Topic Paper #2

Rail Transportation Demand

On August 1, 2012, The National Petroleum Council (NPC) in approving its report, *Advancing Technology for America's Transportation Future*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Task Groups and/or Subgroups. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

Freight Rail Fuel Requirements to 2050

Demand Task Group / Rail Subgroup

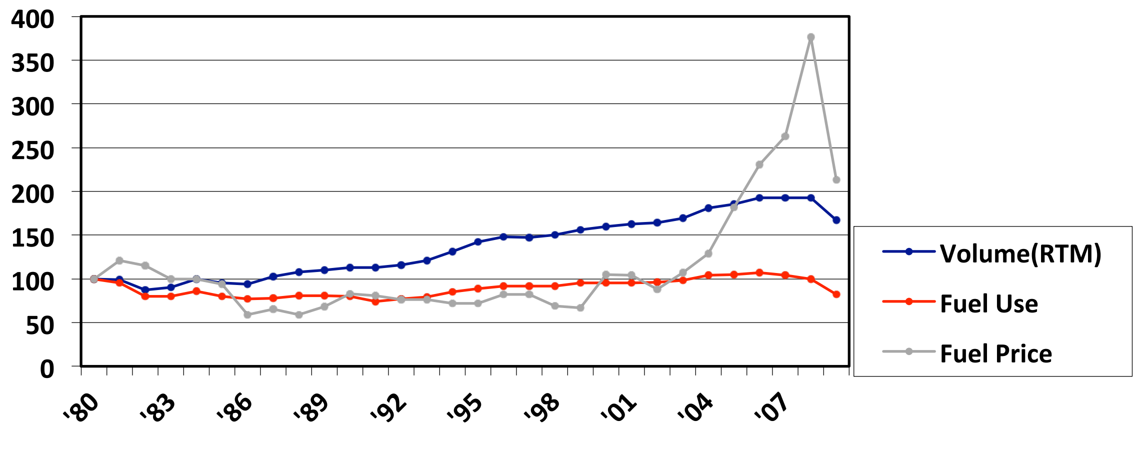
Background

The United States is served by the most efficient, affordable, and environmentally responsible freight rail system in the world. The seven large Class I railroads,[1] in conjunction with more than 500 local and regional railroads, carry 43 percent of intercity freight ton-miles — more than any other mode of transportation.

From 1980 to 2007, freight rail traffic nearly doubled from 919 billion ton-miles to 1.771 trillion ton-miles — an average annual gain of 2.5 percent. Growth accelerated towards the end of this period, especially from 2003 through 2006, when growth reached 4.1 percent annually.

Fuel efficiency has been the subject of intense railroad management focus for many decades — stemming from the intense pressure to control costs of all production factors: labor, materials, and consumables such as fuel. In 1980, one gallon of diesel fuel moved one ton of freight an average of 235 miles by rail. Today, railroads haul a ton of freight an average of 480 miles on a single gallon of fuel — a 104 percent improvement since 1980. This productivity improvement has permitted a doubling of the rail traffic during this time period while total fuel consumption has remained virtually unchanged at approximately 3.9 billion gallons annually.

United States Class I Railroads
Freight Volume and Fuel Usage and Price
1980 – 2009



Source: Reports R-1 to the Surface Transportation Board 1980 – 2009

[1] Class I railroads — those with freight revenues of $378.8 million or more in 2009 — operated 67 percent of U.S. roadway and earned over 93 percent of the industry's freight revenues.

Since completing the conversion from steam locomotives around 1960, the freight railroads have relied almost exclusively on diesel-electric locomotives for both road (line haul) units and switch locomotives. The typical road unit purchased during the past decade employs a 2- or 4-cycle diesel engine with 4,000–4,500 horsepower to drive an alternator, which then supplies electrical power to operate traction motors mounted on six drive axles. As of 2009, U.S. Class I railroads had 24,040 diesel-electric locomotives in service. During 2008, before the worst of the recession-driven decline in traffic, the Class I railroads consumed 3.897 billion gallons of fuel, of which 3.586 billion were for line haul service, 300.5 million were used in yard switching, and 10.5 million were used in passenger service (principally for commuter operations).

A major portion of the railroads' gain in fuel efficiency has resulted from their massive investments in roadway and structures, locomotives, and freight cars. Unlike trucks and barges, which travel on highways principally paid for by passenger vehicle user fees and public funds, and waterways that are mainly paid for by the government, America's freight railroads operate almost exclusively on infrastructure that they build, maintain, and pay for themselves. In fact, from 1980 to 2009, railroads re-invested more than $460 billion of their own funds on locomotives, freight cars, tracks, bridges, tunnels and other infrastructure. Their ability to carry the traffic that is forecast for rail, and to continue to improve their fuel efficiency, will depend in large part on their financial condition in the years ahead.

Historical Rail Traffic Trends

Since the Staggers Rail Act of 1980 eliminated many of the most damaging regulations that hindered efficient, cost-effective freight rail service, freight rail traffic nearly doubled from 919 billion ton-miles in 1980 to 1.771 trillion ton-miles in 2007— an average annual gain of 2.5 percent. By offering improved service — in large measure the result of improvements in the physical condition of their equipment and infrastructure made possible by their improved financial condition — and almost tripling productivity which permitted them to cut their rates in half in inflation-adjusted terms, railroads have gained traffic. Rail market share (measured in ton-miles) has trended slowly upward and is now 43 percent, following decades of decline.

Railroads also benefitted from two key developments during this period: the rapid expansion of coal movements from the Powder River Basin to utilities across much of the Nation (increasing tonnage hauled moderately, and greatly increasing average length of haul), and the huge influx of imported containerized traffic, particularly through the West Coast ports (and, to a lesser degree, an increase in export traffic moving by rail).

Railroads moved record tonnage in 2006, despite serious weakness in two key sectors: automobiles and lumber (which is tied to the housing market). Other business lines offset those weak traffic segments until November 2008, when the growing recession finally spread to all of the other rail traffic. In 2009, rail ton-miles fell by 13.8 percent. Traffic is growing moderately again as the economy emerges from the recession, although it will take additional time to return fully to pre-recession levels.

Rail Traffic Forecast: AEO 2010 Base Case

The Demand Task Group has adopted the U.S. Department of Energy's Annual Energy Outlook 2010 as the base case for the NPC study. The AEO analysis of energy use by freight rail is developed in the Transportation Sector Module of the National Energy Modeling System (NEMS) — specifically in the Rail Freight Submodule. The projections are based upon estimated rail traffic, measured in ton-miles, and an estimate of rail energy efficiency.

Rail coal traffic (in ton-miles) is estimated based upon coal production for two regions: East and West. Ton-miles are estimated based upon total tonnage produced in each region and the distance the coal moves. Other rail traffic is estimated for 12 industrial categories used in the Trucking Submodule, using a projection of the value of output by the sector and a factor associating rail traffic growth to growth of industrial output on a value basis for each category of traffic:

1. Chemicals, Rubber, and Plastic
2. Primary Metals
3. Processed Food
4. Paper Products
5. Petroleum Products
6. Stone, Clay, Glass, Concrete
7. Metal Durables
8. Other Manufacturing
9. Agriculture
10. Mining
11. Utility
12. Government

The freight railroads have concerns with several aspects of the Base Case:

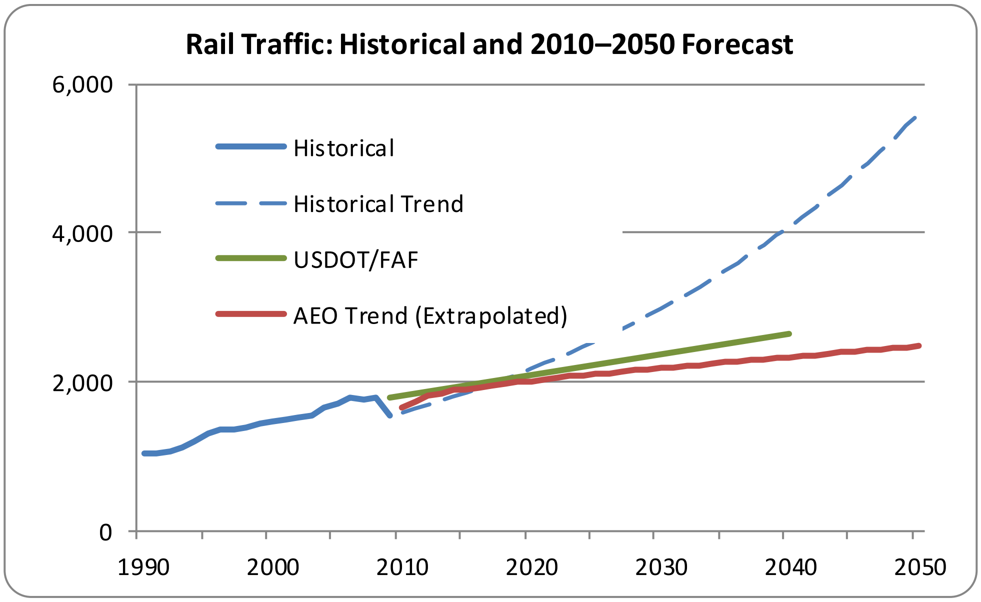
Total Rail Ton-Miles: Because the historical traffic data used to forecast rail traffic reflects only the Class I railroads, it understates total rail traffic by an estimated 3–5 percent.

Traffic Growth: The AEO forecast for 2007–2035 assumes an average compound annual growth rate (CAGR) for rail ton-miles of 0.8 percent — far below the historical increase of 3.2 percent achieved by the Class I railroads from 1990 to 2007, prior to the recession that began in December 2007. For this study, the AEO 2010 forecast has been extrapolated to produce estimates for 2036–2050 by applying the 0.63 percent average growth rate from the period 2030–35 to the 2035 traffic forecast — resulting in a forecast of 2.479 trillion ton-miles. By comparison, application of the historical growth rate to the reduced 2009 level of traffic results in an estimate of 5.607 trillion ton-miles in 2050.

While freight railroads have been increasing their share of traffic ton-miles for the past two decades or so, and these forecasts generally assume only maintenance of each mode's share (or, in the case of AEO 2010, each mode's relationship to value The U.S. Department of Transportation has forecast an increase in tonnage of 48.3 percent from 2009 to 2040, or 1.3 percent annually in its recently released Freight Analysis Framework 3.[2] Assuming that rail

[2] See U.S. Department of Transportation, FHWA Freight Management and Operations, *Freight Analysis Framework 3* at http://ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm.

length of haul also increases, this would represent something significantly above the AEO 2010's 0.8 percent growth and the historical trend.



Because we have no way of anticipating new developments that will reshape the transportation landscape over the next several decades — if not the entire economy — it is not possible to accurately forecast rail traffic levels 40 years hence. A critical determinant of rail traffic levels will undoubtedly be public policy, as it unfolds. First, some proposals to increase economic regulation of the railroads would curtail rail earnings sufficiently that future investments in rail infrastructure and capacity — made almost entirely by the private sector railroads themselves — would be reduced, preventing railroads from maintaining their market share. Second, energy policy and concern about greenhouse gas emissions — along with environmental regulations and development of Clean Coal technologies — will drive the future use of coal in the U.S. and the resulting level of coal traffic. Since coal accounts for nearly half of the Class I railroads' tonnage, coal traffic levels will be a major determinate of the industry's fuel requirements.

In addition to these negatives, the industry also has tremendous opportunities to increase market share in the decades ahead. These rail traffic forecasts ignore entirely the potential for modal shifts given the energy and environmental advantages of rail. As such, it represents a status quo base line, leaving the Demand Task Force free to examine opportunities for shifting freight to rail.

Coal: Using a separate approach for coal is certainly sensible, given that coal represented over 47 percent of tonnage originated by U.S. Class I railroads in 2009, and the AEO of necessity focuses significant resources on the coal production estimate. That said, there is considerable uncertainty about future production levels for coal, both for the primary utility market and the export market. Basing the estimate on a simple East-West split (i.e., ignoring Illinois Basin production as a separate source), and not examining specific market opportunities for rail and related origin-destination service requirements, results in a broad aggregation of the analysis. We have not seen details of the resulting coal traffic forecast, and therefore cannot comment on its reasonableness.

Other Traffic: The traffic categories from the truck subsector model represent many of the products commonly transported by rail, although it is unclear how fully the Agriculture category reflects grain, oilseeds, primary forest products, and lumber and wood products; or how well Other Manufacturing reflects the key motor vehicles and parts segment of rail traffic. Even more seriously, rail intermodal traffic, which accounts for over 15 percent of rail ton-miles, appears not to have been analyzed. An analysis based on a slightly different set of commodity groups might produce an estimate more closely aligned with rail markets.

The macro economic forecasts of value of output by sector have not been reviewed, nor has the development of the factor that relates rail traffic growth to output in the various segments of the economy. Finally, we have not seen the base level traffic figures.

External Factors with the Potential To Produce Dramatic Shifts in Rail Traffic

The railroads face several external factors that could significantly reduce major segments of their traffic base, or hamper their ability to provide the capacity necessary to handle the forecast traffic efficiently.

Coal/GHG policy: The markets in which coal will participate in the future remain the subject of conjecture. At this time there are no substitutes for coal which have sufficient capacity or which have displayed sufficient long-term price stability to meet national power generation requirements. However, coal remains under attack due to its power generation role and the degree to which this role results in the production of carbon dioxide. Whether technology that permits coal's efficient, clean use will be allowed to proceed to commercial development also remains a policy question. However, because coal remains the most plausible and reliable source of energy independence, it will be necessary to resolve these two potentially conflicting policy positions at some point in the future. At the same time this domestic debate is taking place, it is also clear that a very significant international market is developing for American coal. How resolution of these complex policy and market issues takes place will have a dramatic impact on the rail industry since coal movement represents about one-quarter of rail revenue and almost 50 percent of rail tonnage handled. Any significant reduction in coal use would strand billions of dollars of rail assets, and result in the elimination of many thousands of rail jobs, as there is no other traffic for rails to handle to or from the top coal mining regions of the Powder River Basin in Wyoming and Montana, the Appalachian states of Kentucky, West Virginia, and Pennsylvania, or the Interior region mines of Illinois and Indiana. Unfortunately, for purposes of this study, it is not possible to reliably predict the outcome of either the policy debate or the market developments. We can only note that this outcome will have many significant impacts on the rail industry.

Reregulation/financial shortfalls: Despite the enormous benefits that have accrued since railroads were partially deregulated in 1980, and the severe harm that excessive rail regulation caused prior to the Staggers Act's passage, some groups are calling for the re-regulation of railroads. However, the artificially-lower rates that would be brought about by re-regulation would translate directly into lower rail earnings — and this, in turn, would lead to lower spending on rail infrastructure and equipment — outcomes that are incompatible with a growing, healthy economy. Railroads would be unable to add capacity as needed to handle a growing freight market.

Rail Intermodal Service: Rail Intermodal business has also been an area of significant growth over the past two decades —and an area where growth can be expected to continue going forward. Much of the last decade's growth has been driven by the expansion of imported goods mostly moving from the West Coast ports to inland points in the U.S. However, since 2008 the growth has been driven more aggressively by domestic movements seeking to take advantage of improving intermodal service levels and economics that were more attractive and stable than those provided by truck competition. These economic advantages first became clearly favorable during the 2008 fuel price spike and appear to have been sustained even during the recession. The economics were reinforced by rail service improvements that were driven by a decade of high capital expenditures on upgrading and expanding the capacity of the rail network. Both of these factors came together at a time of growing awareness of environmental issues that placed an emphasis on minimizing carbon dioxide production accomplished through the relatively low fuel utilization of rail transportation.

All of these factors have come together at a time when emerging public policy proposals suggest that intermodal freight transportation is an effective remedy for both environmental concerns and highway congestion relief. The recently released National Rail Plan Update prepared by the Department of Transportation's Federal Railroad Administration suggest that an appropriate national goal would be the conversion of at least fifty percent of all traffic in the United States that moves over five hundred miles to intermodal service. Whether this goal will become Federal policy remains to be seen. However, the implication of the suggested goal is clear – rail intermodal transportation provides an effective way to combine the values of rail and truck distribution in order to meet environment, fuel conservation and quality of life goals in a manner that is cost effective for transportation users. The latter point is critical in this issue since public policy, by itself, will have no effect on mode choice. Only the total economics for the transportation user will ultimately determine their willingness to use rail intermodal or to use motor carriers who specialize in this mode.

The net result of all of these factors is that, absent negative events, intermodal will, in all probability, continue to be the leading growth engine in the rail business and will continue to grow at rates exceeding those of other business lines. The most important economic factor that will determine the rate of this growth is likely to be fuel price. To the extent that fuel prices increase, the economic advantage of intermodal improves —as does the advantage of all rail freight business lines. To the extent that prices are stable the relative position of intermodal in the economic market is likely to stay the same, unless other factors such as truck safety regulation or changes in user fees alter the relative economic of the two modes.

Truck Size and Weight: The most important potential negative policy change related to intermodal and all other rail business levels are changes in government positions on truck size and weight. Analysis has indicated potential diversion to truck of 15–20 percent of rail business if allowable truck weights were increased to 97,000 pounds from the current 80,000 pounds. Additional business diversions would also take place if truck lengths were allowed to substantially increase. The area of this latter diversion would be almost entirely from rail intermodal business. However, this diversion could be eliminated if truck facility user fees were increased to reflect motor carrier payment of the total costs of their impact on highway infrastructure at the levels suggested over the past decade by the Federal Highway Administration.

Rail Passenger Service: As the Federal Railroad Administration's recent *Vision for High Speed Rail in America* points out, a combination of express and regional high-speed corridors — evolving from upgraded, reliable intercity passenger rail service — has helped reduce fuel use, enhance mobility, and foster interconnected communities all around the world. Efforts are underway to make it happen here too. On average, each day in 2008 approximately 78,500 people rode one of 315 Amtrak trains on 43 different routes — 29 million passengers in total. Approximately 71 percent of the miles traveled by Amtrak trains were on tracks owned by freight railroads. Striking the right balance while growing both passenger and freight rail is key to ensuring that railroads keep America's economic engine running. Because America's economic health and global competitiveness would suffer if freight railroads were impaired by passenger railroads, great care must be taken to ensure that there is enough capacity for current and future freight and passenger rail service. In all cases, though, safety concerns must be paramount, and compensation and liability issues must be addressed fairly.

Historical Rail Fuel Efficiency Trends

Between 1980 and 2009, railroad fuel efficiency — measured in ton-miles per gallon of fuel — increased by 104 percent, or 2.5 percent annually. While there are many individual factors that have led to these productivity improvements, the most important areas of change can be summarized as follows:

Freight Car Design: Improvements in railcar design including huge improvements in the ratio of weight of freight loaded into each railcar (the revenue tons) to the tare weight of the railcar. In addition there have been major improvements in wheel and truck design as well as in the aerodynamic performance of intermodal equipment.

Diesel Engine Technology: Improvements in diesel engine technology in locomotives linked with improvements in the efficiency of delivery of electrical power to the driving axles. These technological changes have been particularly important for heavy haul rail business where the development and deployment of alternating current traction motors has reduced the power requirements to move very heavy loaded trains. Parallel improvements in locomotive quality and maintenance processes have also reduced the need for redundancy in operations and thus, the total number of locomotives required to power trains.

Distributed Power: Development and widespread application of technology permitting the positioning of locomotives throughout the length of a train (distributed power) which reduces, overall, the total horsepower required for movement of tonnage and requires less power to start or change the speed of trains. Also, by reducing the number of trains that need to be operated, this technology reduces train-to-train movement conflicts that require speed changes or additional locomotive idle time.

GenSet Locomotives: During the last five years, significant deployment of "GenSet" locomotive technology began. This technology replaces the single large diesel engine employed in most locomotives with multiple smaller engines. Digital control of these individual engines allows real time tailoring of their power application so that only that necessary to perform a particular function at a particular time is utilized. Current applications are primarily in terminal switching areas, however, GenSet technology appears to have much broader application. Measurement of the performance of the present GenSet fleet indicates fuel savings of as much as 37 percent are possible compared to older switch locomotives.[3]

Training: Training of operators and operational discipline associated with power use and shutdown policy. This has been supplemented by dramatic improvements in idle reduction technology.

Improvements in Infrastructure and Operations: Improvements in track technology, infrastructure maintenance, line-of-road control systems and infrastructure capacity have resulted in significant reductions in speed change requirements, have minimized line-of-road idle time and reduced extended operation at very low speeds on line-of-road. Additionally, investments in infrastructure improvements have been fundamental to the widespread deployment of freight cars that can carry heavier payloads.

Rail Lubrication: Development, and large-scale deployment of automated lubrication processes for wheel flanges and railhead to reduce train friction.

Understanding how these changes have shaped the rail industry's fuel productivity improvements over the last three decades is basic to understanding the road forward in this area. While improvements in process, design and technology provided a number of "breakthrough" areas, the real key to widespread productivity improvement was their deployment throughout the industry. The rate of deployment was, in turn, governed by the

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[3] Union Pacific website, Environmental Management / A Green Railroad at https://www.uprr.com/she/emg/index.shtml, November 30, 2010.

discipline of private capital investment processes and, through this discipline, the economic turnover rate of assets.

The impact of this asset turnover process on fuel productivity should not be underestimated. Freight cars have an average economic life span of 40 years, or longer, while locomotives frequently serve twenty-five years in type of service for which they are originally purchased and much longer in tasks to which they may be subsequently downgraded. Infrastructure components may last far longer still. Process improvements can be implemented in a shorter time frame, however, even the impact of these is slowed by the need to train tens of thousands of employees in their use.

Rail Fuel Efficiency Forecast: AEO 2010 Base Case

The AEO 2010 Base Case estimates that there will be essentially no improvement in rail fuel efficiency from 2010 to 2035 — an improvement of just 0.1 percent annually. Thus, rail fuel consumption is forecast to rise linearly with rail traffic. In view of the fact that many of the trends that have contributed to increases in rail fuel efficiency in recent years will continue to provide benefits for the foreseeable future, the assumption of negligible gains going forward is excessively conservative particularly since none of the technologies noted above have yet to see full deployment. Their full deployment alone, without additional advances, would result in fuel productivity improvements averaging slightly over 1.3 percent annually between now and 2050. This, in fact, sets the lower bound for expected fuel productivity improvements.

Future Rail Fuel Efficiency

An important characteristic of virtually all of the technologies which influenced fuel productivity is that they were in existence and were either being deployed and being prepared for deployment 30 years ago. This would indicate that the technology which influences fuel productivity in 2050 is, in all likelihood, in existence or under development today. If it is not, it is unlikely that the asset turnover rate will permit it to have a significant influence on fuel productivity by 2050 unless that new technology is truly revolutionary, both in terms of its technical capabilities and its economics. Such a technology would require the compelling economics associated with such changes as the conversion of the railroad industry from steam to diesel power between 1940 and 1960 — and even that change was foretold by technology developments that were well underway by 1920.

It is also important to note that many of the technology changes noted above were, in 1980, subject to long-term ongoing improvement programs most of which remain active today. There is no reason to expect that these ongoing programs will cease in the future. In fact, it is most likely that further developments in existing programs will provide the principal advancements in fuel productivity improvements.

Many of the trends that have contributed to rail's fuel efficiency gains over the past three decades will continue to yield additional benefits in the years ahead. A more detailed discussion of one of these — freight car design — illustrates this concept:

Freight Car Productivity Improvement: In 1980 the industry was early in the process of deploying freight cars having a capacity of 100 revenue tons and a tare weight of 30 tons. Today, freight cars with a capacity of 110–117 revenue tons are being deployed and these cars have tare weights of 25–30 tons. Full deployment of cars of this size will take an additional 15–20 years. Meanwhile, under development are cars that have a capacity of 120–130 payload tons with tare weights of 27–30 tons. Deployment of cars of this size will require further advances in car design, metallurgical improvements for both wheels and rail and will need infrastructure upgrades across much of the rail network just as was needed for the advances seen during the last 30 years. However, prototypes of some car types already exist and we can expect that the technology will be sufficiently improved over the next four decades to permit widespread utilization of this equipment. Thus, we can conclude that this factor is likely to continue to provide fuel productivity improvements.

Simply stated, the continued improvement and full deployment of the technology factors noted above, as well as successive generations of these factors, would, by itself be sufficient to ensure continuation of the current trends in fuel productivity improvement. This sets the "most likely" case for fuel productivity improvement of 2.5 percent annually – the average rate for the last 30 years.

However, there is one factor that does have the potential to significantly change relative, although not absolute, fuel productivity — traffic mix. Traffic mix describes the composition of the business portfolio that the rail industry carries for its customers. It can be defined in a commercial context in terms of the commodities carried such as coal, automotive, consumer goods, forest products, metals and ores, chemicals or minerals. Alternately, it can have a more operational definition that speaks to the type of train needed to provide service. It is the latter definition that is meaningful for this discussion. Categories of traffic within this definition would include train types, such as bulk trains, general merchandise trains, automotive trains and intermodal trains, where, within each type, the operational characteristics are similar even through the commodities carried may vary. These operational characteristics define the fuel requirements for providing service.

These four traffic categories permit the grouping of train types around the relationship between the ratio of revenue weight per train and the total weight of the train. Bulk trains, when loaded, have a very high revenue weight-to-total weight ratio but their empty movement, accounting for fifty percent of their total train miles, has a zero revenue weight-to-total weight ratio. Merchandise trains have a lower revenue weight-to-total weight ratio but rarely move completely empty. Intermodal trains have a low revenue weight-to-total weight ratio but are more likely to be loaded in both directions. Automotive trains have a very low revenue weight-to-total weight ratio and are likely to move one direction empty.

Another factor that has a significant impact on the amount of fuel required for each category of train is the performance requirement that a particular train type must meet to be competitive in the marketplace. This is reflected in the amount of power required to move trains at the service velocities as dictated by the particular market in which they compete. These power requirements are expressed as Horsepower per Trailing Ton (HPTT) and representative values may range from 0.6 HPTT for trains moving bulk goods to over 2.0 HPTT for more time sensitive intermodal and automotive traffic.

Table 1 summarizes these relationships and also indicates the relative fuel utilization, per revenue ton-mile, for each type of train service. As can be seen, there is significant difference in the fuel requirements for the two service types having high payload-to-weight ratios and low HPTT versus the two having low ratios and high HPTT. However, it is important to note that even the least fuel efficient of the rail services far outpaces its highway competition. Part of this is due to the fact that both bulk and automotive trucks face many of the same "empty return" challenges as do railroads.

Table 1

Train Type	Revenue Weight (tons)	Tare Weight (tons)	% Empty Return	Revenue : Total Weight Ratio	Horsepower/ Trailing Ton	Fuel Use RTM/Gallon
Bulk	10,000 - 16,000	3000 - 3375	100%	0.63 - 0.70	0.7 - 1.0	763
Merchandise	5600 - 9600	2100 - 3600	85%	0.53	0.8 - 1.2	459
Intermodal	1800 - 5000	1650 - 3500	20%	0.22 - 0.28	1.8 - 2.6	214
Automotive	1450 - 1900	2250 - 2700	95%	0.24 - 0.26	1.8 - 2.2	118

Table notes on representative train types:

Bulk - Small train = 100 cars @ 100 net-tons/car, tare weight = 30 tons.
Large train = 135 cars @ 118.5 net-tons/car, tare weight = 25 tons

Merchandise - Small train = 70 cars @ 80 net-tons/car, tare weight = 30 tons
Large train = 120 cars @ 80 net-tons/car, tare weight = 30 tons

Intermodal - Small train = 100 containers @ 18 net-tons/container on 5 unit spine cars, tare weight = 62.5 tons/railcar and 4 tons/container
Large train = 280 containers @ 18 net-tons/container on 10 unit well cars, tare weight = 85 tons/railcar and 4 tons/container

Automotive - Small train = 50 cars carrying 18 small autos/car @ 1.6 tons/auto, tare weight = 45 tons
Large train = 60 cars carrying 10 small trucks/car @ 3.2 tons/truck, tare weight = 45 tons

Clearly, the proportion of each type of traffic in future business portfolios will be a significant determinant of relative fuel efficiency even if the technology trends going forward continue to improve absolute fuel efficiency. Looking at the changes that have taken place in rail traffic during the last 30 years as well as the 30 years before that emphasizes the folly of assuming that either market share or traffic composition will remain the same during the period between now and 2050. The question is not whether these factors will change but whether we can see any trends at present that can help us predict what the magnitude and direction of those changes might be.

The most important trends that we can currently see that would have an impact on the composition of future rail traffic involve the two largest categories of traffic, coal and intermodal, and the two with significantly different fuel use productivity characteristics.

As was discussed earlier, public policy towards coal use will determine the future of nearly half of current rail tonnage. As noted in Table 1, this tonnage is handled in an extremely fuel efficient manner and has a huge impact on the average fuel efficiency of the industry. Clearly, any policy actions that cause either an increase or diminution of coal volumes will have a significant impact on relative fuel efficiency. Unfortunately, for purposes of this study, it is not possible to reliably predict the outcome of either the policy debate or the market developments. We can only note that this outcome will have many significant impacts on the rail industry.

The implications of intermodal's market position on relative fuel efficiency are important, since they suggest that intermodal business will continue to be an increasing portion of the total business portfolio. Because it has lower relative fuel efficiency per revenue ton-mile than do other portfolio components, its growth will tend to moderate gains in rail fuel efficiency during the next 40 years. However, it is important to note that a recent Federal Railroad Administration study found that rail double-stack intermodal operations were 2.7–5.5 more fuel efficient than that of the truck competition.[4]

In summary, fuel efficiency improvements have been consistently important to the rail industry. They have been the result of a number of ongoing initiatives, most of which can be expected to continue indefinitely into the future. Although the technology of the improvements is important, the key to making them effective is their deployment over extended periods as they replace earlier technologies. Much of the relative fuel efficiency of the various rail business lines is due to differing characteristics of each of these businesses and the ways in which those characteristics define a business line's requirements for locomotive power. The "mix" of these business lines will almost certainly change during the next 40 years as it has over the past 30, and the most important areas likely to change are the coal and intermodal businesses. How these lines will change cannot be predicted at this time as it will be subject to complex economic and political factors.

Alternative Fuels

Since making the transition from coal-fired steam locomotives more than 60 years ago, freight railroads have relied almost entirely on diesel fuel to power their locomotives. Diesel continues to enjoy major advantages in terms of energy density, the availability of existing distribution channels, an in-place and reliable asset base of locomotives.

Despite these advantages for diesel, railroads have continuously been evaluating alternative technologies with a focus on reducing costs.

> **Electrification:** One "game changing" technology that is often suggested for the rail industry is electrification. This technology is heavily used overseas most particularly where there is high density or high speed passenger service but also, in some locations, where there is substantial freight service, both heavy haul and traditional. It is undeniably an effective technology where very high density of passenger train operations can make effective use its locomotive's performance characteristics such as quick acceleration. It is also frequently employed in areas where petroleum resources may be limited, where a nation has strategic security concerns related to petroleum availability or where a country seeks to limit local use of petroleum resources in favor of their exportation. These factors have

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[4] U.S. Department of Transporation, Federal Railroad Administration, *Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors*, November 19, 2009, p. 5.

frequently made its deployment as much a political decision as one which is based on operational or economic demands.

There have been only a few documented circumstances where it has been employed strictly for economic reasons including the electrification of what is now the Northeast Corridor of the United States when it was privately owned and operated. However, the economics of that electrification were based on the replacement of 1920 era steam locomotives in both high density passenger and heavy duty freight service, not modern diesel-electric technology. By 1980, the freight portion of even this operation had been terminated as being prohibitively expensive when compared to the cost and flexibility of diesel-electric technology of that time.

The fundamental issue with electrification is the very high capital expense associated with its installation. This expense comes from several areas. The first, and most obvious, is the cost of installation of the power distribution system itself. This complex system has several significant components all of which require substantial capital investment, environmental remediation and construction time. They include the power generation source itself, the distribution system from the power generation source and the installation of the overhead wiring (the catenary system) above the track. Even if only the most densely used main lines, those handling over twenty million tons per year, were to be electrified, this task would extend to over 50,000 route miles and tens-of-thousands more track miles of second and third main tracks, sidings and terminal tracks.

The second major area of expense is the replacement of the current high performance diesel fleet with electric locomotives whose initial cost is over twice that, per unit, of the diesels. While electric locomotive technology is clearly a mature technology there has been relatively little work done in the past 50 years on development of heavy haul electric locomotives of the type that would be required to meet North American requirements. While adapting current technology to the heavy haul environment should be a fairly straightforward process, the resulting locomotives are likely to be, if overseas experience is any indicator, very expensive machines.

A third major area of up-front expense would be the requirements to adapt the existing support infrastructure to maintain and service electric locomotives and to restructure the existing signal and control system to be operationally compatible with electric operations. These expenses would include both new facilities such as repair shops and retraining of personnel in the care of these locomotives. It is important to note that through 2050, even if there is a reason for electrification to be widely implemented, it is very unlikely that diesel operations would be eliminated. There would remain lower density and terminal operations that could not afford the capital required for electrification that would remain in operation much as they are today. Thus, even in the best case, there would need to be two sets of support infrastructure and two labor forces for the different technologies.

The latter emphasizes another feature of electrification that is important and would be very expensive: the transition process during the deployment of the technology. Unlike the technologies noted earlier that could mix freely with existing systems, electrification requires its own specialized "fuel delivery" and support system. It is not an evolutionary technology.

What are the conditions that might foster electrification? There are two reasons that the technology might see implementation, economics or politics. The economic case is straightforward - an increase in real fuel cost over an extended period of time that would be sufficient to justify the capital and transitional expenses associated with the technology. While there have been no recent studies attempting to quantify the level of cost necessary to provide incentives to undertake electrification, we do know that the fuel price levels during the spike of 2008 would not have provided sufficient incentive for action.

The political case is, as might be expected, more complex. The justification for public funding of electrification would most likely come from two sources - energy independence or environmental mitigation. The energy independence issue would arise if for either strategic or economic reasons imported fuels were no longer found to be in the country's interest and alternatives were sought which could limit demand to the level of domestic production. This, in turn, could lead to consideration of rail electrification both for passenger movement and for expanded goods movement by rail. If electrification were done for dense passenger movements it could have some operational value. However, it is unlikely that the same value would accrue to freight operations. It would, however, change demand for fuels by some unknown and unpredictable amount.

Similarly, environmental mitigation would, in all likelihood, be driven by the desire to limit the use of fossil fuels. Electrification would permit the operation of a substantial portion of the transportation system without use of fossil fuels if the electricity were provided by a source other than a fossil fuel power plant. If the latter were not the case, it would simply represent the substitution of one fossil fuel for another. The practical results would be the same as those described above for the energy security case.

In summary, electrification is an unlikely technology for rail implementation during the time period of this work due to the very high capital requirements for its deployment. A purely economic case for its use is probably not credible. A political case, while possible, is unlikely given the high costs to the public and the potentially marginal impact on the phenomena that it would be meant to address.

Natural Gas: As early as the 1930’s, the railroad industry took an interest in gaseous fuels. In 1936 the Plymouth Locomotive Company built a propane-fueled locomotive for the Joplin-Pittsburg Railroad in Missouri; the fuel was stored under the car body in three cylinders, supplied a 450 hp, spark-ignited engine. Since the mid-1980s, the North American rail industry has undertaken several projects to assess the viability of natural gas fueled locomotives, while additional research has been conducted in Russia, Germany, Japan, Finland, and the Czech Republic. In 1987, the Burlington Northern (BN) Railroad, working with outside vendors, converted two 3,000 hp EMD SD40-2 locomotives to run in a dual fuel mode.[5] In addition, a fueling station was constructed in Staples, Minnesota, and two 25,000 gallon tender cars were manufactured. In 1992 these locomotives were placed in revenue service on a coal train operating in the Midwest, where they served until 1995. Separately, in 1993, MK Rail Corporation (now known as MotivePower Industries, a Wabtec Company) introduced a 1,200 hp LNG-fueled switch locomotive that utilizes a spark-ignited natural gas engine. Four of these units were put into service (two by BNSF Railway and two by Union Pacific Railroad); today they are operating in switch service in California.

Decades of research and development activities and over-the-rail locomotive prototype demonstrations have given the railroads a great deal of information about the practicality of using natural gas-fueled locomotives. At present, the Class I railroads believe that while there may be certain niche applications such as in switch service in Los Angeles, their widespread adoption — especially in high power, line haul locomotives, which consume most of the diesel fuel used by the industry — is unlikely. In addition to the critical issue of their cost effectiveness, there are significant questions about their ability to match new diesel locomotives' emissions performance. The freight railroads will, however, continue to assess the potential use of natural gas-fueled locomotives.

Biofuels: The performance of various biodiesel fuels has been tested in both 2- and 4-stroke, medium-speed diesel engines used in North American locomotives, although there is far less experience than there is with high-speed engines. Norfolk Southern Railway Co. and Electro-Motive Diesel are currently conducting tests of biodiesel fuel for locomotive applications in revenue service, including blends of B10 and B20.[6]

While the tests have generally been successful with a variety of fuel blends, there have been concerns relating to compatibility with existing engines, and with a possible tradeoff for environmental goals given an increase in NO_x that . Little increase in NO_x from locomotives meeting Tier 1 and Tier 2 PM and NO_x levels can be tolerated before NO_x emissions will exceed the line haul certification limit. While there is more of a margin for switch service, EPA regulations require locomotives to meet both standards.

Cost and fuel handling issues are also expected to be significant factors limiting the widespread adoption of biodiesel in the near term. Because the energy content of biodiesel is lower and specific gravity is higher than No. 2 diesel, loss of engine power and increased fuel consumption can be expected.

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[5] For some engine conditions — start, idle, and low notch [power] settings — the locomotive operated exclusively on diesel fuel. The locomotive could also operate solely on diesel in all notches if required.
[6] EMD press release, *EMD and NS Launch Extensive Biodiesel Fuel Test Program,* April 13, 2010.

Conclusion: Rail Fuel Use Estimates

1. Based on past trends and on other economic forecasts that are available the AEO forecast probably understates rail ton-miles for the study period. In fact, it basically predicts "no growth" for the next 40 years contrary to all other predictive models. This understatement may be by as much as 3 trillion ton-miles per year by the end of the forecast period and is almost certainly 1 trillion ton-miles short by 2050.

2. The AEO forecast, as it has been made available, does not have commodity component forecasts which would permit an analysis of traffic mix changes going forward and their impact on relative fuel productivity. Without these it is not possible to provide an accurate forecast of total fuel use since traffic mix will almost certainly change significantly during the study period just as it has during similar past periods.

3. A large number of technology changes over the past thirty years have produced fuel productivity improvements at an annual rate of 2.5 percent during that period.

4. Railroads operate with very long-life assets and the key to obtaining fuel productivity is the deployment of new technology as these assets are replaced over many years.

5. None of the technologies reviewed have been fully deployed, to date, and their full deployment alone, without further advances would be sufficient to produce fuel productivity improvements averaging slightly over 1.3 percent annually during the study period.

6. Advances already underway with the present technologies, and their deployment as they mature during the study period, would permit a continuation of the present fuel productivity trend of 2.5 percent annually for the next 40 years.

7. Locomotive technology, while important, is only one of many factors used to improve fuel productivity. Thus, while new locomotive technologies, including those based on alternative fuel sources, may be important contributors to future efficiency, their deployment will be based on their ability to perform economically as well as technically. Due to the state of development of these technologies and their probable deployment rate, they are likely to have an impact on total rail fuel productivity only toward the end of the study period.

8. Due to its extremely high capital costs, electrification of significant portions of the rail network, particularly the freight network, is unlikely during the study period unless undertaken for political reasons. The only foreseeable exception to this would be electrification due to a very significant (unpredictably large) increase in diesel fuel prices for a sustained period of time.

Based on these conclusions, the fuel demand forecasts for the freight rail industry are as follows, noting particularly the caveats of conclusions 1 and 2 above:

Year	Revenue Ton-Miles (trillions)	Low Productivity Case Diesel Fuel Use (billions of gallons)	Most Likely Productivity Case Diesel Fuel Use (billions of gallons)
2009	1.66	3.45	3.45
2020	2.01	3.60	3.19
2030	2.19	3.41	2.71
2040	2.33	3.17	2.25
2050	2.45	2.94	1.87