proved that it will be practical to increase the
axle loading of coal cars to 26 tons and that of
electric locomotives to 28 tons. The trailing mass
will then be 20 800 tons.

Tests have already been carried out that approxi-
mate the performance of a 200-car train on a re-
graded line, and measurements indicate that a spe-
cific energy consumption of about 7 W·h/ton-km for
the loaded train and 34 W·h/ton for the empty one
can be expected. These reductions are due not only
to better use of momentum with a heavy train 2.5 km
long, but also to a better ratio of trailing mass to
locomotive mass, in which a 130 percent improvement
over the present ratio by using 84-car trains is ef-
fected.

CONCLUSION

After the first year of full electric operation and
two major fuel price increases, the first of which
in 1973 led to the decision to electrify this line,
the figures given fully justify this decision and
confirm the economical use of electric traction in a
heavy main-line operation of this nature. An annual
saving of 120 million L of diesel fuel is now being
effected on this line alone.

In the future in South Africa, it is foreseen
that most diesel and other fuel oils will be ob-
tained by conversion from the abundant coal re-
sources. However, to convert coal to electricity
and use this for an electrified railway is a 100
percent more-efficient use of this natural re-
source. This fact and the economic advantages il-
lustrated in this paper have led to a decision to
proceed with a further 2700 km of electrification on
four major routes by 1985. This will result in a
total of 16 000 km of electrified track in the re-
public.

Already 70 percent of all traffic on a ton-kilo-
meter basis is hauled electrically on the South Af-
rican Railways, and with these extensions and other
traffic increases the target is to increase this
figure by 85 percent.

Railroad Electrification: An Alternative for Petroleum Savings

ROBERT K. WHITFORD

Evaluation of various scenarios of construction rates, freight growth, and fuel-
price escalation shows that electrification of the nation's high-density railroad
routes is a cost-effective alternative when compared with the cost and output
of synthetic-fuel plants. If 15 000 miles of the existing rail routes, which
handle more than 30 percent of the nation's freight, were electrified today,
the cost of the diesel fuel saved would be equivalent to $1.00/gal or less. After
a 30-year period of construction and with a reasonable freight growth, the re-
sulting 25 600 miles of electrified rail network would save more than 300 000
bbl of oil per day over the amount that would have been used by not electrify-
ing. The investment per fuel equivalent produced or saved is approximately
the same for the two alternatives. However, the fuel plant has a specific and
limited output, whereas the growth in freight traffic that can accrue on electri-
fied rail will generate increasing substantial returns on the investment, an in-
vestment that has the potential to last 50 years. The principal barrier to elec-
trification is the large investment required relative to the railroad's financial
condition. Preliminary analyses of costs and returns, however, indicate that
rail electrification is a feasible energy-conservation opportunity. A mature
technology, as shown by more than 60 000 route miles worldwide, it would
provide substantial returns on investment and improve productivity. Given
the escalation of fuel prices and a national desire for energy independence,
electrification should be of high priority on the list of energy policies.

The use of electricity in railroads offers an option
to diversify fuel sources by replacing a system now
dependent on petroleum with energy generated from
other basic resources such as coal, hydroelectric
power, or nuclear reactors. Nurtured on inexpensive
fuels such as wood and coal, railroads currently
derive more than 97 percent of their energy from
petroleum products. In the 1940s and 1950s, the
switchover from steam to diesel-electric locomotives
brought considerable improvement in energy produc-
tivity because of the low cost of oil then and the
increase in propulsive efficiency. Now soaring

diesel fuel costs indicate that it may be time for
another switchover, this time to the electrification
of the high-density portions of the U.S. railroad
network. In addition to fuel conservation, electri-
fication offers other advantages to the railroad,
namely, an increased return on investment [generally
well above 15 percent (1,2)] and improved productiv-
ity, mainly through reduced consist weight and lower
maintenance costs.

This paper combines cost and planning data from
several existing electrification and synthetic-fuel
studies in order to compare investment in railroad
electrification as a fuel-conserving option with an
alternative investment in liquid-coal plants to
produce an equivalent amount of fuel oil. Resulting
cost analyses reveal that railroad electrification
is both competitive as an energy-saving investment
and efficient in the use of coal. This study treats
total national costs, borne either by the railroad
or by the electric utility, according to a systems
perspective. Ultimately, of course, decisions about
investments in electrification must be made on the
basis of individual route segments, although differ-
ences among individual segments should not be sig-
nificant enough to invalidate the general results.

INVESTMENT SCENARIOS

The Railroad Revitalization and Regulatory Reform
Act of 1976 (4R Act) required that the Federal
Railroad Administration (FRA) perform a study of the
potential costs and benefits to be derived from
electrification of the high-density lines. Forty

Table 1. Electrification buildup rate for three scenarios.

| Scenario | Buildup Rate (miles/year) | | | | | | | | | | | Total at 30 Years |
| | Year from Start | | | | | | | | | | | |
	1	2	3	4	5	6	7	8	9	10	...	
A	0	0	100	200	250	300	350	350	350	350	...	9 250
B	0	0	200	300	500	700	900	1000	1000	1000	...	25 600
C	0	0	200	400	600	800	1000	1200	1300	1500	...	37 000

links on 14 railroads have been identified as good candidates (2) and would in fact form a base network for national electrification. These routes constitute about 26 000 miles.

Construction Levels

As part of Purdue University's overall investigation of potential paths for energy transition in transportation (3), three scenarios that cover 30 years of construction have been assumed that involve multiples of link segments about 350 miles each that cover a design and construction span for each of three to four years:

A. Business as usual (results in a 9250-mile network),
B. Accelerated development (results in a 25 600-mile network), and
C. Technical limits (an approach that requires the highest priority and results in a 37 000-mile network).

These three levels result in networks reasonably consistent in size with those proposed by other studies. In their electrification-network studies, the Mitre Corporation (4) developed three priority levels of networks for electrification based primarily on tonnage carried: 8199 route miles of very-high-priority railroad, 29 301 route miles of medium-priority railroad, and 4518 route miles of lower-priority railroad, a total of 42 018 route miles. The Arthur D. Little Company analyzed networks of 10 000, 26 000, and 40 000 route miles for the U.S. Department of Transportation (DOT) (5).

In scenario A (business as usual), the railroads would electrify on their own and have very little government encouragement. This scenario projects limited electrification, which would build up to a rate of 350 new route miles each year on the most heavily traveled corridors beginning in 1987. Scenario B projects 1000 route miles/year (6), a rate that probably requires strong financial incentives to help the railroads cope with difficult cash flow and low return on equity. The rate of growth might be limited initially by the capability of electrical-equipment industries to respond to the increased demand for substation equipment, accessories, and wire, particularly if there were an increased demand for electrical products in other sectors of the economy as well. Scenario C projects a 50 percent increase over scenario B and represents a guess as to the real limits on the electrification rate if maximum pressure were applied and help from foreign equipment suppliers were available. Table 1 shows the buildup rate in miles per year for these three scenarios.

Freight Model

The amount of traffic carried by the railroad in the future will depend on industrial growth, the geographical location of the railroad, the commodities it carries, and the service offered. Growth of freight movement has been estimated in this paper in terms of three overall rates: no growth, 2 percent growth per year, and 4 percent growth per year. The National Transportation Policy Study Commission report (7) gives overall rates to 2000 of 2.1 percent, 4.4 percent, and 5.6 percent in rail ton miles for their projected low, medium, and high growth rates, respectively. The Mitre report states that "the overall annual growth rate...is very close to 2 percent" (4, p. 15).

Electrification Priority

The very-high-density lines are to be electrified first; electrification will occur on the basis of the simplified scheme given below:

Miles Electrified	Annual Tonnage (million gross tons)
First 2 500	70
Next 5 000	55
Next 10 000	40
Next 10 000	20
Remainder	20

The baseline freight assumed for 1980 is 910 billion revenue ton miles, about the same as for 1979. According to the scheme above, the 9250-mile network (scenario A) will carry 23 percent of the total U.S. tonnage; the 25 600-mile network (scenario B), 50 percent; and the 37 000-mile network (scenario C), 61 percent.

Track Model

The track to be electrified will generally be a combination of double and single track. It has been assumed for this study that the first 5000 miles electrified will be double track. After that, electrification would occur on the basis of 25 percent on double track and 75 percent on single track. These levels are close to those suggested by C.H. Spenny (2).

Fixed Plant Investment

Estimates of fixed plant investment vary according to differences in the amount of civil reconstruction needed to provide for the height of the catenary, changes required by the power stations to provide large surges in single-phase power on the utility grid, and proximity to existing electric utilities. Investment costs also depend on the voltage chosen and on the amount of single versus double track. For example, see the report by Schwarm (8).

Single-track and double-track costs are based on recent data from actual design studies collated by Spenny (2), summarized below (since the 25-kV systems, which are most likely to be used in the East, are more expensive than the 50-kV systems prevalent in the West, the costs dictated by the 25-kV system are used):

| Item | Cost ($000s/track mile) | |
	Single Track	Double Track
Catenary	160	280
Substation	80	140
Utility connection	15	20
Signaling and communication	130	190
Civil reconstruction	50	70
Engineering	65	100
Total	500	800

Locomotive Investment and System Maintenance

Diesel locomotives, which have an 18-year life, will be replaced with more-powerful, more-efficient electric locomotives that have a 30-year life. Displaced diesel locomotives not worn out will continue to be used in the nonelectrified portion of the system. Maintenance costs for the electric locomotive are $0.65/unit mile as opposed to $1.33/unit mile for diesel locomotives. Catenary maintenance rates of $2500 and $4400/route mile of single and double track, respectively, are included in the electric operating system. As electrification occurs, diesel locomotives will still be needed in other parts of the system and will be transferred or sold for alternative service.

Due to higher availability and increased horsepower, 12 electric locomotives rated at 5100 hp that have a 75 percent availability should replace 35 diesel electrics rated at 3000 hp that have a 50 percent availability. According to information from General Electric and General Motors, diesel-electric locomotives cost about $300/hp, whereas electrics when ordered in quantity will cost from $240 to $300/hp. Our present-value analysis indicates that electric-locomotive costs, which include locomotive and catenary maintenance, are about 2.5 times less than the cost of a comparable diesel-locomotive capability, including the maintenance.

ESTIMATING FUEL SAVINGS

A realistic value for the fuel saved for each ton mile that is shifted from diesel-electric to pure electric locomotion depends on many variables, particularly on the type of service offered, the terrain of the route, and the composition of the consist. Table 2 indicates the wide range of values that could be considered. For most of this analysis an average of 1.8 gal/1000 gross ton miles is used. This value is also varied to show the sensitivity of results to electrification of high-density routes that operate on either high-speed manifest service (2.4 gal/1000 gross ton miles) or drag service (1.2 gal/1000 gross ton miles).

Table 2. Fuel-use factor from simulations and other data sources.

Variable	Tonnage (billion gross ton miles)	Fuel Used (million gal)	Use Factor (gal/1000 gross ton miles)
1978 average[a]	2092	3718	1.77
Mixed freight ([1])	38	47	1.24
High-speed freight ([1])	68	124	1.82
Unit coal train ([1])	30	22	0.74
10 000-mile network ([1])	502	950	1.88
Drag or general freight service [([4], Table 37)]			0.94-2.29
Manifest service [([4], Table 37)]			1.24-2.61
Trailer-on-flatcar service[b]			3.88

[a] Computed from 1978 Association of American Railroads Yearbook of Railroad Facts by combining average data on fuel used, revenue ton miles, and car miles (tare weight of 32 tons/car).
[b] Computed from data found in DOT publication on intermodal freight program ([9]).

There is also a difference between the gross ton miles moved per horsepower of diesel locomotion and electric locomotion. The ratio of locomotive to consist weight for diesel electrics can vary from 11 percent (at 1.5 hp/ton) to 25 percent (at 3 hp/ton), depending on service and ruling grades, whereas electrics may vary from 7 to 14 percent for the same consist. This paper uses 17 percent for the diesel electric and 7 percent for the electric. To convert revenue tons to trailing tons, a factor of 2.1 [consistent with Association of American Railroads (AAR) data] is used.

The amount of electricity consumed by the electrified system, measured at the rail substation meter, will vary from 10 to 14 kW·h/gal of diesel fuel needed to pull the same trailing tons. The value used in this paper is 12 kW·h/gal. [The conversion from gallons to kilowatt-hours at the meter considers factors of the efficiency of the diesel at 30 percent, the fact that no electricity is used when trains are stopped, and losses of 20 percent from the meter to the rail. At 136 000 Btu/gal and 3412 Btu/kW·h, this factor is 10.46 ([10], pp. A-12, 14).]

COMPARISON OF RAILROAD ELECTRIFICATION BY USING SYNTHETIC FUELS

A major reason for this investigation is to compare diesel fuel savings from railroad electrification with the cost of providing the equivalent amount of freight movement by using diesel fuel produced from coal. National averages are used for the investment time line and the related output levels for the coal-liquefaction plants.

Investment in Place

For a variety of reasons, which include geography and the availability of other resources such as labor and water, the output in barrels per day per dollar invested for liquid-coal plants ranges from $36 000 to $50 000 of investment ([11]).

Figure 1 shows the average number of barrels of diesel fuel saved per day when the assumed railroad investment is in place. Even with no growth, scenario B saves about one-half the diesel fuel used by railroads today. With 2 percent freight growth, the saving on the 25 600-mile network grows from about 220 000 bbl/day on completion to almost 350 000 bbl/day in year 50. Figure 2 shows the investment in dollars (total made in years 1-30) divided by the average number of barrels per day saved in years 31-50 for six different railroad-electrification cases: (a) the three scenario levels that have average service (1.8 gal/1000 gross ton miles) and 2 percent annual freight growth; (b) case a when the marginal cost of the electric utility investment is added; (c) manifest service (2.4 gal/1000 gross ton miles) operating on the 9250-mile network with annual freight growth rates of 0, 1, 2, and 3 percent; (d) the 25 600-mile network with 2 percent annual freight growth and various service levels from drag to manifest; (e) the savings on the 9250-mile network at completion and 10 and 20 years later with 2 percent freight growth; and (f) the Southern Railroad route from Cincinnati to Atlanta, based on a 20-year average with 0, 1, and 2 percent annual growth in traffic. [For the Southern Railroad, data were obtained verbally from the Tennessee Valley Authority. Briefly, the route is 500 miles long, consists of 750 track miles, and carries 80 million gross tons annually. The ratio of horsepower to gross tons averages 1.63. When the equivalent work of 1 gal of diesel fuel is done, 14.2 kW·h are consumed. Electricity prices for 1980 were

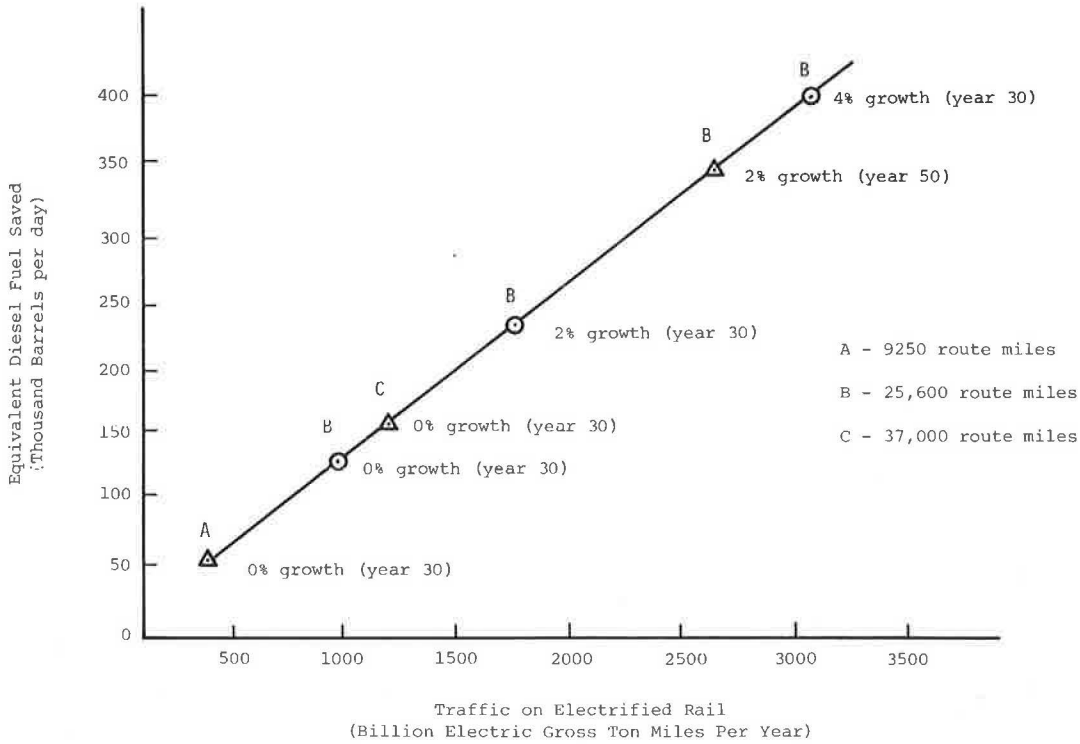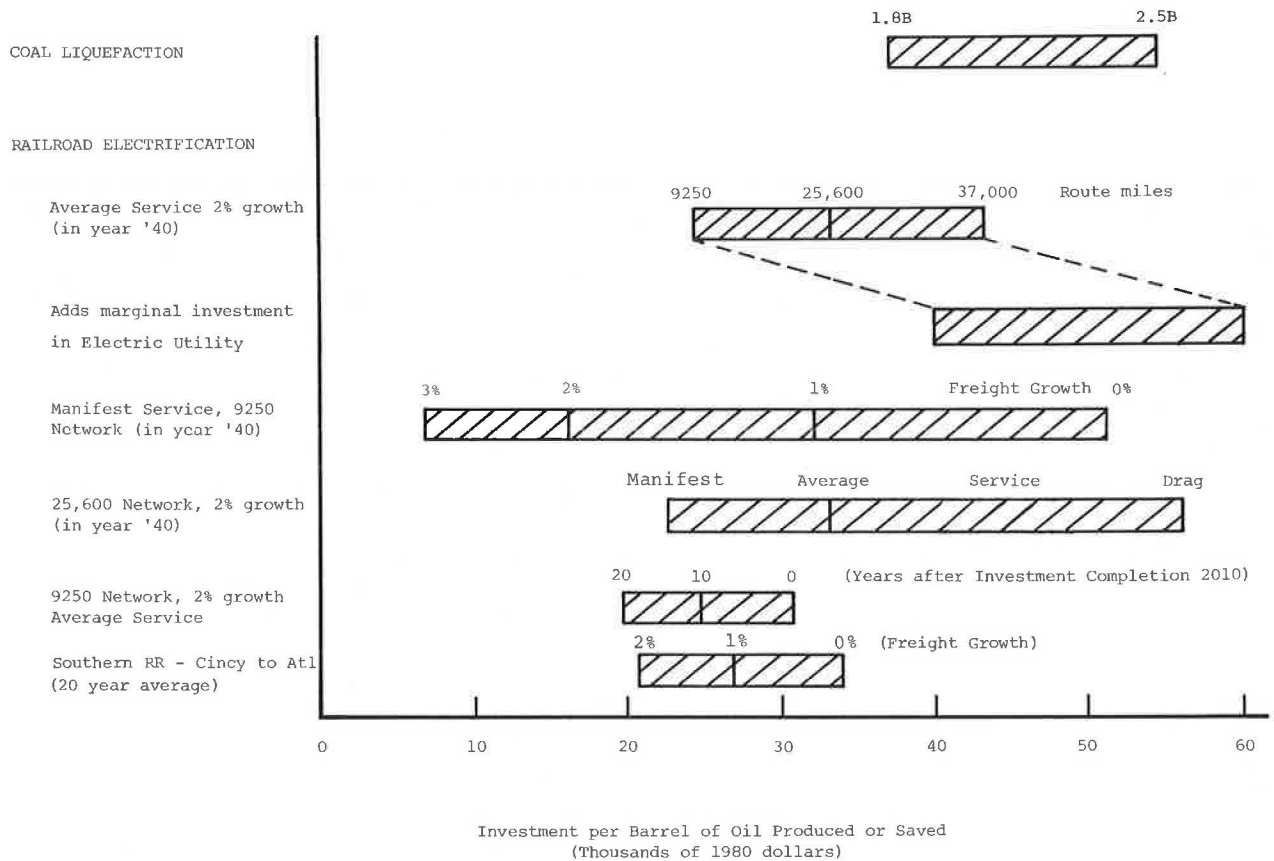**Figure 1. Fuel saved as function of traffic on electrified routes.**

Figure 2. Investment per barrel of oil equivalent produced or saved.

$0.29/kW·h. Fixed plant investments are estimated to be $176.5 million, whereas $82 million is required for new locomotives. This analysis also provides cost reimbursement for diesel-electric locomotives that will be replaced and moved to nonelectrified service.]

The marginal power plant investment is calculated to be about $15 000-$20 000/bbl/day. This amount would have to be added to the other investment cases shown to cover the full national investment. In the analysis below, the average electricity rate of $0.04/kW·h includes about $0.13 to cover the capital charge rate of the electric utility investment (2).

Present Value of Time-Phased Investment

An alternative method for comparing investment in electrified railroad construction with investment in liquid-coal fuel-plant construction is to calculate the present value of the stream of investments for equal fuel saved or produced over time. The railroad investment, for example, will be made over many years as more miles are electrified and as the freight traffic grows. If synthetic-fuel plants are built on a schedule to produce diesel fuel (equivalent British thermal units) in amounts identical to the savings attributed to rail electrification, the two streams of time-phased investments can be compared on an equivalent economic basis. The money rate that was used for the analysis is the July 1980 U.S. Treasury Note Redemption Quoted Rates for 2005-2010 (10.27 percent). Table 3 shows the net present value of investments for a 50 000-bbl/day synthetic-fuel plant--in the range of $1.8-$2.5 billion--and the values for two electric locomotives, $240/hp and $300/hp.

The model used for each synthetic-fuel plant was six to eight years from start of construction to full production and construction investments of 20 percent in the fourth year, 60 percent in the fifth year, and 20 percent in the sixth year (12). This comparison also indicates that, as energy alternatives, the present values of investment in railroad electrification and coal liquefaction are reasonably close.

Total Price per Barrel of Oil Saved

It is also possible to compare the total cost per barrel of oil equivalent by adding the variable costs and feedstock costs to the capital payments on debt. This comparison would be equivalent to the railroad's having a pool of oil that they could use for their diesel-electric system or sell if the economics are favorable to electrifying the track and purchasing electricity for fuel.

In the scenario suggested here, the amount of variable or operating cost for the synthetic liq-

uid-coal plant is relatively constant over time. However, the estimates vary in value from $7.60/bbl (2) to costs well above $10.00/bbl (13). For electrification, the operating or variable cost applied will be the difference between the maintenance of the diesel locomotive and that of the electric locomotive plus its catenary. Because of the lower maintenance costs of the electric locomotive, this element of variable cost for the railroad is negative. It is assumed that all other variable railroad costs remain the same as those for the baseline diesel system.

The feedstock for the synthetic-fuel plant is coal; for the electrified rail, it is the electricity delivered to the railroad substation. Data from liquid-coal plants indicate that about 22 000 tons/day are required to produce 51 000 bbl/day of fuel oil equivalent (13). As previously indicated, about 12 kW·h are needed to produce the same effect at the rail as 1 gal of fuel; thus 1 bbl/day is equivalent to 504 kW·h/day. At $0.04/kW·h, the electricity to save one barrel of oil costs $20.52/bbl, whereas by using coal at $22.50/ton, it costs $9.70 to produce one barrel of oil. To compare the write-off of the capital investment over time, identical capital charge rates are used for both the liquid-coal plants and the railroad. They are based on 45 percent debt at 15 percent interest and 55 percent equity funding at 20 percent return on equity.

Table 4 shows that the minimum price per barrel of oil produced by an operating mature synthetic-fuel plant is about $42. Estimates of the delivered price range from $48 to $55/bbl. The price of fuel saved from operating a 1000-mile segment of electrified single or double track varies according to the gross tonnage carried. With no future growth, the price per barrel for a double-track road carrying 80 million gross tons is $35.

Figure 3 shows the equivalent price of diesel fuel saved for varying annual tonnage. Figure 4 compares several fuel options and clearly indicates that electrification is already competitive (14-16). Also shown is the estimate of cost per barrel of petroleum that would be saved by electrifying the Southern Railway route from Cincinnati to Atlanta. For traffic of 80 million gross tons with an 11 percent annual capital charge rate, that cost appears to be about $26/bbl of oil saved.

Energy Efficiency

The comparison of alternatives is not complete without a review of anticipated efficiencies. The relative efficiencies for supplying refined fuels from crude oil, shale oil, and the several coal liquefaction processes range from about 0.9 to 0.7. As technologies develop, that efficiency may improve; however, compared with that of petroleum (0.85-0.95), efficiency of synfuel technologies will always be considerably less (13).

Figure 5 shows that an electrified rail system that uses electricity from a utility fueled by coal has about the same efficiency for energy delivered to the track as does a diesel-electric locomotive that operates on diesel fuel from crude petroleum (16). When coal is turned into synthetic crude, however, there is a sizable reduction in energy efficiency. Further efficiency benefits accrue to the electric system from reduced locomotive weights (provided there is adequate adhesion) and from the potential of relatively easily obtained regeneration for start-stop operation and travel on hilly terrain. A study by Carnegie-Mellon University (17) shows a possible 9 percent improvement on the Harrisburg-Pittsburgh route of the Consolidated Rail

Table 3. Present value of railroad electrification compared with that for liquid-coal plants.

Type of Investment	Net Present Value (billions of dollars)		
	2% Freight Growth in 30 Years	2% Freight Growth in 50 Years	4% Freight Growth in 50 Years
Railroad electrification (scenario B)			
With locomotives at $240/hp	3.19	3.95	2.01
With locomotives at $300/hp	3.41	3.20	2.41
Liquid-coal plants (50 000 bbl/day)			
At $1.8 billion/plant (20-year life)	2.65	2.92	4.47
At $2.5 billion/plant (20-year life)	3.69	4.05	6.22
At $2.5 billion/plant (40-year life)	3.42	3.58	5.05

Table 4. Technology specifications.

Capital Cost ($)	Operating Cost ($)	Feedstock Cost ($/bbl)	Construction Time (years)	Debt Life (years)	Useful Life (years)	Minimum Price per Barrel of Oil[a] ($)
Coal Liquids (Mature Liquid-Coal Plant)						
2.5 billion per 50 000-bbl/day capacity	10/bbl	9.70[b]	8[c]	16[c]	20	42 (48-55)
Railroad Electrification						
800 000/double-track mile 500 000/single-track mile[d]	800/million trailing ton miles savings 4400/double-track mile catenary maintenance cost 2500/single-track mile catenary maintenance cost	20.16[e]	3/segment	20	30+	

[a] Amortization rate at 0.163 (45 percent debt at 15 percent interest and 55 percent equity at 20 percent return on equity).
[b] Coal at $22.50/ton = 0.43 ton/bbl of synthetic diesel fuel.
[c] Backus, Greene, and Masevice (12, p. 51).
[d] Less locomotive capital savings.
[e] 504 kW·h at $0.04/kW·h.

Figure 3. Price of fuel saved versus annual traffic.
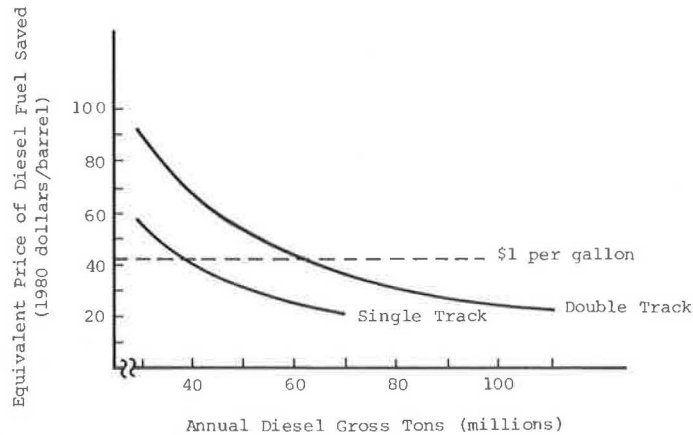

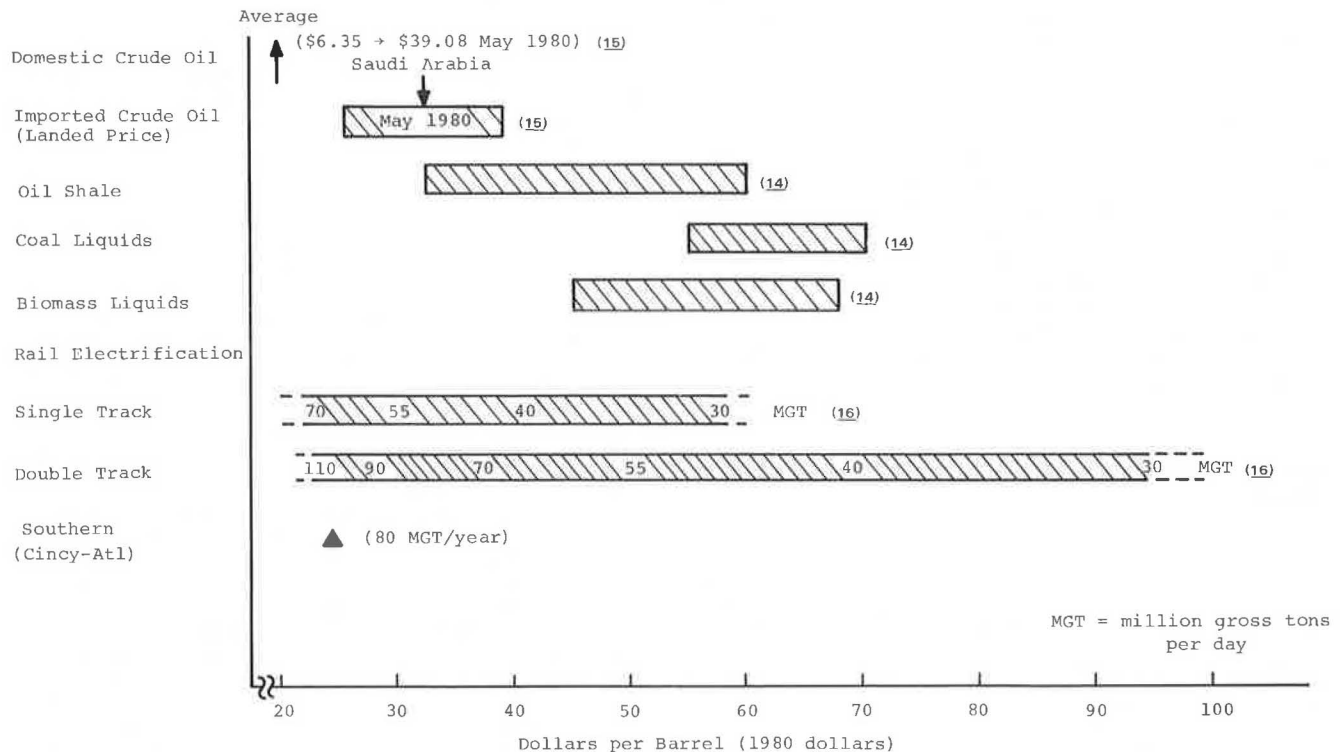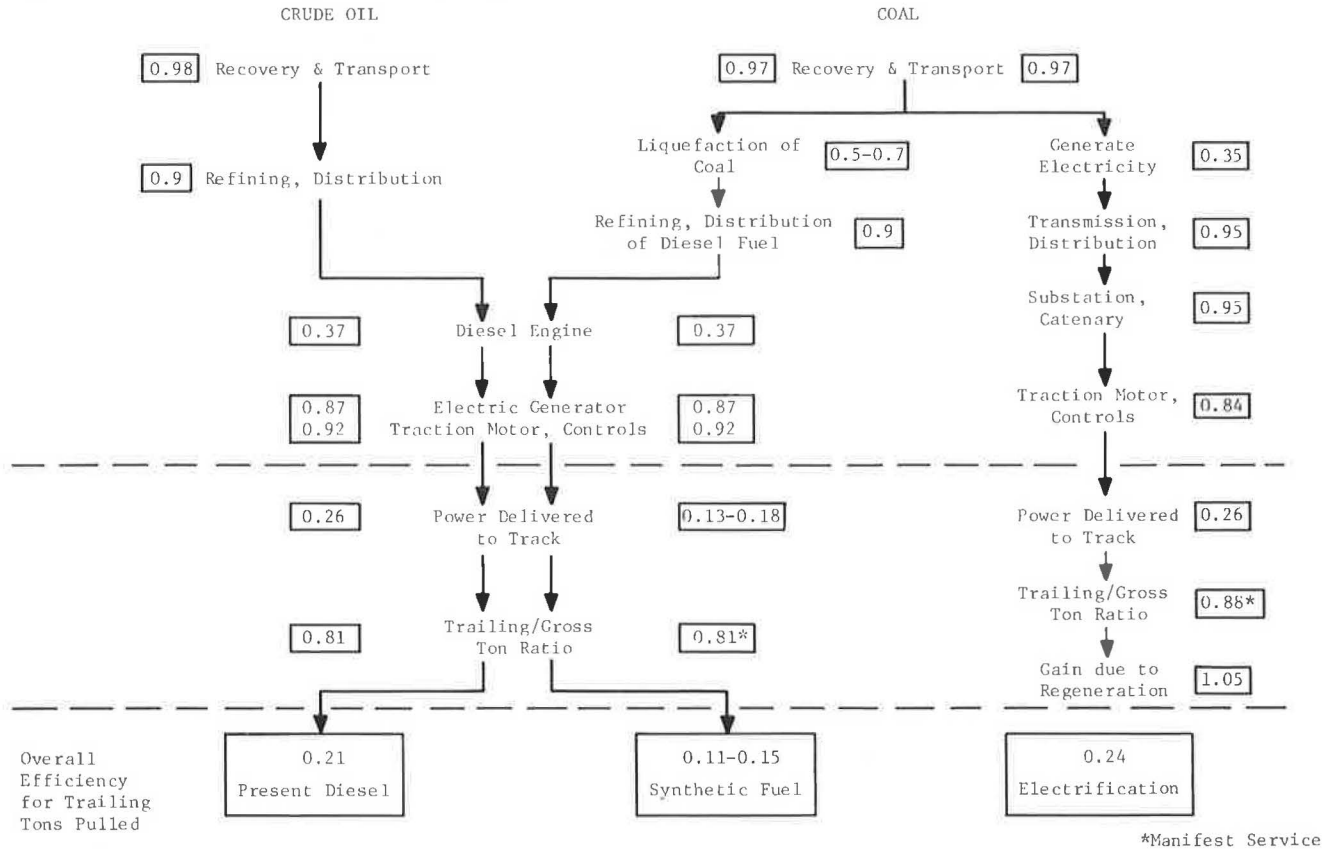**Figure 4. Costs of oil saved or produced by various fuel options.**

Figure 5. Relative efficiencies of freight movement by using petroleum and coal.

CRUDE OIL   COAL

| 0.98 | Recovery & Transport | | | 0.97 | Recovery & Transport | 0.97 |

Liquefaction of Coal — 0.5-0.7   Generate Electricity — 0.35

| 0.9 | Refining, Distribution | | Refining, Distribution of Diesel Fuel | 0.9 | | Transmission, Distribution | 0.95 |

Substation, Catenary — 0.95

| 0.37 | Diesel Engine | 0.37 | | Traction Motor, Controls | 0.84 |

| 0.87 / 0.92 | Electric Generator Traction Motor, Controls | 0.87 / 0.92 |

| 0.26 | Power Delivered to Track | 0.13-0.18 | | Power Delivered to Track | 0.26 |

Trailing/Gross Ton Ratio — 0.88*

| 0.81 | Trailing/Gross Ton Ratio | 0.81* |

Gain due to Regeneration — 1.05

Overall Efficiency for Trailing Tons Pulled

| 0.21 Present Diesel | 0.11-0.15 Synthetic Fuel | 0.24 Electrification |

*Manifest Service

Corporation (Conrail). If we discount somewhat for national average, 5 percent is assumed for regeneration improvement.

In addition, the energy lost from the diesel is lost to the outside air. However, for the electric-generating plant it is possible to improve efficiency by using the lost heat for cogeneration. Although the diesel-electric locomotive efficiency is now being improved, the theoretical limits on the efficiency of the internal-combustion engine would still place it well below an electric-generation plant with known cogeneration potential.

Technological and Environmental Risks

With more than 62 000 route miles of electrified railway in the world today, there is no apparent technological risk. However, there are no commercial-scale processes that now exist to provide coal liquids directly. (The Exxon Donor-Solvent SCRII, catalytic hydrogenation, and several other processes have been developed, but only on a pilot scale.) Low-efficiency indirect liquefaction techniques, such as the Fischer-Tropsch process, have been developed and are in use in South Africa (SASOL plants). Methanol can also be produced from coal gases by using known technologies; however, the conversion of methanol to transportation fuel has only been accomplished on a small-scale basis with the Mobil zeolite process (13).

Environmental and societal impacts exist for all the options; however, most electrification effects are known and are not severe when compared with those from synthetic-fuel development. New liquid-coal plants and above-ground retorting of shale require significant amounts of water from a limited or distant supply. The influx of workers to staff new synfuel plants in the West will create the need for new towns, which will require both services and land. There are potential health hazards to workers in coal-liquefaction plants from handling the toxic and carcinogenic products and byproducts.

Although the additional electricity needed to power locomotives will increase power-plant pollutants, the pollution source is stationary rather than mobile, which makes environmental control much easier. As far as noise and emissions are concerned, electrified railroads are much quieter than their diesel-powered counterparts. Deterrents to rail electrification may be the aesthetic effect (disruption of the landscape by the catenary), the increased number of transmission lines, or the minor (but real) safety hazard represented by the miles of exposed catenary.

SOME FINANCIAL CONSIDERATIONS

The intent of a financial discussion is to briefly examine the investment in its relationship to the energy question. A present-value analysis has been performed by using the weighted cost of capital in 1980 dollars. This approach, which accounts directly for the percentage of equity in electrification, the desired return on equity, the interest rate on commercial loans for electrification, and the tax rate (which reduces the interest cost), is used to evaluate the cost-effectiveness of the present worth of the investment.

Analysis shows that the average annual rate of return, even with no growth in freight and with minimum anticipated increase in fuel prices of 1 percent per year, is more than 13 percent even for the most ambitious scenario (C), which earns the lowest amount. The average annual pretax rate of

return, shown in Figure 6, is sensitive to freight growth and fuel-escalation approaches but relatively insensitive to the network scenarios. One fuel-escalation rate, reflective of some current views of the fuel-price increase, predicts the increase in the real price of fuel to $3.00/gal in 10 years followed by a slow growth to $4.00 in 50 years. In each case, electricity price growth is held constant at 1 percent in real terms.

For the annual freight growth of 2 percent, there is a general and substantially significant high average rate of return over the 50-year period. The difficulty is time phasing the investment and return. At the investment costs given, electrification of the Los Angeles-Chicago route, on which fuel savings can be very great, can take up to 6 years and will cost from $1.5 to $2 billion. This significant sum is the equivalent of the 1978 sales and about 15-20 times the 1978 profit of the Santa Fe Railroad (one of the more economically healthy railroads in the nation).

One financing approach would be to set up an investment company, which might be called the Corporation for Rail Electrification (CORE). CORE would provide the investment for the fixed plant and then lease it to the railroad at a predetermined rate, perhaps based on a computed value of fuel saved or electricity used. The railroad would buy the electric locomotives as well as operate and maintain the system once built. Figure 7 plots the equivalent return to the railroad and cost to CORE as a function of fuel saved for the assumptions indicated. If CORE adds a charge of 20 percent of total expense for management plus profits and a lease charge of $45/bbl of fuel saved, or about $0.09/kW·h used, the net present value becomes positive about the middle of the 17th year.

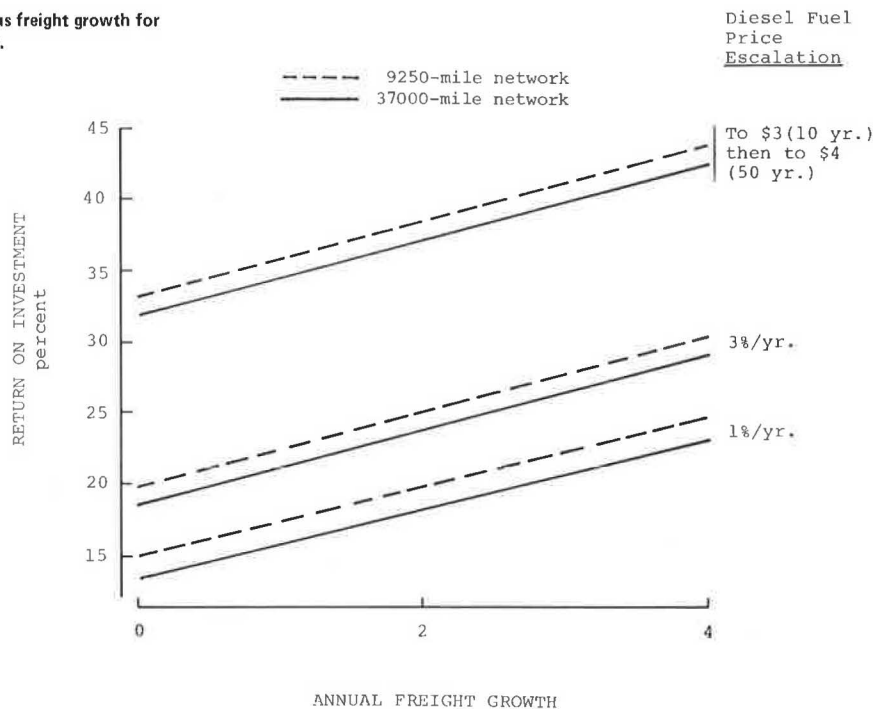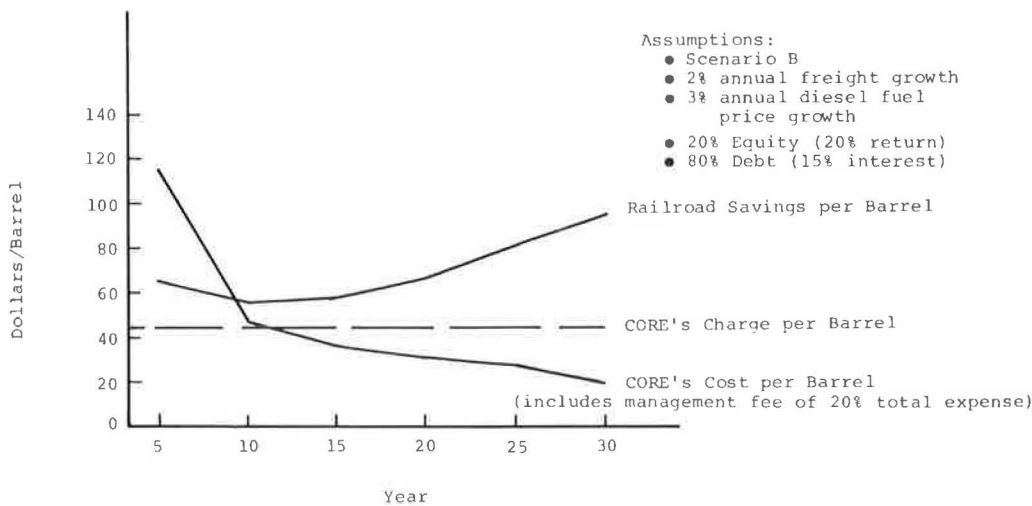Figure 6. Rate of return versus freight growth for three fuel-escalation scenarios.

Figure 7. Cost per barrel to CORE versus railroad savings per barrel.

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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Energy Considerations for Railroad Electrification in the United States

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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-