the landing/take-off cycle.

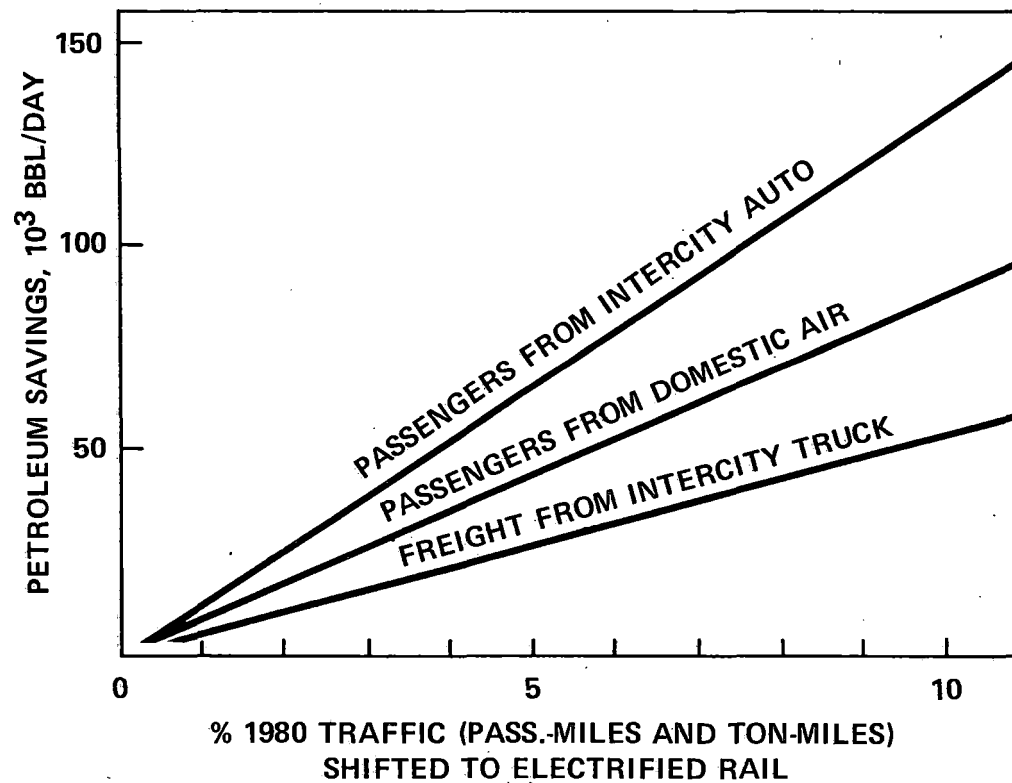
APPROXIMATE MODAL EFFICIENCIES-PASSENGER TRAVEL



Data Sources: Jack Faucett Associates [8]
Hirst [9]
Fraize [16]

Since electrification presently is the only feasible means to utilize coal or nuclear power for intercity movements of freight and passengers, petroleum savings can be realized if freight is shifted from trucks, and passengers from auto and air, to electrified railroads. The information presented in this graph is based only on predictions of passenger and freight transportation by petroleum consuming modes. It does not consider the likelihood or means of achieving these modal shifts, the subject of several other recent studies [9, 16, 17].

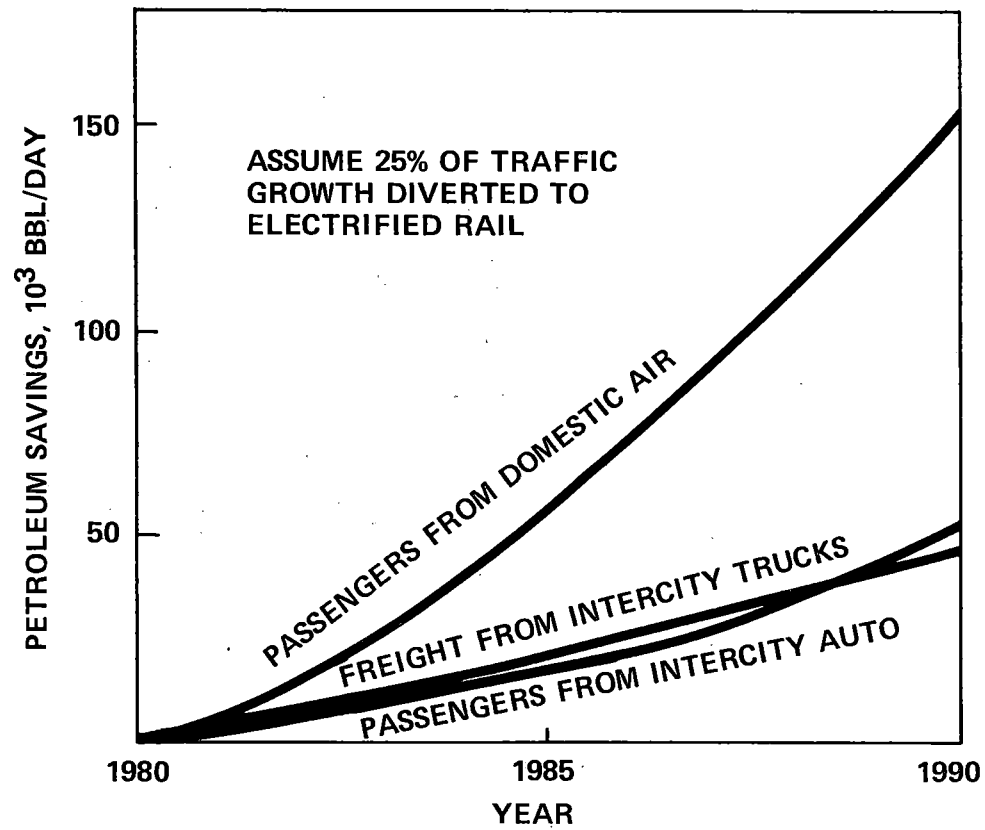
PETROLEUM SAVINGS BY MODAL SHIFTS TO ELECTRIFIED RAIL



Data Source: Jack Faucett Associates [8]

Because several transportation modes are predicted to have substantial growth (considerably higher than rail traffic growth) even with increasing energy costs, diversion from these modes to electrified rail can result in substantial petroleum savings. Again, the information presented in this graph is based only on predictions of passenger and freight transportation. It does not consider the likelihood or means of achieving these modal shifts.

**GROWTH IN PETROLEUM SAVINGS WITH MODAL SHIFT
TO ELECTRIFIED RAIL**



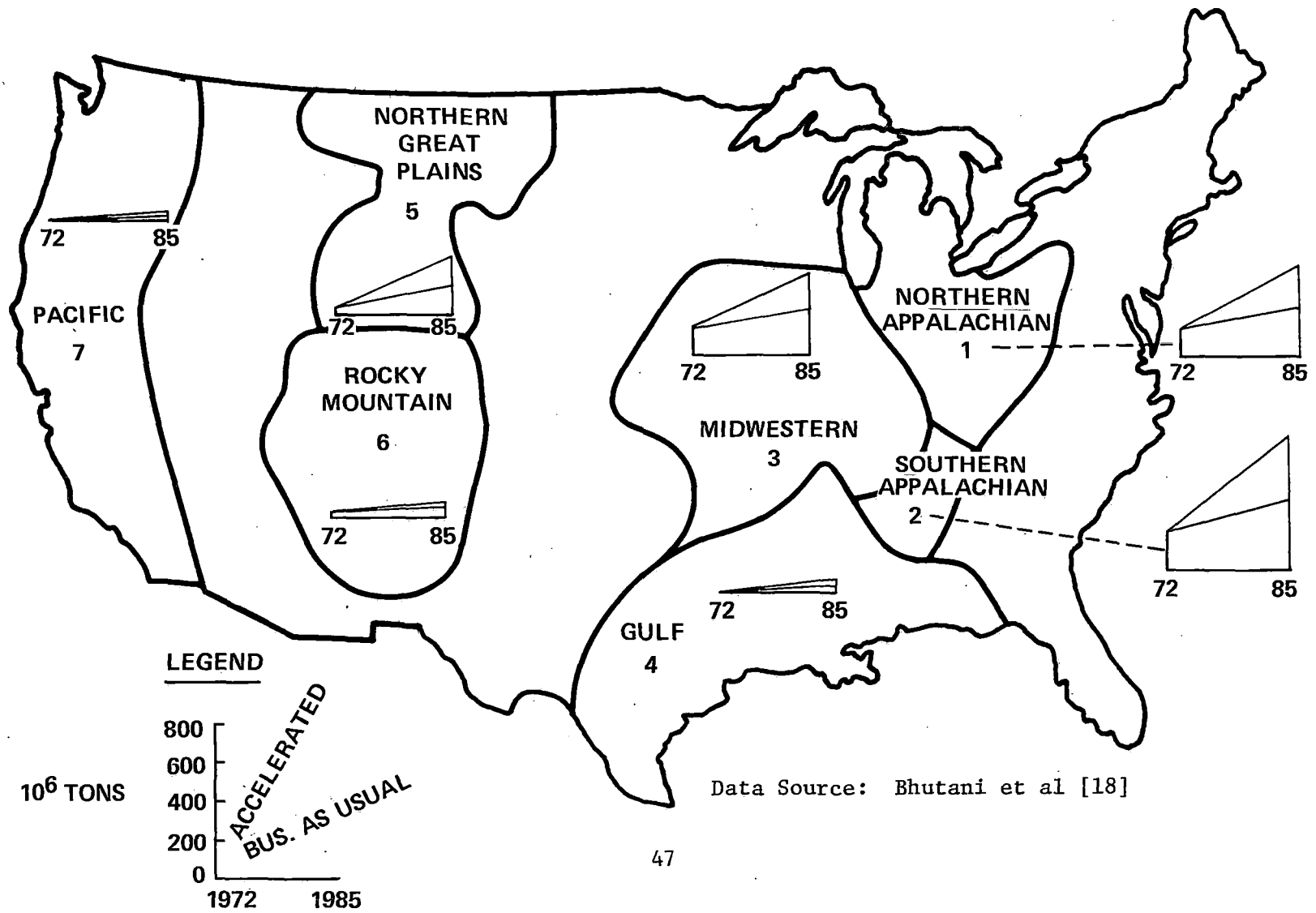
Data Source: Jack Faucett Associates [8]

TRANSPORTATION ASPECTS OF INCREASED COAL PRODUCTION

At the turn of the century, coal supplied 90% of the nation's energy consumption, but by 1950 coal's share had dropped to 38%. Coal production has remained almost constant for the past 50 years, but because of its relative abundance as a domestic energy source it is expected to become increasingly important in supplying the nation's energy needs in the near-term future.

FEA prepared two supply scenarios for input to the Project Independence analysis. The Business-As-Usual Scenario was developed based on recent trends; the Accelerated Development Scenario encompasses a number of institutional changes [3]. This chart displays the FEA projections for seven supply regions. The preponderance of coal comes from the Appalachian supply regions and will continue to do so. The largest rate of growth will be in the Northern Great Plains.

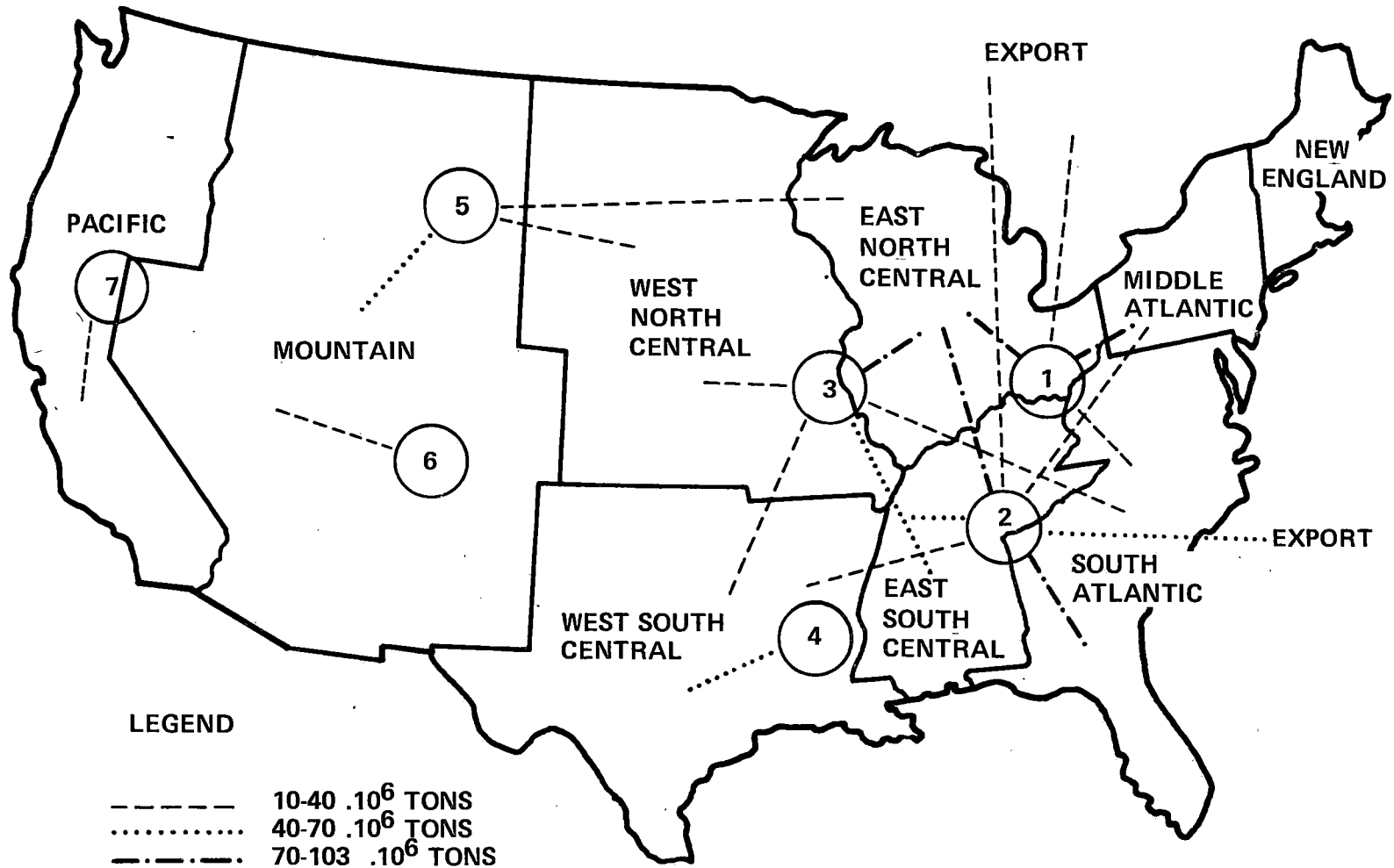
COAL PRODUCTION PROJECTIONS



While some coal is consumed close to the production site, a considerable amount is transported long distance. This chart shows major shipments from the producing regions of the previous chart to geographically identified consuming regions. Railroads are the largest carriers of coal in the U. S., with 78% of all coal moving by rail. Barge traffic on domestic waterways accounts for 15% of coal movement and smaller amounts are carried by truck and slurry pipeline.

Overall, coal makes up about 15% of the total revenue ton miles of railroads and is the predominate business of some railroad lines. The average coal haul in 1972 was 283 miles. In the future, not only will the volume of coal to be moved over traditional routes be expanded, but other impacts will emphasize new routes [19]. The new and expanded coal shipments may help create a favorable situation for railroad electrification.

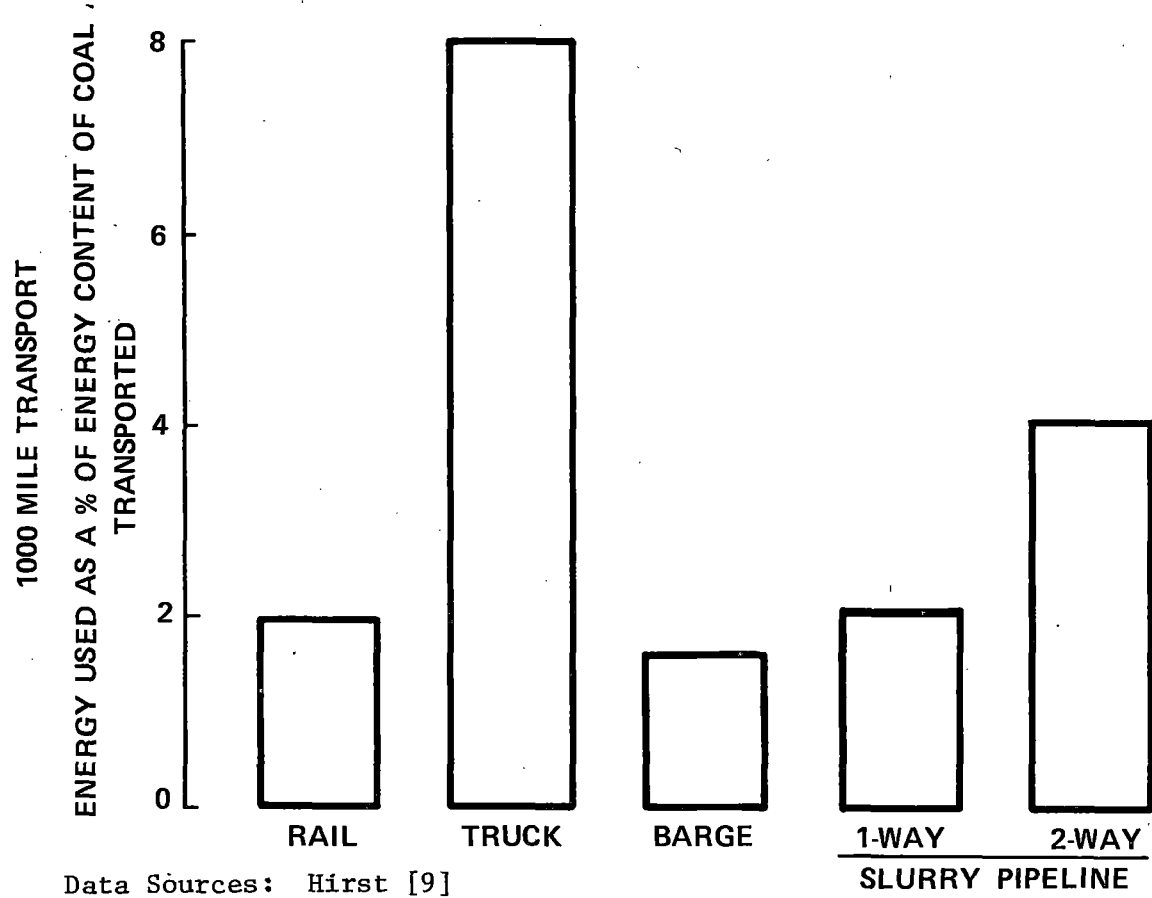
TRANSPORTATION OF COAL FROM SUPPLY TO DEMAND REGIONS



Data Source: Bhutani et al [18]

For new coal shipments, the means of transporting the coal (or the electrical energy it generates) must be selected on the basis of economic, environmental and energy considerations. On long hauls, the amount of energy consumed in transportation can become a significant portion of the energy content of the fuel.

ENERGY REQUIRED FOR TRANSSHIPMENT OF COAL

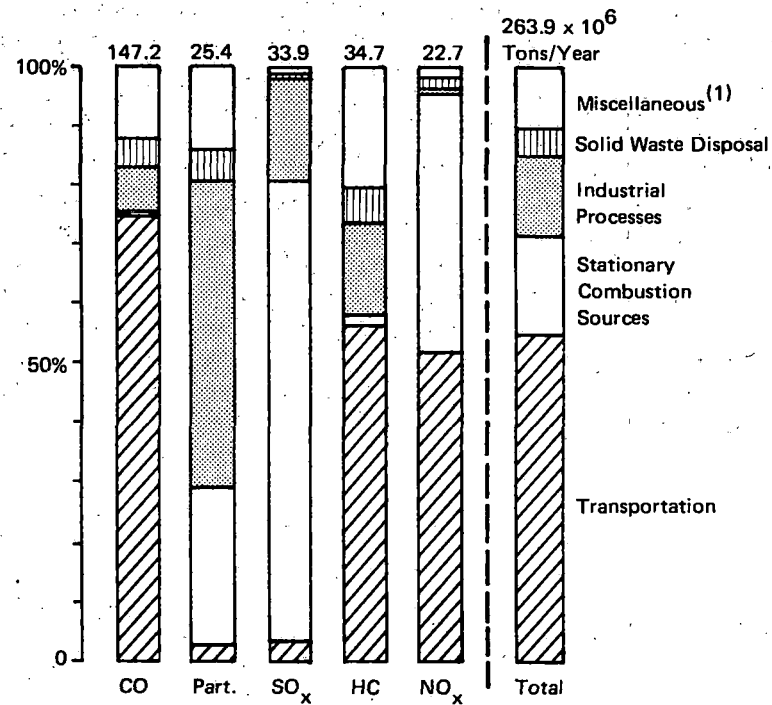


Data Sources: Hirst [9]
Cooper [20]

ENVIRONMENTAL FACTORS

A major environmental impact of transportation is air pollution. The primary air pollutants are carbon monoxide (CO), particulates (part), oxides of nitrogen (NO_x). Transportation contributes better than 50%, by weight, of the total emissions of the three species associated with internal combustion engines--CO, HC, NO_x. Although CO may reach toxic levels in concentrated highway traffic, its overall estimated relative toxicity is low. NO_x and HC undergo reaction in the atmosphere to form photochemical smog which can cause eye irritation, vegetation damage, visibility reduction, and respiratory irritation. Stationary combustion sources (e.g. power generation plants) contribute about 75% of the SO_x and about 25% of the particulates. SO_x contributes to lung and respiratory tract irritation, is potentially corrosive to certain metal and ceramic surfaces, and is also a phytotoxicant to sensitive plant species, and may contribute to atmospheric visibility reduction. The major potential impacts of particulate matter are depositing of large particles near the sources, the soiling of material surfaces, reduction in visibility and the possibility of small particles (particularly with gas molecules absorbed to their surfaces) acting as respiratory irritants [20].

U.S. ATMOSPHERIC POLLUTANTS (WEIGHT BASIS) – 1970



(1) Primarily Forest Fires, Agricultural Burning

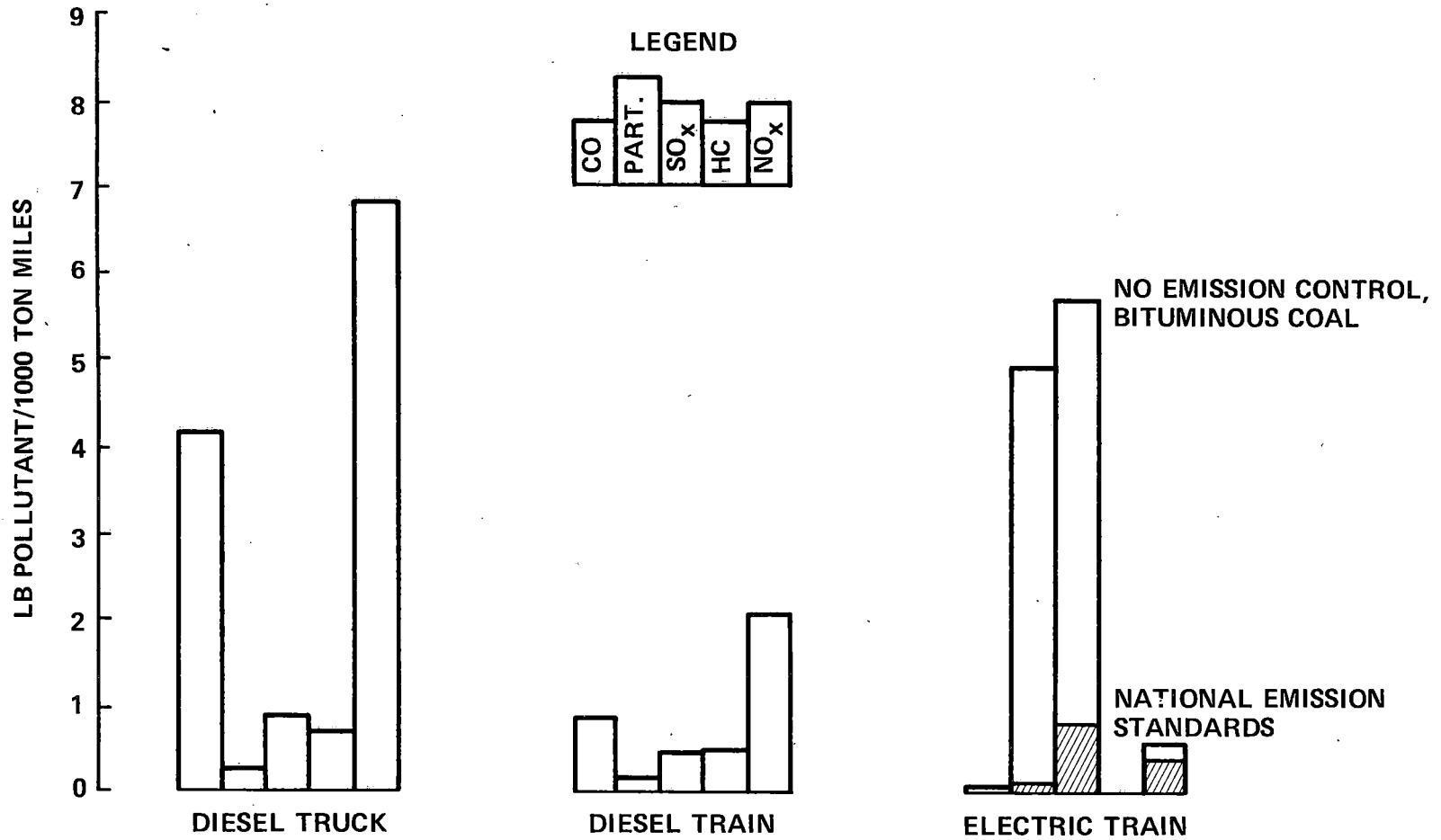
Data Source: CEQ [21]

The amount of pollutants generated by freight modes under typical conditions is shown in this chart. The air pollutant impact actually depends on many other factors including ambient air quality, population distribution with respect to the source, and meteorological conditions.

In general, train diesel engines tend to produce more pollutants per gallon of fuel than truck diesel engines, but the better fuel efficiency of railroads reduces their pollutants on a ton-mile basis. For coal-burning electrical power generation, particulates and SO_x are the problem areas. The amount of these is directly proportional to the ash and sulfur content of the coal. The national emission standards have been established for these pollutants, initially resulting in some fuel shifts at existing plants, but new emission control technology (particularly desulfurization of coal) and equipment will help to achieve clean electrical power from coal.

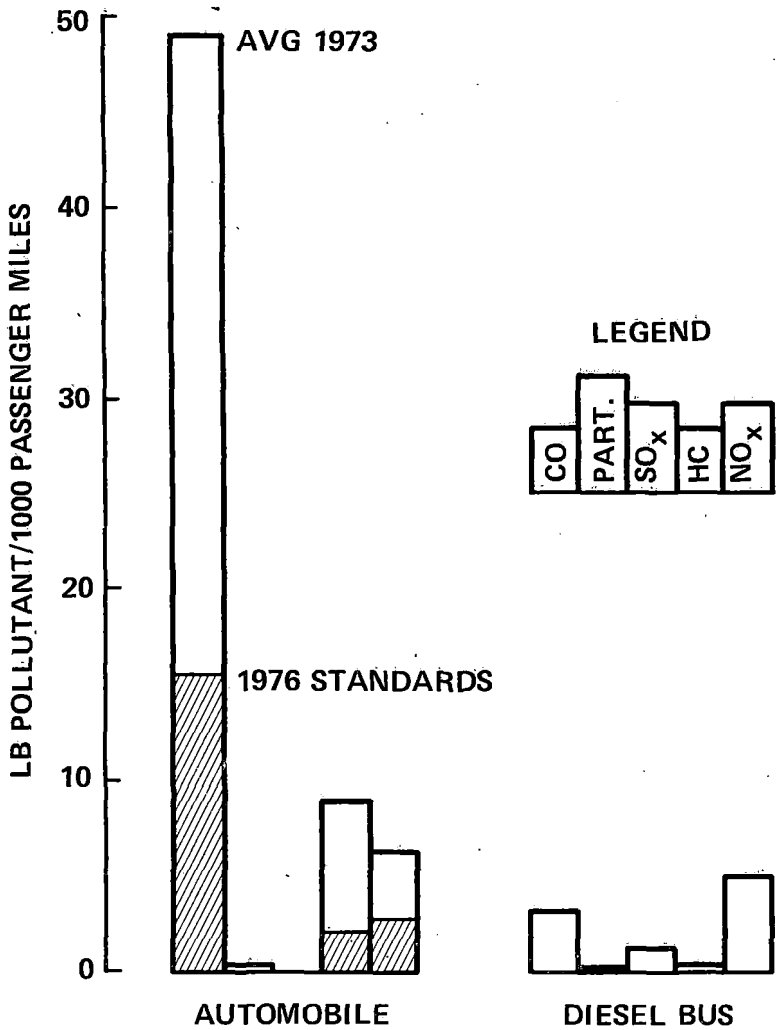
AIR POLLUTANT EMISSIONS - FREIGHT TRANSPORTATION

Data Sources: Cooper & Richards [22]
EPA [23]



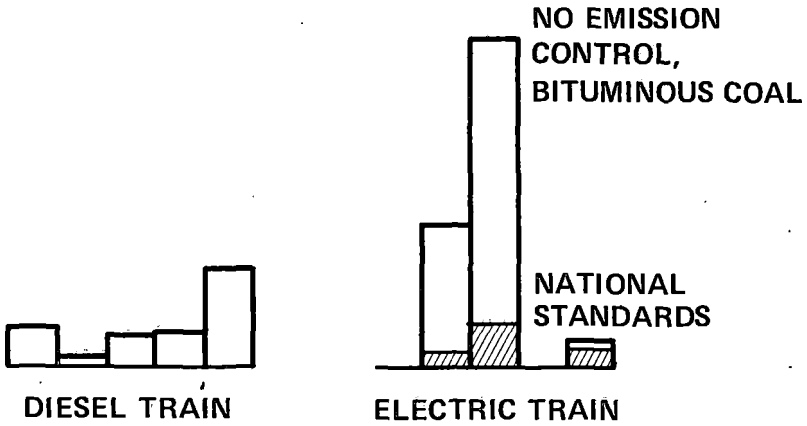
The automobile is recognized as the worst contributor to air pollution in passenger travel, but the federal emission standards, even on a delayed or reduced basis, will lead to progress in improved air quality. Buses and trains are roughly comparable to each other and considerably lower than automobiles because of their fuel efficiency. The electric train, with the achievement of national standards on electricity generating plant emissions, will contribute little atmospheric damage.

AIR POLLUTANT EMISSIONS -



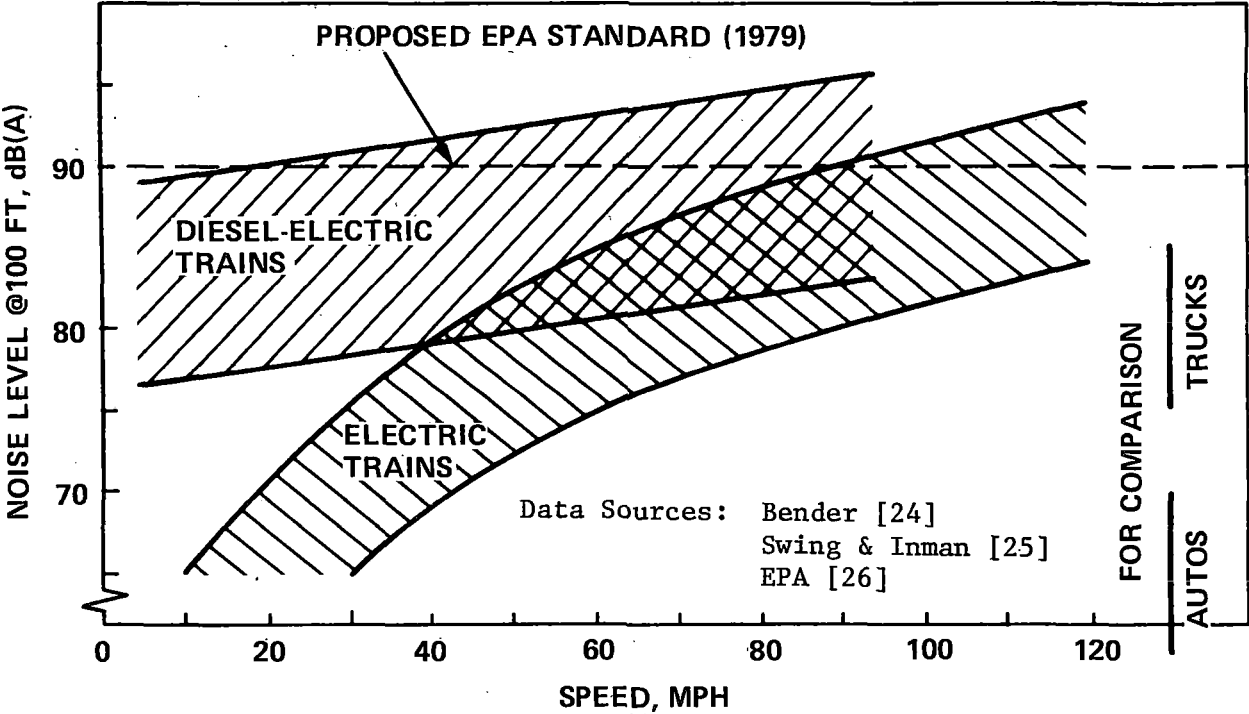
-PASSENGER TRANSPORTATION

Data Sources: Cooper & Richards [22]
EPA [23]



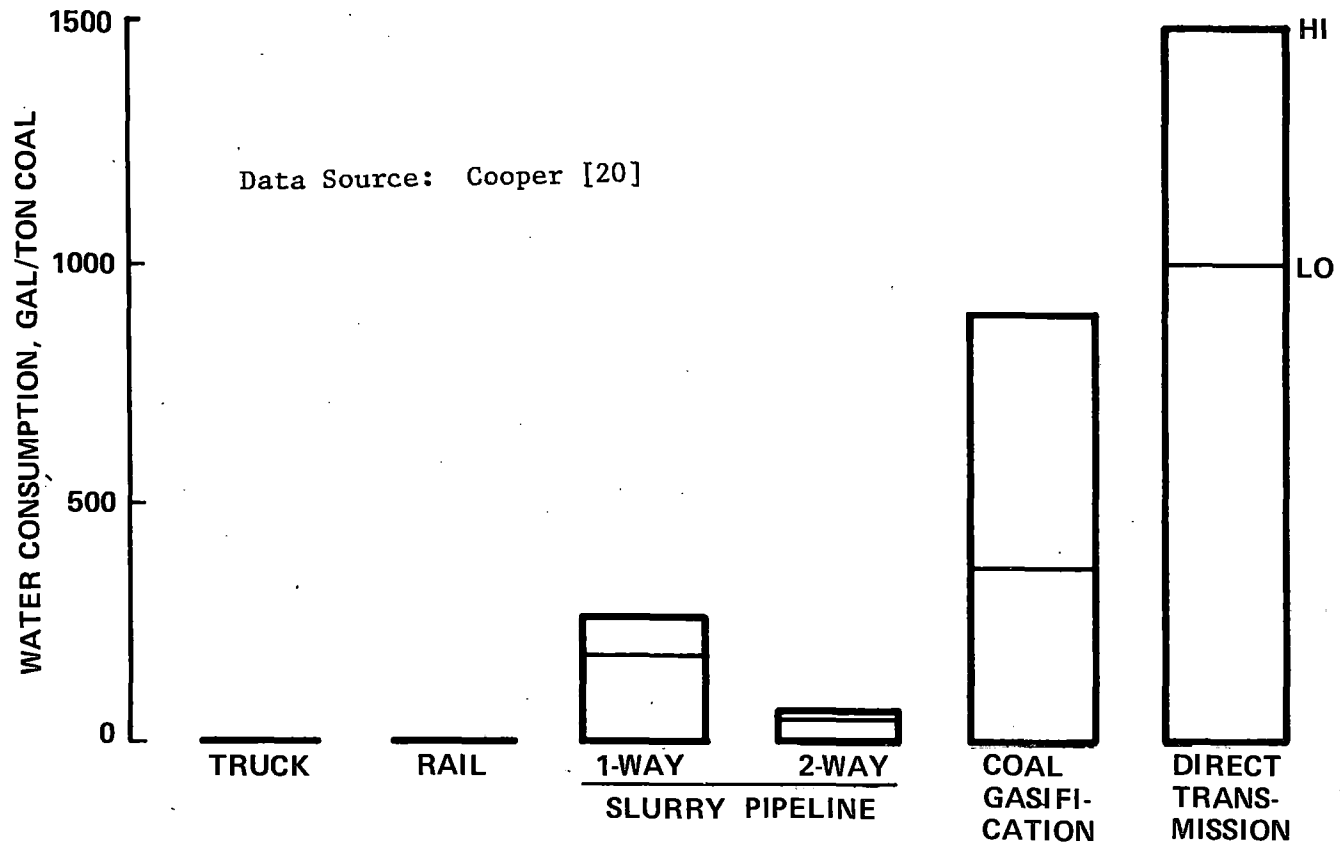
The adverse impact of environmental noise on humans has recently been recognized and regulations to control noise, by both federal and local agencies, are becoming more commonplace. EPA has recently proposed allowable noise level standards [26] that will require the addition of exhaust mufflers on diesel-electric locomotives. Electric trains, in general, are quieter than diesel-electric trains, particularly at low speed. At higher speeds, wheel/rail interaction noise and aerodynamic noise which are common to any train begin to predominate.

NOISE LEVELS OF TRAINS



Coal in the western mining regions is located in arid areas where water is comparatively scarce. In the decision of how to transport or convert coal, the water requirement may be a critical factor. The water required for rail or truck shipment is negligible and is only used to keep the coal dust down. Considerable amounts of water are required for coal slurry pipelines. The amount may be reduced by pumping the water back to the mine, but at the cost of increased energy consumption and capital investment. Coal gasification or "mine-mouth" generation of electricity would take large amounts of water.

WATER REQUIREMENTS FOR LONG DISTANCE COAL ENERGY TRANSSHIPMENTS



STATUS OF RAIL ELECTRIFICATION

Of the major nations in the world, only the North American countries do not have sizeable portions of track electrified.

In Europe, the availability of hydro-electric power in mountainous regions caused extensive electrification of rail lines in Italy, West Germany, Switzerland, Norway, and Sweden. Electrification also has been justified because of national security or other social reasons that transcend economics.

COMPARISON OF WORLD'S RAILROADS

<u>COUNTRY</u>	<u>LAND AREA</u>	<u>POPULATION</u>	<u>RAILROAD ROUTE MILES</u>	<u>% ELECTIFIED</u>
UNITED STATES	3,675,545	208,615,000	206,000	LESS THAN 1%
U.S.S.R.	8,649,500	243,722,000	84,000	25%
CANADA	3,851,809	21,530,000	41,000	nil
INDIA	1,261,597	547,000,000	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%

Data Sources: FRA [1]
 Maholtra [27]
 Rand McNally [28]

Although attempts to drive a rail vehicle by electric power were reported as early as 1835, the first successful attempt was in 1879 by Siemens, who produced an electric locomotive and demonstrated it successfully at an exhibition in Berlin. In competing with the steam locomotive, electricity offered an attractive alternative mainly on mountain lines and underground railways. In this country, electrification projects were undertaken to overcome various problems. Terminal and trunk-line tunnels were electrified to eliminate smoke, soot and noise associated with steam locomotives. This led to electrification of adjoining main line track. Passenger terminal and suburban services were electrified to speed services through utilization of the high acceleration capability of electric traction. Electrification of portions of the Pennsylvania Railroad was done largely to increase track capacity and to improve operating efficiency over what was then possible with steam power. Electrification on portions of the Milwaukee Road, Norfolk and Western, and the Virginian took advantage of the increased efficiency, speed and tractive power of electric locomotives on hauling heavy freight over steep grades, resulting in widespread savings on operation, overhead, and maintenance in comparison with steam operation [1, 29].

Electrification declined in this country because of the availability of relatively inexpensive and efficient diesel-electric locomotives and the then low priced and readily available petroleum fuels.

SELECTED MILESTONES IN ELECTRIFICATION

- 1879** **FIRST SUCCESSFUL ELECTRIC RAIL VEHICLE – GERMANY**
- 1895** **FIRST U.S. ELECTRIFICATION ~ B & O's BALTIMORE TUNNELS**
- 1907** **NEW YORK CITY PROHIBITS EXTERNAL COMBUSTION ENGINES
FORCING ELECTRIFICATION**
- 1932** **MAXIMUM AMOUNT OF ELECTRIFIED TRACKS IN USA ~6,700 MILES**
- 1938** **COMPLETION OF PENNSYLVANIA RR ELECTRIFICATION – LAST
MAJOR PROJECT IN US**

Data Source: Haut [29]

A variety of electrical traction systems have developed through the years. The earliest systems used direct current transmission, with the higher voltage alternating current distribution systems developing as longer lines were electrified. Many of the older systems are still in operation--a testament to the long life of electric trains.

Most of the recent advances have been in the area of control. State-of-the-art and developmental systems use solid-state power electronics to provide effective and efficient control.

PROGRESS IN RAIL ELECTRIFICATION

	WAYSIDE EQUIPMENT	ON BOARD EQUIPMENT	TYPE OF CONTROL	TRACTION MOTOR	
EARLY SYSTEMS	TRANSFORMER AND MOTOR/GENERATOR	—	SERIES/PARALLEL CONNECTIONS	D.C.	LONG ISLAND RAILROAD NEW YORK CENTRAL RAILROAD MU CARS IN CITY & SUBURBAN SERVICE
LATER SYSTEMS	TRANSFORMER	MOTOR/GENERATOR	SERIES/PARALLEL AND FIELD CONTROL	D.C.	GREAT NORTHERN RAILWAY VIRGINIAN RAILWAY
		TRANSFORMER	SERIES/PARALLEL AND FIELD CONTROL	AC UNIVERSAL	PENNSYLVANIA RAILWAY NEW HAVEN RAILWAY AND SEVERAL OTHERS
		TRANSFORMER	POLE CHANGING MOTORS & ROTOR RESISTANCE	INDUCTION MOTOR	EXTENSIVE USE IN EUROPE NORFOLK & WESTERN RAILROAD NOT WIDELY USED IN US
STATE OF THE ART	TRANSFORMER	TRANSFORMER AND RECTIFIER	THYRISTOR CHOPPER	D.C.	PASSENGER AND TRANSIT CARS LIKE BART
		TRANSFORMER	THYRISTOR PHASE CONTROL		BLACK MESA, LAKE POWELL RAILROAD AMTRACK BETWEEN NEW HAVEN AND WASH D.C. MUSKINGUM RAILROAD
DEVELOPMENT	TRANSFORMER	RECTIFIER AND INVERTER	VARIABLE FREQUENCY VARIABLE VOLTAGE	THREE PHASE IND. MOTOR	BROWN BOVERI/HENSCHEL FOR GERMAN FED. RAILWAY (OCT 74) BROWN BOVERI EQUIPMENT FOR SWISS FED. RAILWAY (NOV 1972) GM DEVELOPED SUCH A SYSTEM BUT HALTED FURTHER WORK FEW YEARS AGO

Railroads have been looking at electrification with steadily growing interest. To date, reportedly at least 16 U. S. and Canadian railroads have been involved in electrification studies, with the six companies shown here considered as serious candidates for an early start to electrification [30].

The Burlington Northern (BN) studied electrification feasibility for some 1200 miles of line, including the route between Billings, Mont. and Lincoln, Neb. More recently BN has limited its studies to the 360-mile segment between Alliance and Lincoln, Neb.

Union Pacific has made feasibility studies of some 2250 track miles on routes from North Platte, Neb. to Salt Lake City, Utah, and Pocatello, Ida. Two half-mile test installations were built to give some experience with different catenary systems.

Southern began electrification studies several years ago for the 338-mile Cincinnati-Chattanooga route, its most heavily trafficked line. Subsequently, another 153 miles of line between Chattanooga and Atlanta were added to the study.

Southern Pacific (SP) was one of the first roads to begin the current cycle of serious electrification studies. SP selected the 760-mile El Paso-Colton route for a detailed technical feasibility study carried out in 1970.

Canadian Pacific (CP) began electrification studies almost five years ago for some 850 miles of line in the Canadian Rockies that included the main line from Calgary, Alta., and Vancouver, B.C., as well as the secondary main line from Golden to Sparwood, B.C. In 1971 CP engineers carried out a series of tests in Norway with a leased 5000 hp thyristor locomotive. Late in 1972, CP erected a quarter-mile test section of catenary to study cost and difficulty of erection, and to gain maintenance experience under adverse weather conditions.

ROUTE ELECTRIFICATION STUDIES BY RAILROADS

		TEST TRACK
BURLINGTON NORTHERN	1560 MI	----
UNION PACIFIC	2250 MI	1 MI
ILLINOIS CENTRAL GULF	1000 MI	----
SOUTHERN	338 MI	----
SOUTHERN PACIFIC	<u>760 MI</u>	----
TOTAL U.S.	5908 MI	
CANADIAN PACIFIC	<u>850 MI</u>	.25 MI
TOTAL N. AMERICA	6758 MI	

Data Source: Middleton [30]

The reasons why U. S. railroads have not proceeded with electrification center around economic issues--the sizeable capital investment required, aggravated by the difficult present financial conditions of the railroads.

Fuel issues have not been critical, with diesel fuel being relatively inexpensive and in abundant supply.

The relative standardization on diesel-electric locomotives in the U. S. has tended to reduce their cost and divert engineering and development efforts from all-electric traction.

The needs of national energy policy and the increasing cost and scarcity of motor fuel, along with changing governmental attitudes and an evolving national transportation policy, are creating conditions that have led to a high current level of interest in electrification.

REASONS WHY RAILROADS HAVE NOT EXPANDED ELECTRIFICATION

- **INVESTMENT IS LONG TERM OBLIGATION**
- **EARNING PROSPECTS HAVE NOT BEEN STRONG**
- **ECONOMIC BENEFITS OCCUR GRADUALLY**
- **INVESTMENT MAY BECOME SUBORDINATE TO PREVIOUS
MORTGAGE COMMITMENTS**
- **DIESEL FUEL HAS BEEN INEXPENSIVE & PLENTIFUL**
- **DIESEL-ELECTRIC LOCOMOTIVE HAVE BECOME STANDARD
AND ARE RELATIVELY INEXPENSIVE**
- **ENGINEERING, DEVELOPMENT & LEARNING COSTS**

Data Source: FRA [1]

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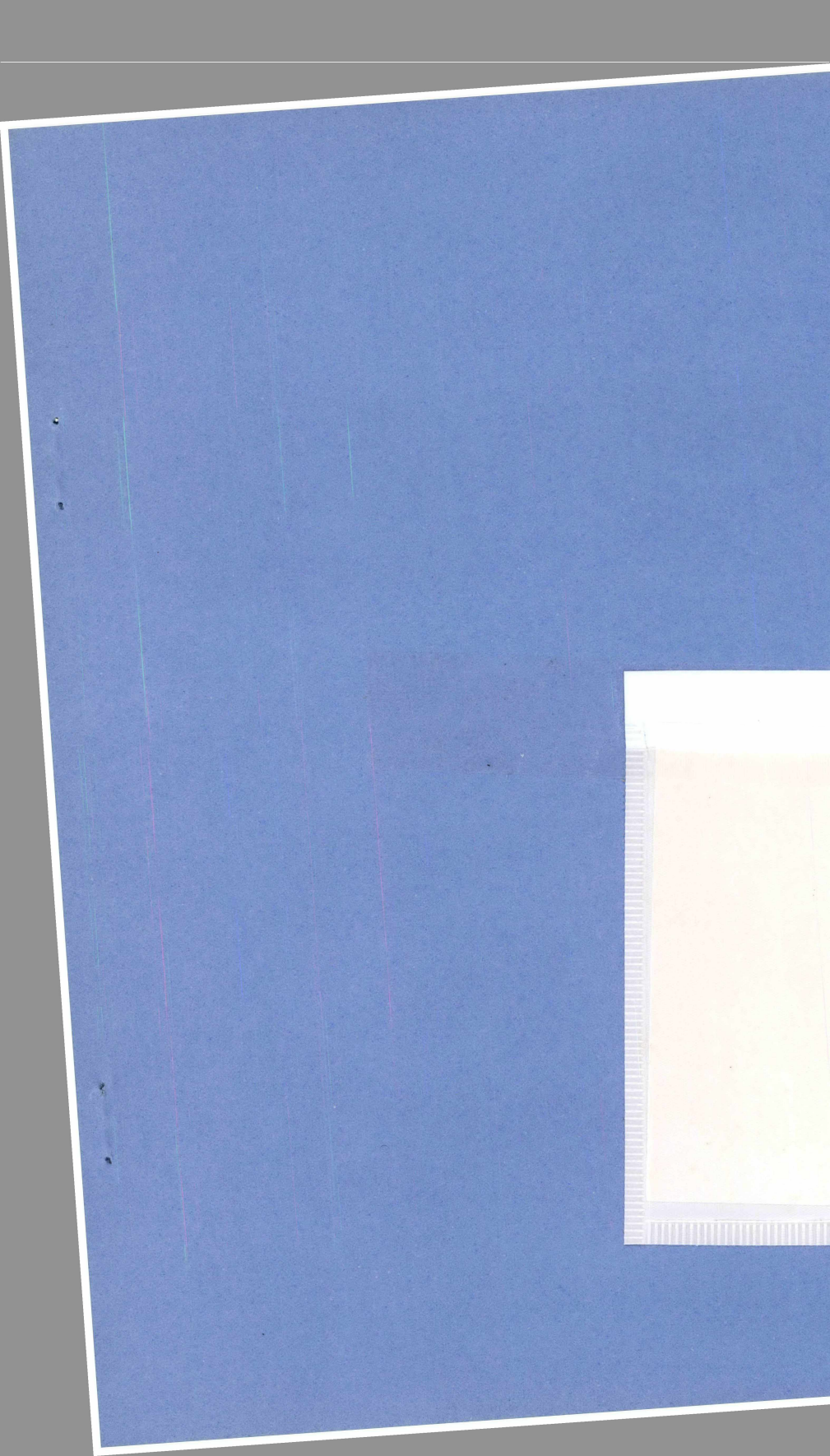
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