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Future Impacts of Coal Distribution Constraints on Coal Cost

Author
McCollum, David L

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Future Impacts of Coal Distribution Constraints on Coal Cost

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DAVID LLOYD MCCOLLUM
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Future Impacts of Coal Distribution Constraints on Coal Cost

David L. McCollum
Institute of Transportation Studies
University of California
Davis, CA 95616

ABSTRACT

After years of relatively slow growth, coal is undergoing a renaissance. Some 140 coal power plants are planned, and the Energy Information Administration (EIA) projects that the U.S. will consume almost 1,800 million tons of coal in 2030, up from about 1,150 million tons this year. In addition, while EIA's estimates do not take coal-to-hydrogen production into consideration, several recent studies suggest that if the hydrogen economy ever comes to fruition coal could be a feedstock of choice, at least in the U.S. which has huge reserves of coal (~250 years' worth at current consumption rates), which are relatively cheap and easy to mine.

An increase in future coal demand fuels legitimate concerns about the impacts on global climate and regional air pollution. While carbon capture and storage is often mentioned as a solution to these two problems, another impact, often overlooked, is the possibility that the current coal distribution infrastructure may not be able to reliably deliver the additional demand. Railroads deliver about two-thirds of U.S. coal at present, but certain coal-carrying rail corridors are already up against their capacity limits. Any future demand increases will probably necessitate significant capital investment by rail companies.

This study seeks to identify existing capacity and potential constraints within the coal distribution infrastructure and to identify the costs of alleviating these constraints under several growth scenarios for coal demand. The scenarios differ based on whether or not pulverized coal (PC) or integrated gasification combined cycle (IGCC) power plants are built, as well as the amount of coal that is used to produce hydrogen for fuel cell vehicles.

Coal transportation along the nation's vast rail network is modeled with a freight routing model that uses the Surface Transportation Board's confidential Carload Waybill Sample data as an input. For each coal demand growth scenario, I identify the rail corridors that could potentially reach their capacity limits in the future due to increasing coal traffic, and I quantify the investment that might be needed to boost the coal-carrying capacity along these lines.

Some of important questions that I have attempted to answer through this analysis include the following: (1) Will the nation's rail-coal distribution system be able to handle the future increases in coal demand that could result from traditional uses, as well as from coal-to-hydrogen production; and (2) What is the trade-off between building more efficient, albeit more expensive, IGCC power plants versus modern PC plants, if costly investments in coal transportation infrastructure can be avoided?

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The prospect of increased coal demand in the U.S. potentially poses a number of challenges, from regional air pollution to global climate change. Less attention has been paid to the capacity constraints that the nation's coal transportation system, especially rail, must overcome in the future if "King Coal" is to continue in its role as a dominant energy source. While The National Research Council (NRC) notes that "future growth in coal use will depend on the availability of sufficient rail capacity to deliver increasing amounts of coal, and the railroad industry's ability to do so reliably and at reasonable prices," I am aware of no recent studies that have attempted to analyze the future capacity constraints and quantify the investments that might be needed to boost capacities of major coal-carrying rail lines (NRC, 2007, p. 70). This research project begins to fill this gap in knowledge.

As the NRC concludes in its recent study, future coal demand is uncertain, owing to uncertainties about carbon legislation and the ability of technologies to ensure that coal remains competitive in a carbon-constrained world. A number of organizations[1] throughout the world have attempted to make projections for coal demand, but the range of forecasts is wide and varied (NRC, 2007). In light of these uncertainties, this study looks at several different scenarios for coal demand growth in the U.S. The scenarios consider the trade-off between building either pulverized coal (PC) or integrated gasification combined cycle (IGCC) power plants, and the possibility of using an additional amount of coal to produce hydrogen for fuel cell vehicles.

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[1] U.S. EIA, IEA, PNNL, World Energy Council, ExxonMobil, European Commission

Scenario[2]	*Description*
BAU1	A baseline scenario using EIA projections for coal power demand, and assuming that all new coal plants will be pulverized coal (PC)
BAU2	*BAU2a and BAU2b*: A similar scenario to BAU1, but assuming that all new coal plants will be integrated gasification combined cycle (IGCC) (Same power demand as BAU1, but lower overall coal demand due to the higher efficiency of IGCC versus PC) *BAU2b only*: In addition to building new IGCC plants, all old PC plants are gradually retrofitted to IGCC
BAU2+LowH2	A similar scenario to BAU2b, except that in addition to IGCC plants being built, extra coal is used to supply a fleet of hydrogen fuel cell vehicles, which obtain a 50% share of the total vehicle market by the year 2050
BAU2+HighH2	A similar scenario to BAU2b, except that in addition to IGCC plants being built, extra coal is used to supply a fleet of hydrogen fuel cell vehicles, which obtain a 100% share of the total vehicle market by the year 2050

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[2] The reader should note that ‘BAU’ in this case refers to Business-As-Usual power demand, not the types of technologies that might be deployed in the future. For example, one could argue that IGCC plants are not BAU. But in this report BAU has to do with the EIA’s AEO2006 Reference Case projections for power demand. The various scenarios all assume these same projected power demands; the power plant technologies used to meet those demands may be different across scenarios, however.

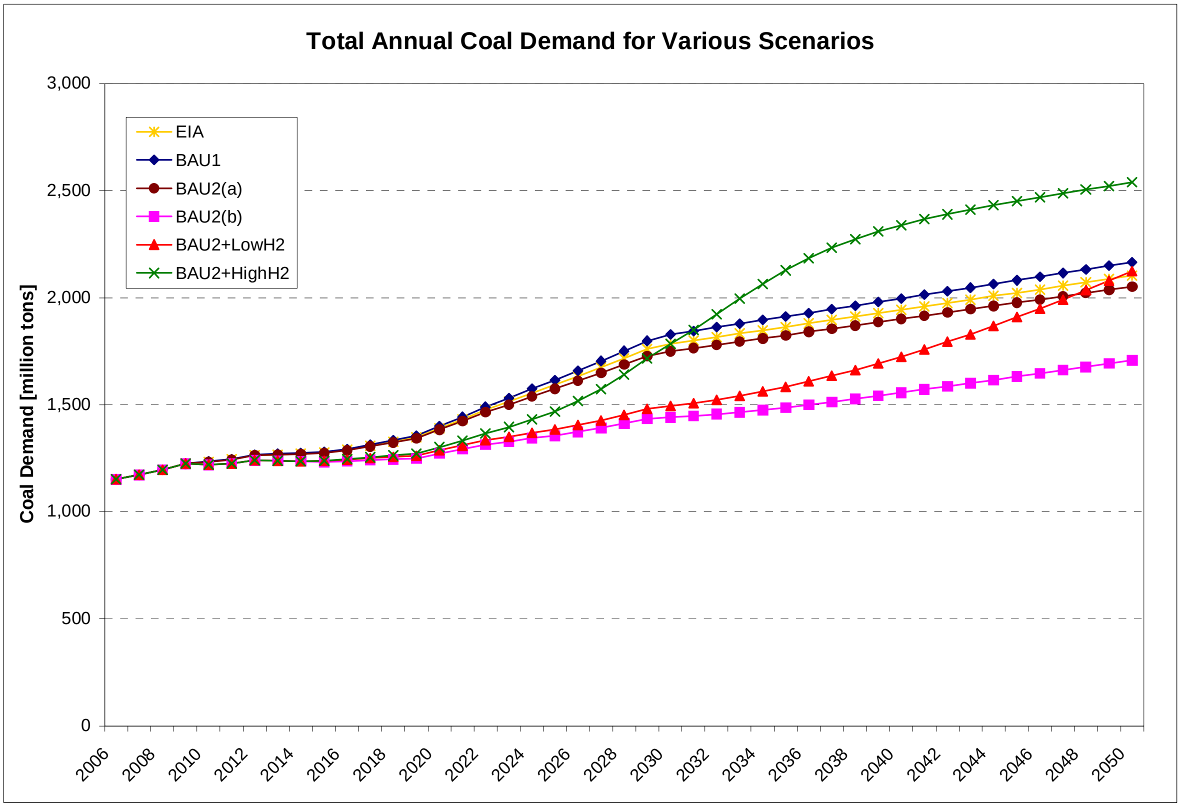

Figure ES-1: Total annual coal demand projections under various scenarios

Using the projections of total national coal demand under the various scenarios, I attempt to disaggregate and spatially distribute these demands widely over the rail-coal transportation network, thereby projecting coal traffic on each and every rail line. To do this modeling, I make use of an extensive confidential data set known as the Carload Waybill Sample. The Waybill Sample is considered to be the best data set available for providing detailed information on the various types of railroad freight shipments transported between a multitude of origins and destinations on the rail network and consists of a record of approximately 600,000 railroad shipments made within, to, or from the United States in a given year (STB, 2007). To project future rail traffic flows, I tie the highly disaggregated Waybill Sample (year 2004) to the much more aggregated projections of the Freight Analysis Framework 2 (FAF2) program, which provide estimates of freight commodity flows between U.S. states, sub-state regions, and international gateways (DOT, 2007). I divide FAF2 projections for the various commodities into two categories: coal and non-coal. Non-coal projections are taken directly from FAF2, but coal projections are modified to reflect the varying levels of growth in each of the different coal demand scenarios. After generating hypothetical versions of the Waybill Sample for future years and various scenarios, I worked with ALK Technologies, a consulting firm in Princeton, NJ, to assign/route the current and projected freight traffic onto the rail network. In addition to the base case year 2004, I develop “static snapshots” of the freight rail system in the years 2030 and 2050 for each of the coal demand growth scenarios.

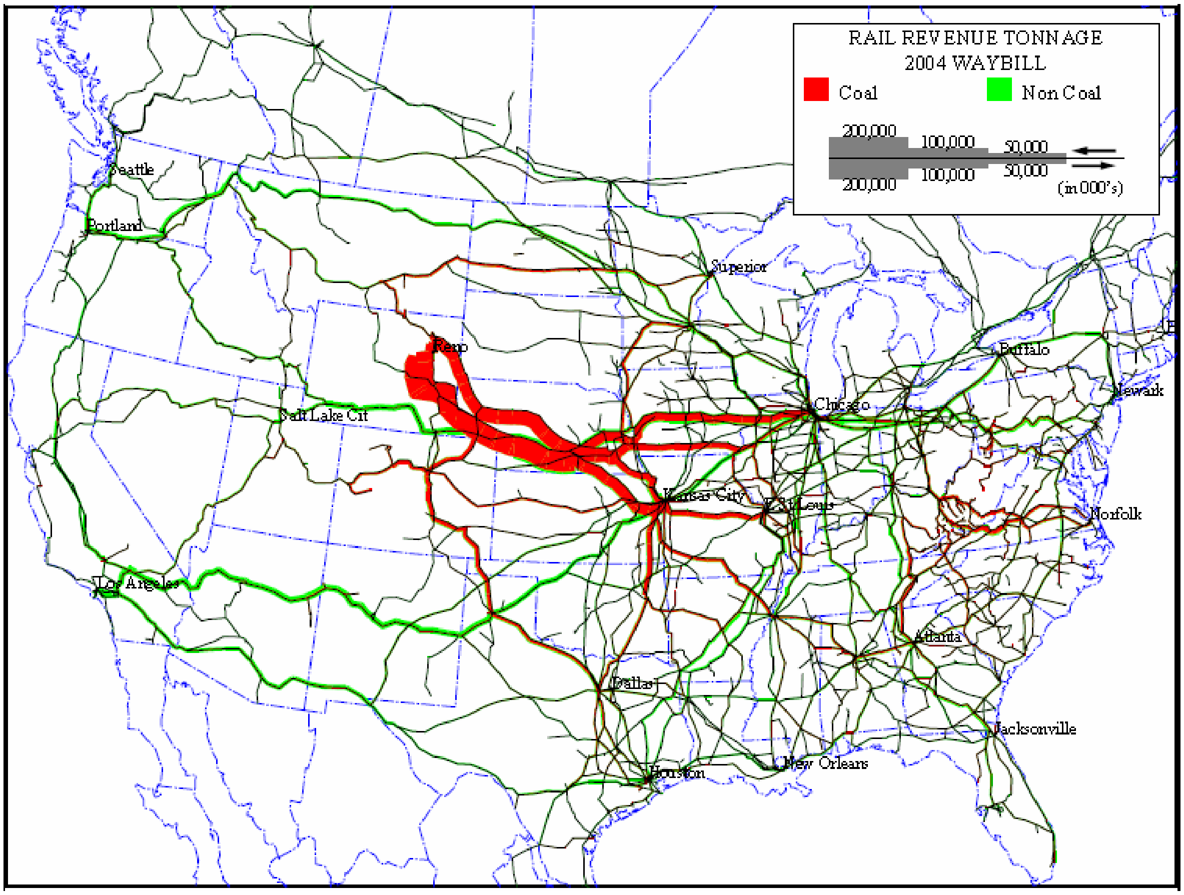

Figure ES-2: Freight rail traffic on the U.S. rail network in 2004 (using Waybill Sample data)

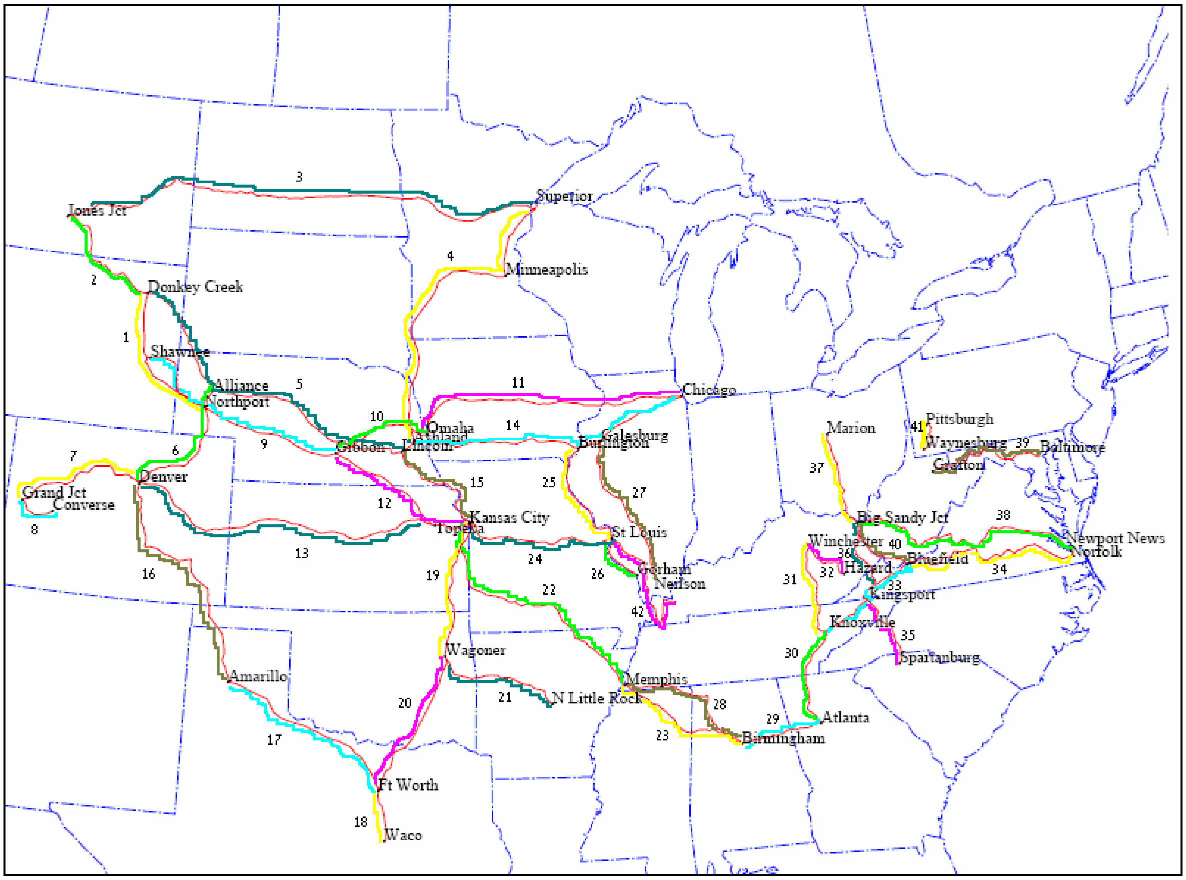

Figure ES-3: Major coal-carrying rail routes analyzed in this study

Based on the projected traffic levels, I identify 42 routes that will likely carry the bulk of coal demand in the future. These routes, which are owned by either BNSF, UP, CSX, NS, or CN, represented just 5% of all route mileage in the North American rail network in 2004 but were responsible for transporting more than 80% of all coal shipped by rail. A spreadsheet model has been created to analyze the costs and benefits of investing in the infrastructure and equipment of each of the selected routes in an effort to enhance their capacities. Four different capacity enhancement strategies are analyzed with the model:

1. Upgrading the signaling system to centralized traffic control (CTC);
2. Upgrading the signaling system to positive train control (PTC);
3. Adding new mainline track;
4. Upgrading the quality of mainline track, allowing heavier, higher capacity rail cars to be transported over them.

The costs and benefits of these strategies are inherently uncertain when looking many years into the future. For this reason, Monte Carlo simulation is incorporated into my model, and the estimates that I report are represented as probabilistic ranges rather than point estimates.

I find that, depending on the particular scenario and how the accounting is done, the incremental capital costs of adding capacity (i.e., new trackage and signaling systems) to all 42 of the selected rail routes might be on the order of \$0.5 – \$5.5 billion (in discounted terms). My estimates consider both a future in which PTC is deployed and one in which it is not. Similarly, the capital costs associated with new rolling stock (i.e., new locomotives and coal rail cars) might be in the range of \$1.0 – \$5.5 billion (in discounted terms, over the timeframe 2004 – 2050). While these costs are quite significant, they are still much smaller than the estimated capital costs for the coal power and coal-to-hydrogen plants that would be built in each scenario. Yet, it is the differences in rail and plant costs within and between the various scenarios that are particularly noteworthy. For instance, it appears that in terms of capital costs, an IGCC future (BAU2a) would cost more than a PC future (BAU1), which comes as no surprise; but the total costs to the railroad industry might be reduced as a result of the savings incurred via reduced rail infrastructure investment. This is likely a result that few have considered.

Scenario	Incremental Capacity Costs[3] (discounted billion $)[4, 5]		Incremental Rolling Stock Costs[6] (discounted billion $)		Capital Costs for Coal Power and Coal-to-Hydrogen Plants (discounted billion $)
	CTC	PTC	CTC	PTC	
BAU1	2.25 – 5.34	1.58 – 3.72	2.72 – 4.74	2.76 – 5.05	54
BAU2a	1.88 – 4.45	1.28 – 3.02	2.37 – 4.21	2.40 – 4.43	59
BAU2b	0.64 – 1.48	0.53 – 1.24	1.05 – 2.05	0.98 – 2.02	140
BAU2b+LowH2	1.00 – 2.30	0.76 – 1.73	1.44 – 2.61	1.40 – 2.63	147
BAU2b+HighH2	2.28 – 5.33	1.61 – 3.73	2.84 – 4.93	2.88 – 5.23	166

Table ES-1: Total incremental capital costs of increasing capacity of all 42 selected rail routes (2005$)

How do these total incremental costs for all 42 coal routes translate into costs for individual routes, and what impacts will the costs have on the price of coal delivered by railroads across the country? Outside of a handful of isolated cases, my results show that ***it does not seem likely that the incremental costs of adding new coal-carrying capacity will markedly increase coal transportation rates ($/ton-mile) or the delivered prices ($/ton) of coal throughout the country***. In fact, railroad companies operating the most heavily-trafficked coal-carrying routes—e.g., those traversing the Midwest and Virginia—do not appear as though they will be forced to increase their rail rates in order to compensate for the incremental costs of adding capacity on these routes. This includes the Joint Line (Route #1), which is co-owned by BNSF and UP, and is one of the primary

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[3] "Incremental Capacity Costs" refer to the capital costs associated with upgrading signal systems and adding new mainline trackage from 2004 to 2050.

[4] The discount rate is assumed to be in the range of 7 – 12% and is varied during Monte Carlo simulation.

[5] A range is given for each cost estimate to reflect the multiple costing methodologies and variable input assumptions used in this study.

[6] Incremental Rolling Stock Costs" refer to the capital costs associated with investing in new locomotives and coal rail cars from 2004 to 2050.

routes responsible for transporting coal out of the Powder River Basin (PRB) in Wyoming. Although traffic along the route is expected to reach levels higher than any other during the forecast timeframe, it appears that the huge investments made to increase the capacity of the line, including the addition of fourth and fifth mainline track in some places, will not lead to significantly higher rail transportation rates of PRB coal.

These findings should come as good news to the many electric utilities that own the scores of coal power plants whose coal is transported along the 42 selected rail routes for at least some distance on its way from mine to plant. My results indicate that the price of coal delivered by railroads is not expected to increase even under aggressive scenarios of coal demand growth.

Of course, the results depend on certain key assumptions that underlie my modeling and analysis methodology. Therefore, the reader should acknowledge and consider these assumptions before drawing his or her own conclusions regarding the results. Moreover, this study solely addresses long-term investment in rail infrastructure and equipment. I recognize that capacity constraints currently exist on the rail network and that these are contributing to concerns over the reliability of railroads to meet demand for coal transportation in the short-term. These constraints must be dealt with in a timely manner, but in this study I do not propose how they should be addressed. Instead, this study presumes that in the long-term railroads will seize opportunities to meet new coal demand and will invest in infrastructure and equipment as necessary, so long as the investments are financially attractive and profitable. Assuming that railroads will be able to make the necessary investments (i.e., they are able to obtain loans from the government and/or private investors), this study attempts to estimate just how much these investments might cost in total.

I. INTRODUCTION

Research Purpose and Objectives

Over the years, an enormous amount of research has been directed at the impacts of coal consumption on regional air pollution and global climate change. These are both major challenges that must be overcome if coal is to meet the increasing demand for energy in the years to come, especially in rapidly developing countries like China and India. However, an often overlooked impact of increased coal consumption is the fact that the coal distribution infrastructure—at least in the United States—may not be able to reliably meet the increasing demands. Coal distribution constraints are already developing on certain rail corridors, and the great irony is that some U.S. electric utilities, unable to obtain enough coal from their own country, which is commonly referred to as the “Saudi Arabia of Coal”, have been forced to import coal from other countries. Coal use in the United States is projected to increase by 53% by 2030 (EIA, 2006e). What is needed is a comprehensive assessment of the current U.S. coal distribution infrastructure and its ability to increase its carrying capacity in the years ahead. No assessment like this has been done since the mid-1970s and early-1980s, when the U.S. was considering ramping up coal consumption as a substitute for oil after the price shocks of the 1970s (EPRI, 1976; EPRI, 1982; White, 1978; ANL, 1980). While those earlier studies were focused on coal consumption for power generation, in this research project I analyze coal consumption both for power generation and for the additional coal demand that might result from the production of alternative transportation fuels (hydrogen) from coal. Moreover, while the earlier studies focused only on the question of whether or not the coal distribution system could meet future projected demand, this study looks at the trade-off between investing in new rail infrastructure—thereby allowing the increased transportation of coal—and investing in higher efficiency power plants—which would reduce coal distribution requirements to some degree. The results of this study could potentially be valuable for policymakers who are interested in legislation that promotes less carbon-intensive power plants and vehicle fuels, and that ensures a healthy, efficient railroad industry.

U.S. freight railroads are private industries, which means that companies have an economic incentive to invest in new coal distribution infrastructure if they feel that there is profit to be earned from such investments. It is likely that rail investment will be made when it is needed as long as the required amount of capital can be obtained, either from private investors or the government. One of the goals of this study is to quantify the investment in rail infrastructure that will have to be made to meet the future demand for coal under different scenarios of coal demand growth.

I have developed four scenarios for future coal use in the U.S. from now to 2050. The first scenario (BAU1) is a business-as-usual case where all new coal plants built in the future will be modern pulverized coal (PC) plants. The second scenario (BAU2) is one in which all new coal plants will be more efficient integrated gasification combined cycle (IGCC) plants. (BAU2 is subdivided into two different scenarios, BAU2a and BAU2b. BAU2a is a scenario in which all new coal plants will be IGCC, but the remaining old PC plants continue to operate as PC. BAU2b, on the other hand, is a scenario in which, in addition to building only new IGCC plants, all old PC plants are gradually retrofitted/repowered to IGCC over time.) The third and fourth scenarios

(BAU2+LowH2 & BAU2+HighH2) are essentially the same as BAU2b, except that an additional amount of coal is used to produce hydrogen for vehicles. In BAU2+LowH2, the market share of H2FCVs grows to 50% by 2050. Similarly, in BAU2+HighH2, the market share of H2FCVs grows to 100% by 2050. The amount of capital investment, both in rail infrastructure and in power/hydrogen plants, required under each of these four scenarios will vary. By comparing the investment costs of each scenario, I can analyze the trade-offs between following the different future paths.

Scenario[7]	*Description*
BAU1	A baseline scenario using EIA projections for coal power demand, and assuming that all new coal plants will be pulverized coal (PC)
BAU2	*BAU2a and BAU2b*: A similar scenario to BAU1, but assuming that all new coal plants will be integrated gasification combined cycle (IGCC) (Same power demand as BAU1, but lower overall coal demand due to the higher efficiency of IGCC versus PC) *BAU2b only*: In addition to building new IGCC plants, all old PC plants are gradually retrofitted to IGCC
BAU2+LowH2	A similar scenario to BAU2b, except that in addition to IGCC plants being built, extra coal is used to supply a fleet of hydrogen fuel cell vehicles, which obtain a 50% share of the total vehicle market by the year 2050
BAU2+HighH2	A similar scenario to BAU2b, except that in addition to IGCC plants being built, extra coal is used to supply a fleet of hydrogen fuel cell vehicles, which obtain a 100% share of the total vehicle market by the year 2050

Table 1: Coal demand growth scenarios analyzed in this study

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[7] The reader should note that 'BAU' in this case refers to Business-As-Usual power demand, not the types of technologies that might be deployed in the future. For example, one could argue that IGCC plants are not BAU. But in this report BAU has to do with the EIA's AEO2006 Reference Case projections for power demand. The various scenarios all assume these same projected power demands; the power plant technologies used to meet those demands may be different across scenarios, however.

Overview of Coal Demand

U.S. coal demand has been on the rise for years. After the 1973 oil crisis and the price shocks that occurred several years later, there was a push in the stationary power generation sector to wean the U.S. off of foreign oil and replace it with domestic supplies of coal. This seemed like a good idea at the time because the U.S. was known to have vast resources of coal that were relatively near to the consuming markets. It was not until more recent times that concerns over climate change caused people to rethink the shift to coal power. At present, coal accounts for about 50% of U.S. electricity generation—well ahead of its next closest competitors, nuclear and natural gas, each at about 19% (EIA, 2005). Coal is also used, albeit to a lesser extent, for other industrial uses, such as steelmaking. In total U.S. coal consumption was about 1150 million tons in 2006. Coal power plants currently account for 312.6 Gigawatts of installed power plant capacity in the U.S., which represents 33.1% of total U.S. generating capacity (EIA, 2006a). The reason that coal makes up a much higher (~50%) share of total electricity generation is because coal plants have higher capacity factors than other types of plants, i.e. they are run more often on average than nuclear, natural gas, etc. Coal plants are distributed throughout the U.S. with the majority of them located in the Midwest and Southern regions of the country. The proximity of these plants to Appalachian and Interior (i.e., Illinois Basin) coal mines made for relatively short distance coal transport throughout much of the second half of the 20th century. But given the shift to low sulfur, relatively inexpensive coal from Western mines (particularly the Powder River Basin in Wyoming and Montana), the advantages (namely lower transportation costs) for Eastern and

Interior coals are no longer what they used to be, and coal is shipped increasing distances to power plants.

Coal remains the fuel of choice in many parts of the country, and not coincidentally, these are typically the same areas where electricity rates are the lowest. The maps below show the locations of coal generating units and the relative amounts of coal consumption by state. Coal generating units are any facilities that produce electricity from coal. The electricity may or may not be supplied to the grid, however. If not, the electricity may be used on site for an industrial user or at a cogeneration facility. Moreover, multiple generating units might be operating at the same given location, since a power plant is typically made up of not just one, but several, generating units—the total power output being the sum of the units. To illustrate, there are over 1800 coal generating units currently in operation throughout North America (GED, 2006a). However, there are only 671 different places housing these units, 623 of which are in the U.S. (eGRID, 2002). (For clarity, I will call these 671 independent locations "plants", despite the fact that they may not necessarily be supplying external residential or commercial customers with electricity.) Many of these plants are quite small; for instance, 168 of them have a capacity that is less than 50 MW, with some as small as 1 MW. Obviously, plants of such small size are typically not the ones supplying power to most residential and commercial customers. Conversely, only 236 coal plants are greater than 500 MW, which can roughly be considered as the minimum size of an electric generating coal power plant that would be built today. The average size of coal plants to be built in the next few years is about 600 MW (GED, 2006a). There are also a few "mega" plants scattered throughout the country that merit special attention because of their sheer size. Five plants have capacities greater than 3000 MW (i.e., 3 GW), the biggest of them being the Nanticoke facility in Ontario, which has a capacity of just over 4000 MW. The largest plant in the U.S. is the Scherer facility in Georgia, which has a capacity of over 3500 MW. The Scherer plant alone accounts for about 1.14% of total U.S. coal plant capacity and uses about 1.18% (13.6 million tons) of all U.S. coal demand (GED, 2006b). Interestingly, the Scherer plant gets virtually all of its coal from the Powder River Basin in Wyoming, a shipping distance of more than 1800 miles.

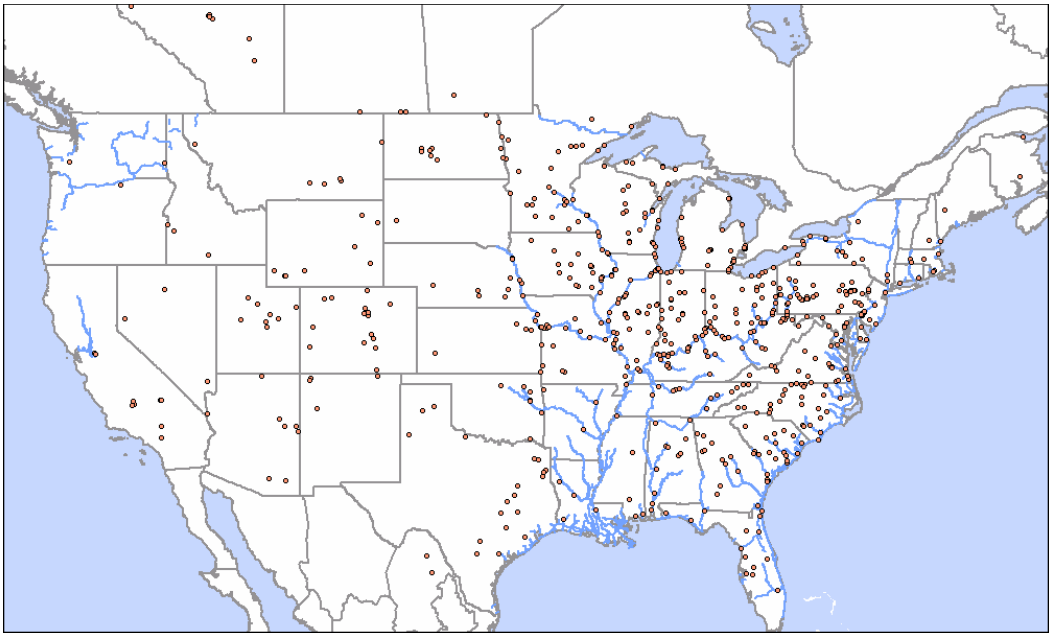

Figure 1: Map of U.S. coal plants and generating units (GED, 2006a)

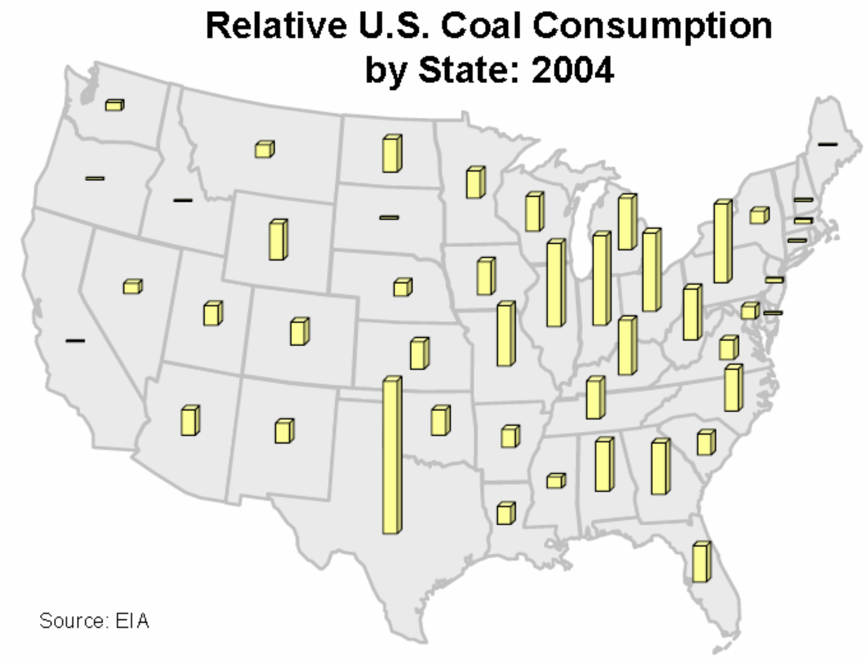

Figure 2: Relative amounts of U.S. coal consumption by state (AAR, 2006a)

U.S. coal demand is expected to grow rapidly in the future. The Energy Information Administration (EIA) uses its National Energy Modeling System (NEMS) to forecast coal demand, supply, and prices from now to 2030.[8] By EIA's estimates U.S. coal demand will grow from 1150 million short tons in 2006, to 1784 million short tons in 2030 (EIA, 2006b).[9] This represents a 63% increase over the next 25 years, with an average annual increase of 1.9% per year. Over the previous 25-year period (1981-2005), U.S. coal demand increased by 54%: demand in 1981 was 732.6 million short tons, and in 2005 it was 1128 million short tons (EIA, 2006c). Of course, the absolute increase in coal demand over the next 25 years will be much greater than over the past 25 (634 vs. 395 million short tons). The main reason for the future increase is EIA's prediction that

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[8] These projections can be found in EIA's *Annual Energy Outlook 2006 with Projections to 2030* (AEO2006). Note that the Reference Case AEO2006 has been used as a benchmark throughout this study, as opposed to the High and Low Macroeconomic or Price Cases.

[9] Note that a "short ton" is simply a "ton", i.e. 2000 pounds, which is different than a metric tonne, i.e. 1000 kilograms or about 2200 pounds.

many new coal power plants will be built in the years around 2020, thereby increasing coal's share of electricity generation from about 50% in 2006, to 57% in 2030 (EIA, 2006d). Total coal demand also grows because of greater coal-to-liquids fuel production and combined heat and power applications. Most of the current coal demand in the U.S. is in the electric power sector—about 92%—with the remainder being used in residential and commercial applications, coke plants, coal-to-liquids production, combined heat and power, and other industrial applications. While the percentage of coal demand for electric power is expected to drop to 84% in 2030, at 1502 million tons it will still make up the lion's share of the total (EIA, 2006b).

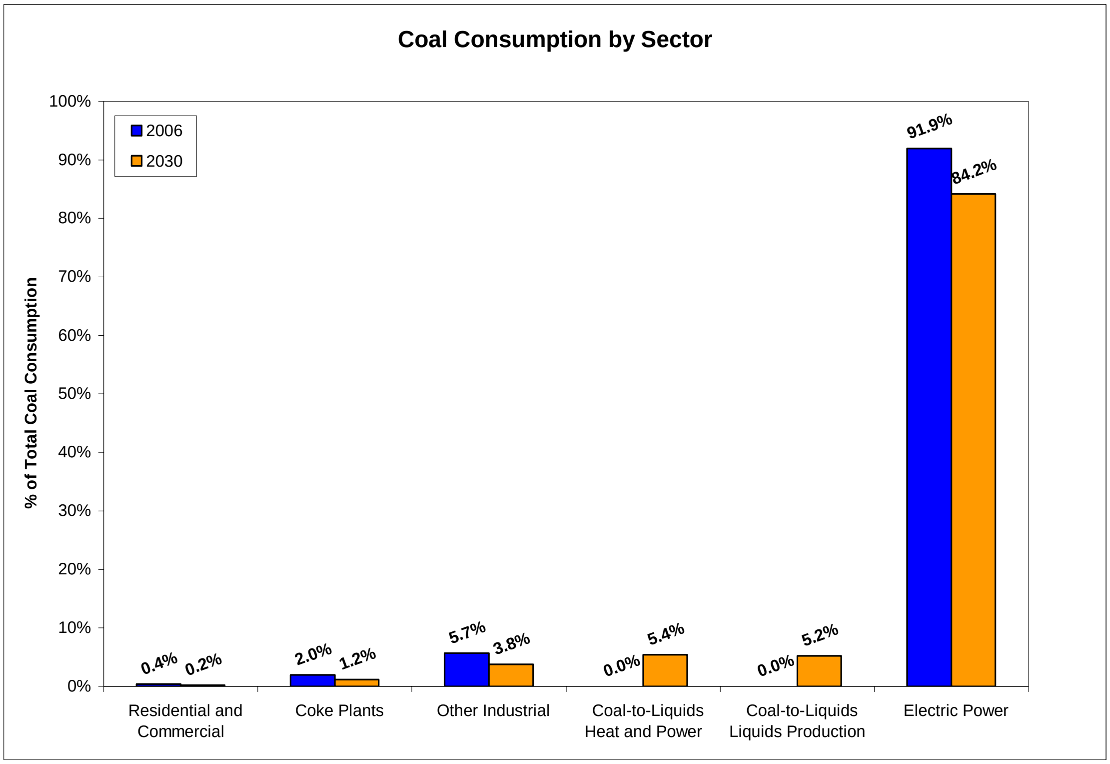


Figure 3: Coal consumption by sector, 2006 and 2030 (EIA, 2006b)

As of 2006, there are 312.6 Gigawatts of installed coal power plant capacity in the U.S., considering all coal plants in the electric power, combined heat and power, and commercial/industrial sectors (EIA, 2006a). This number, which represents 33.1% of total U.S. capacity, is projected to increase to 481 GW by the year 2030, when coal will make up 38.5% of total U.S. capacity. Of these new coal plant capacity additions, EIA projects that 55% of them will be Integrated Gasification Combined Cycle (IGCC) plants, which are more efficient than conventional (sub-critical or super-critical) Pulverized Coal (PC) plants and have lower emissions of both SO_2 and mercury (EIA, 2006e). At present, there are only two commercially operating IGCC coal power plants in operation in the U.S.—the Wabash River facility in Terra Haute, Indiana, and the Tampa Electric Polk Power Station in Florida. Nevertheless, there is much discussion at present in the energy industry about IGCC technology, and a handful of plants are planned/proposed for start-up within the next few years. Some of the new coal plant capacity additions, of all types, that EIA includes in its NEMS model are already in the planning stages, while most of the others have not yet been put up on the drawing boards. In all, there are currently around 140 coal plants being planned across the U.S.

Overview of Coal Supply

The U.S. has aptly been nicknamed “The Saudi Arabia of Coal,” mainly because about one-quarter of the world’s coal resources are located in the U.S (NCC, 2006). The demonstrated reserve base of U.S. coal is estimated at about 494,450 million short tons. This would last the country about 444 years at the current production rate of 1114 million tons per year (NMA, 2006). The United States is the world’s second largest producer of coal, behind China, and accounts for about 18% of global production (EIA, 2006f). Of course, it is unlikely that the U.S. would ever be able to use all of the coal in the demonstrated reserve base. The estimates include coal that cannot be mined due to current land use restrictions or that would be uneconomic to mine based on today's technologies (EIA, 2006f). Taking into account the restrictions on mining, the estimated recoverable reserves of the U.S. coal are approximately 267,312 million short tons, which would last the country about 240 years at the current production rate. Much of these recoverable reserves exist in areas that have yet to be touched by mining.

Within the U.S., there are essentially three general coal-producing regions—Appalachia, the Interior, and the West. The following areas comprise these regions:

- *Appalachia*: Pennsylvania, Ohio, Maryland, West Virginia, Virginia, Tennessee, Alabama, Eastern Kentucky;
- *Interior*: Western Kentucky, Illinois, Indiana, Iowa, Missouri, Mississippi, Kansas, Oklahoma, Arkansas, Texas, Louisiana;
- *West*: North Dakota, Montana, Wyoming, Colorado, Utah, Arizona, New Mexico, Washington, Alaska.

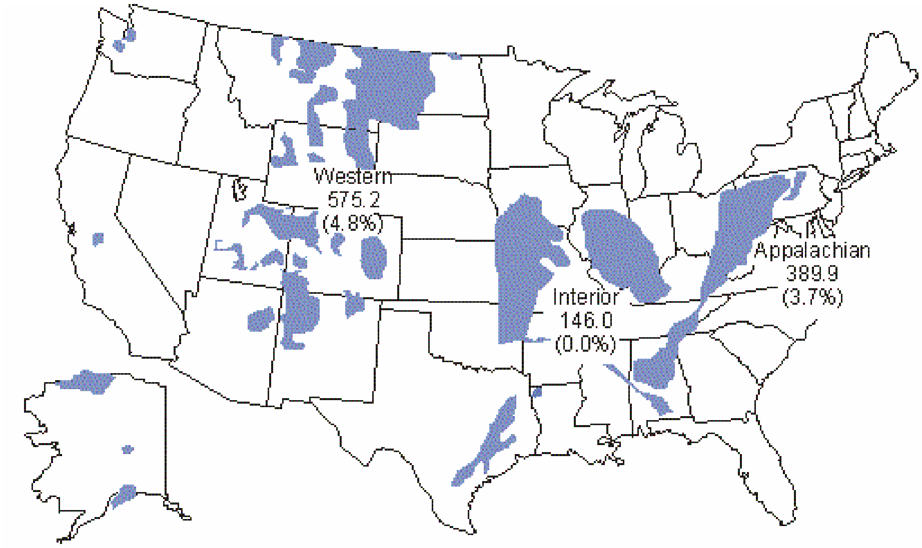


Figure 4: U.S. coal-producing regions; 2004 production (million tons); and percentage changes from 2003 (EIA, 2006h)

The regions can be further categorized into subregions. These classifications are as follows:

- *Northern Appalachia*: Pennsylvania, Maryland, Ohio, Northern West Virginia.
- *Central Appalachia*: Southern West Virginia, Virginia, Eastern Kentucky, Northern Tennessee.
- *Southern Appalachia*: Alabama, Southern Tennessee.
- *Eastern Interior*: Illinois, Indiana, Mississippi, Western Kentucky.
- *Western Interior*: Iowa, Missouri, Kansas, Oklahoma, Arkansas, Texas (bituminous).
- *Gulf (lignite Only)*: Texas, Louisiana, Arkansas.
- *Dakota*: North Dakota, Montana (lignite).
- *Western Montana*: Montana (bituminous and subbituminous).
- *Wyoming, Powder River Basin*: Wyoming portion of Powder River Basin.
- *Western Wyoming*: Wyoming other than Powder River Basin.
- *Rocky Mountain*: Colorado, Utah.

Each producing region contains a particular type of coal, each of which is inherently different from each other. There are four classes of coal: bituminous, sub-bituminous, lignite, and anthracite. These classes are described below.

- *Bituminous*: Mined mainly in the Midwest and Appalachia, with some coming from the West. Average heat content of 24 million British thermal units (Btu) per ton (27.9 MJ/kg).
- *Sub-bituminous*: Mined mainly in the West. Average heat content of 18 million Btu per ton (20.9 MJ/kg).
- *Lignite*: Mined mainly in Montana, Texas, and North Dakota. Average heat content of 13 million Btu per ton (15.1 MJ/kg).
- *Anthracite*: Only mined in northeastern Pennsylvania. Average heat content of 23 million Btu per ton (26.7 MJ/kg).

One of the attractive qualities of coal from the Powder River Basin (PRB) is that it is very low in sulfur content, at least compared to coal from the Interior and Appalachian regions. This allows power plants to meet emissions regulations more easily than with higher sulfur coals. Definitions for sulfur levels in coal are as follows:

- *Low Sulfur*: 0 - 0.60 pounds of sulfur per million Btu
- *Medium Sulfur*: 0.61 - 1.67 pounds of sulfur per million Btu.
- *High Sulfur*: Over 1.67 pounds of sulfur per million Btu.

There are around 1500 coal mines in operation across the U.S. (GED, 2006a). Most of these are old, small mines that can be found in the Appalachian and Interior regions. Many of the newer, bigger Western mines are the ones with the largest production volumes. In fact, the largest 61 coal mines account for about 62% of all U.S. production (EIA, 2006h). Moreover, the top ten mines (based on production volumes) are all in Wyoming. The two largest are North Antelope Rochelle and Black Thunder, which produced 82.5 million and 72.2 million short tons of coal, respectively, in 2004—the equivalent of 7.4% and 6.5% of the entire U.S. production total.

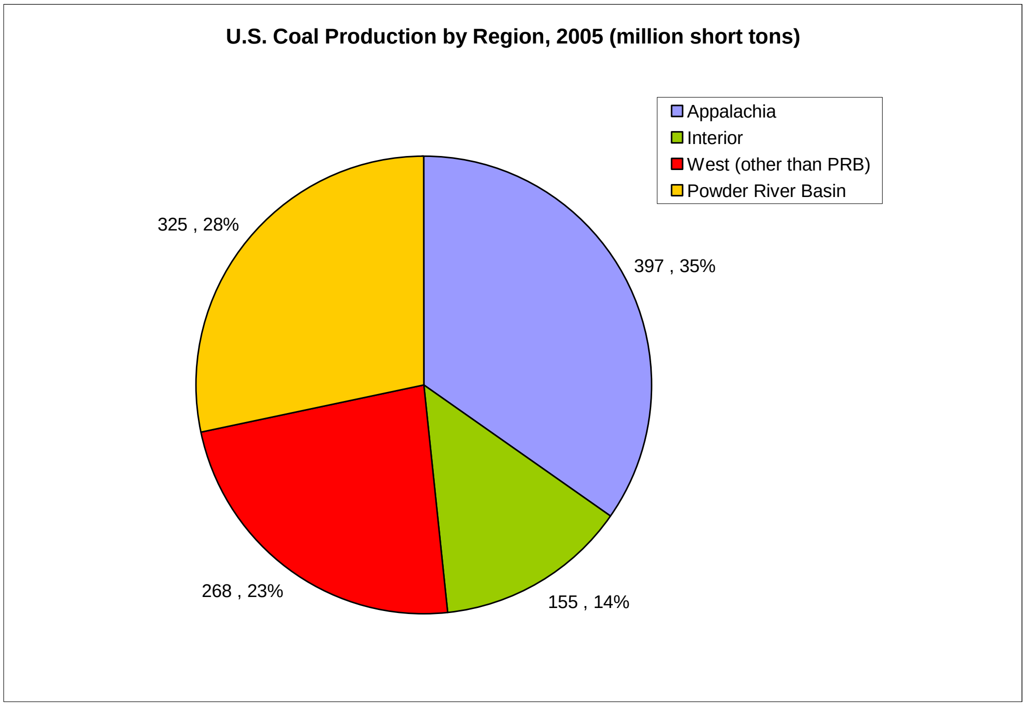


Figure 5: U.S. Coal production by region, 2005 (EIA, 2006b)

Coal mines are only permitted by the government to produce at a certain maximum level. This is known as the ***maximum permissible capacity*** and is often available from the U.S. Bureau of Mines at the regional and state levels. According to

Global Energy Decisions, the data are not uniform and frequently change over short periods of time (GED, 2006c). The best data on maximum permissible capacity are available for mines in the PRB, via the state air permits. But just because a mine is allowed to produce at a certain level does not necessarily mean that the mine has the capability of doing so. For example, GED reports that the total permitted capacity of PRB mines in Wyoming and Montana stood at about 630 million tons per year in 2005 (GED, 2006c). However, the ***actual productive capacity*** (based on equipment, labor, and so on) was probably closer to 451 million tons per year. Thus, what is needed is a more realistic measure of capacity. The EIA collects data on the production capacity of coal mines via its Form EIA-7A, which all mining operators are required to complete. Capacity is always subject to interpretation, but in this instance the EIA defines it in the following way: "…the maximum amount of coal that your mining operation could have produced during the year with existing mining equipment in place, assuming that the labor and materials sufficient to utilize the equipment were available, and that the market existed for the maximum coal production" (GED, 2006c). Unfortunately, the EIA only reports this information at the regional and state levels, which makes it less useful if one is interested in determining the capacity of individual mines. Therefore, I use an alternative approach called the "***proved in-place capacity method***", which I have borrowed from Global Energy Decisions (GED, 2006c). In this approach, I have collected coal mine production data from the previous 14 quarters (3.5 years) for all U.S. coal mines; the Mining Safety and Health Administration (MSHA) and EIA supply these quarterly statistics. Coal production for a given mine often varies over the course of the year based on a variety of factors such as weather, economic conditions, etc. Thus, I take the quarterly production volume that is the largest of the previous 14 quarters and then multiply this value by 4 because there are four quarters in a year. This gives the maximum annual production that a mine could achieve without investing substantially in any new equipment. Any additional production beyond the maximum capacity level, however, would likely require some additional investment on the part of the mine. According to GED, “The rationale is that each mine has demonstrated that it can produce the given volume for a sustained period. The capacity estimates have been confirmed by discussions with coal producers and by experience. Although they consistently exceed the annual estimates published by the EIA, this is likely because most producers are able to ‘coax’ extra production out of their operations by mining in the best areas, pushing equipment to its maximum operating parameters, adding short term labor and other techniques when profitable sales opportunities occur” (GED, 2006c, p. 13). Based on the proved in-place approach, I have estimated that the maximum capacity of U.S. coal production currently stands at about 1422 million tons per year. This estimate should be compared to the 1114 million tons of coal that were mined in the U.S. in 2005 (NMA, 2006). Clearly, the question of whether or not the U.S. can supply the future demand for coal does not rest solely on the mines themselves; U.S. mines have about 28% more capacity than is currently being demanded of them.

So, why then is the U.S. still importing coal from other countries if there is excess production capacity at domestic mines? The answer to this question, some industry analysts believe, is that the capacity of the coal transportation system has not been able to keep pace with the amount of coal that mines are prepared to supply. In other words, coal production is limited by coal transportation. Take, for example, the case of the ten mines that are located along the BNSF-UP Joint Line in the Wyoming portion of the PRB.

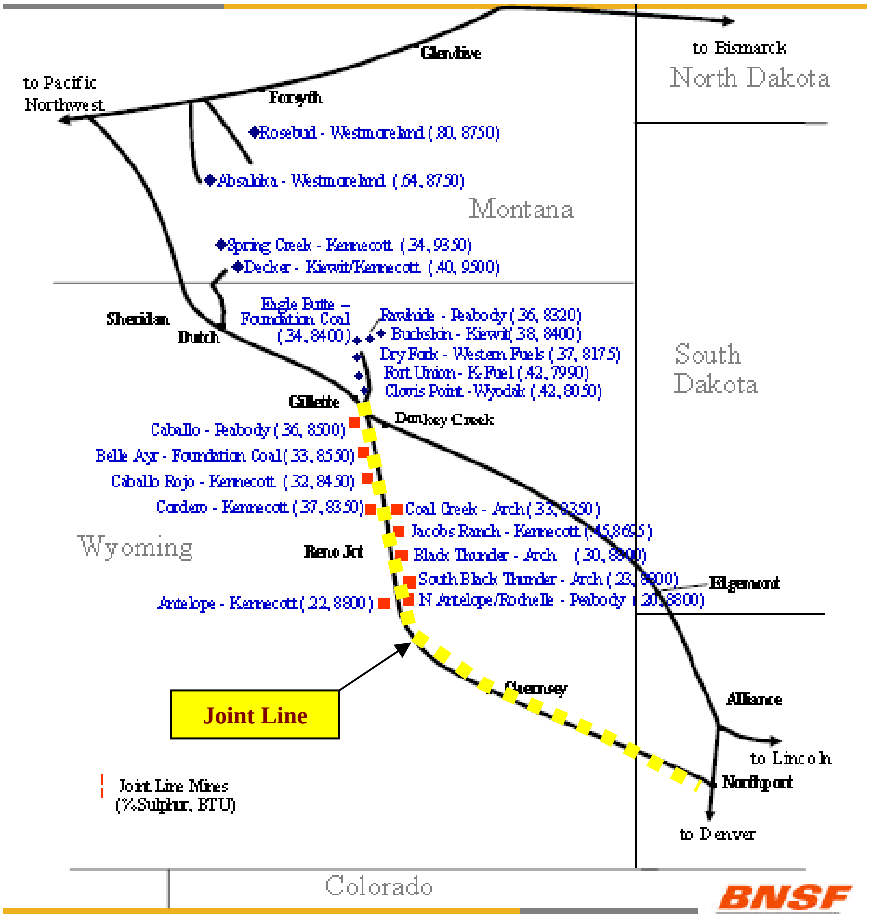


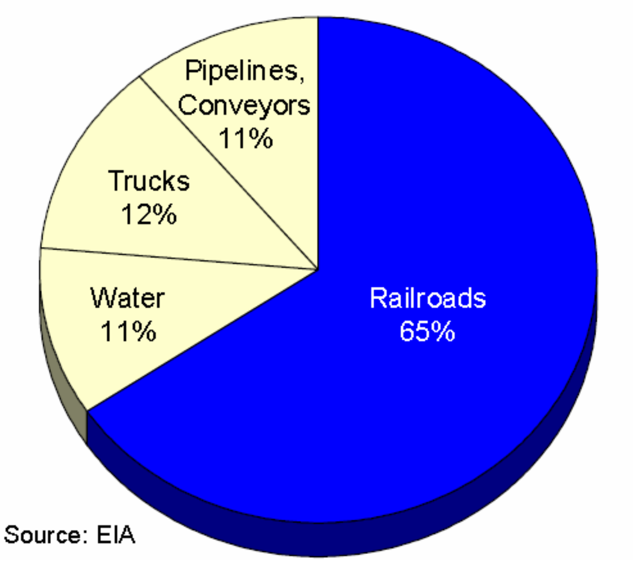
Figure 6: Map of PRB coal mines serviced by the BNSF-UP Joint Line (BNSF, 2005)

I estimate that these ten mines currently have a combined proved in-place production capacity of 352 million tons, but historical data show that their combined production was only 325 million tons in 2005—92% of maximum capacity. Part of the reason for this underutilization is because of two train derailments in May 2005, which had the immediate effect of reducing coal deliveries from the mines to 85% of what demand would have otherwise been (GED, 2006c). While track repairs helped coal production to pick up again later on in the year, there is no doubt that the mines were, and are still, capable of producing more coal than they do. Simply put, they are in the short-term limited by rail capacity—a situation that will potentially be remedied by track additions along the Joint Line, as well as proposed, new rail line out of the PRB. As for the production of the mines along the Joint Line, there are plans to add a new mine and to increase the capacity of the current mines, but it is yet unclear what the resulting capacity will be (GED, 2006c). Measures like these should do well to address concerns over the railroads' short-term ability to meet increased coal demand. How much investment ultimately needs to be made in the long-term is another story, however.

Other potential capacity constraints in the coal supply chain, in addition to coal mining and transport, could potentially be processes such as loading of coal onto rail cars, trucks, and conveyors at mines, and unloading coal at plants. These other constraints have not been well discussed in the literature. They could potentially constrain growth in coal demand in the near-term; but in the long-term, investments in these pieces of the infrastructure will likely be made, though the cost of such investments is yet unknown.

Overview of Coal Transportation

Historically, railroads have been good for coal. And coal certainly has been good for the railroads. While virtually all modes of surface transportation are used to ship coal, rail is by far the most dominant. Nearly two-thirds of U.S. coal shipments are carried to their final domestic destination by rail. The other three major transportation modes—truck, water, and pipeline/conveyor—are, at 11 – 12%, roughly equivalent in their contribution to coal transportation (Hamberger, 2005). Trucks, slurry pipelines, and conveyor belt systems are more or less limited to short distance coal transportation. Yet, most of the coal in this country is located at a great distance from the major population centers where the coal power plants are often located. Hence, long distance transportation of coal via rail and water has become exceedingly common. As far as water transportation goes, ten percentage points of its 11% share can be attributed to movement of coal along the nation's inland waterway network, mainly to coal plants along the Ohio and Upper Mississippi Rivers; the remaining one percentage point is a combination of coal movements via coastal tidewater and the Great Lakes (AAR, 2006a).



Source: EIA

Figure 7: U.S. coal shipments to final destination by mode, 2003 (Hamberger, 2005)

At the same time, coal is the largest single commodity that is carried by U.S. freight railroads, making up 43% of total tonnage, 24% of total carloads, and 20% of total revenue for the Class I railroads (AAR, 2006a). There are over 500 railroads in the U.S., but the seven Class Is account for some 70% of the rail industry's track mileage, 89% of its employees, and 93% of its freight revenue (AAR, 2006b). As one might expect, the vast majority of coal is delivered by Class I railroads. Class Is are the biggest railroad companies in the U.S.; they usually have operations across many states and concentrate their services on the long-haul, high traffic intercity rail corridors. The seven Class I railroads operating in the U.S. are listed below.

1. *Burlington Northern and Santa Fe (BNSF)*;
2. *Union Pacific (UP)*;
3. *CSX Transportation (CSX)*;
4. *Norfolk Southern (NS)*;
5. *Kansas City Southern (KCS)*;
6. *Canadian National (CN)*, (via the Grand Trunk Corporation, which consists of the U.S. operations of CN, including the former Grand Trunk Western, Illinois Central, and Wisconsin Central);
7. *Canadian Pacific (CP)*, (via the former Soo Line, which is owned by CP)

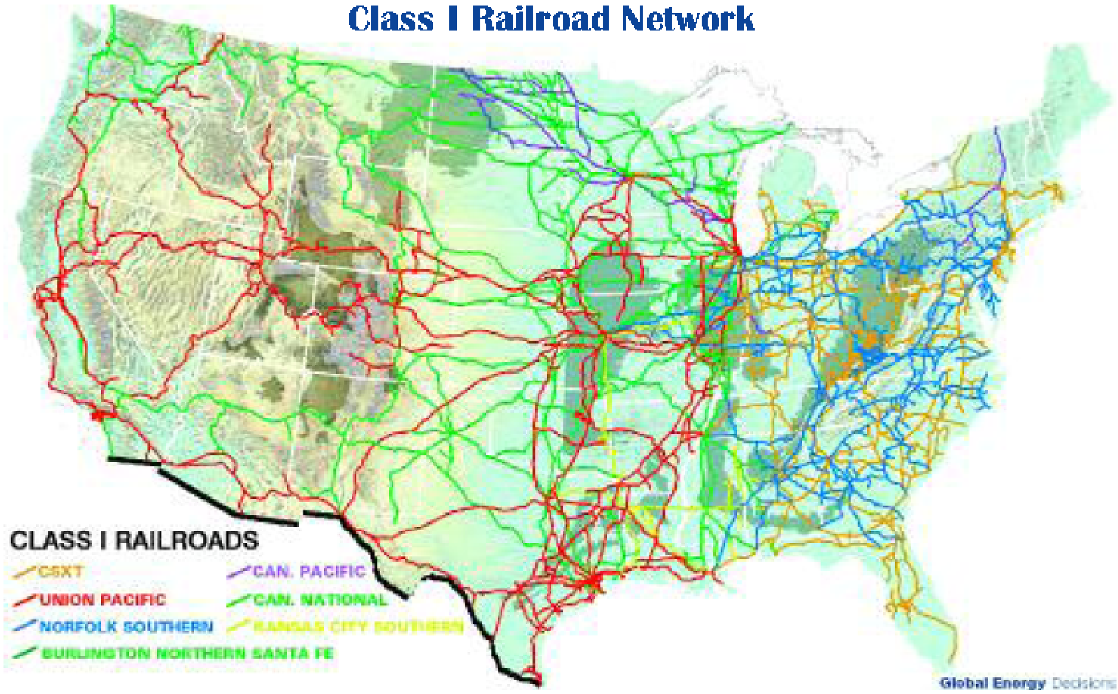
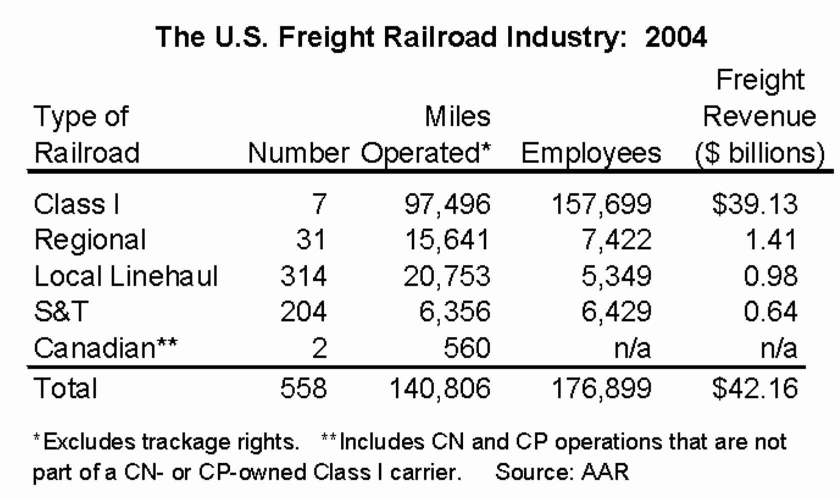


Figure 8: The U.S. Class I railroad network (NCC, 2006)

Non-Class I railroads fit into one of the following other categories (in order of annual revenue): regional railroads, local linehauls, and switching and terminal carriers.



The U.S. Freight Railroad Industry: 2004

Type of Railroad	Number	Miles Operated*	Employees	Freight Revenue ($ billions)
Class I	7	97,496	157,699	$39.13
Regional	31	15,641	7,422	1.41
Local Linehaul	314	20,753	5,349	0.98
S&T	204	6,356	6,429	0.64
Canadian**	2	560	n/a	n/a
Total	558	140,806	176,899	$42.16

*Excludes trackage rights. **Includes CN and CP operations that are not part of a CN- or CP-owned Class I carrier. Source: AAR

Figure 9: The U.S. freight railroad industry: 2004 (AAR, 2006b)

Over the years, railroads have become more efficient at carrying coal. They have done this through utilizing higher capacity cars and more powerful locomotives. For example, the average carload of coal in 2003 carried 111.4 tons, a 10% increase from 1993 and a 19% increase from 1983. Likewise, in 2003 the average horsepower of a locomotive was 3415 Hp, which was a 23% increase from 1993 and a 52% increase from 1983 (Hamberger, 2005). Most coal is transported on so-called “unit trains”, which are trains that transport a single commodity (in this case coal) and have a dedicated route that runs from the coal mine to the power plant without interruption. The unit trains then return empty back to the mine. The most efficient unit trains operate on a predetermined schedule, have dedicated equipment, and follow the most direct shipping routes possible; thus, the cost of coal transportation via unit trains is cheaper than by non-unit trains. About 85% of all railroad coal shipments are made via unit trains that are 50 or more cars in length (AAR, 2006a). Though, it is not uncommon for unit trains to be over 100 cars in length, with some as long as 135 cars or more. In terms of distance, these trains may be upwards of a mile and a half long. One of the reasons why unit trains are not longer is because most coal loading and unloading facilities would not be able to handle them. Depending on where in the country the coal is coming from and going to, it can take several days or even a week for a unit train to deliver its coal from mine to plant and then make its way back to the mine. Due to the combination of unit train service and the expansion of Western coal mining, the average distance for coal shipments grew from 594 miles in 1994 to 751 miles in 2004; meanwhile, rail coal ton-miles grew from 406 billion to 652 billion over the same time period (AAR, 2006a). Large coal power plants may be serviced by one or more unit trains every single day. Once at the station, plants typically employ a system whereby the unit train moves through a loading zone, and one-by-one each of the rotary gondola coal cars is emptied by flipping it upside down. Adjoining cars need not be unhitched from one another thanks to special rotating couplers. The coal drops onto a conveyor belt and is taken to the coal storage facility. At the other end of the delivery—i.e., at the point of loading—rail cars are usually loaded overhead as the train pulls under a kind of conveyor belt-fed silo arrangement. It takes about three hours both to load and unload a coal unit train (Southern Railways Railfan, 2007; Wikipedia, 2007a). Large surface mines, like those in the west, may load two or three unit trains each day (Wyoming Coal, 2007).

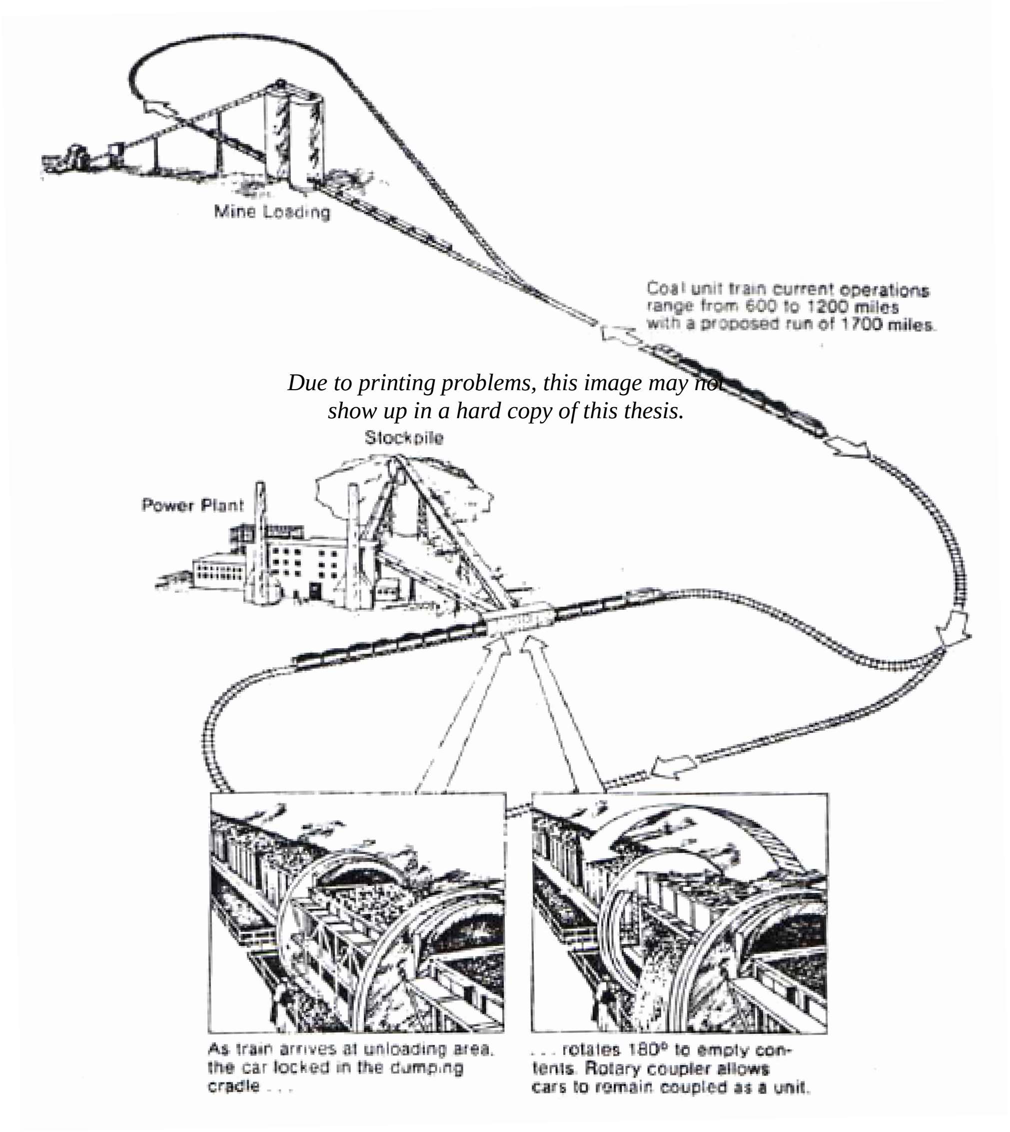


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Figure 10: Schematic of coal unit train operation (White, 1978)

Figure 11: Loading a coal unit train (Peabody Energy, 2006)

Yet, there have recently been some concerns regarding the adequacy of the U.S. coal supply system to meet the growing demand for coal, and these concerns reached a crescendo during the weeks and months after May 14, 2005. It was on this day that two different trains derailed within a few miles of each other along a short section of track in Wyoming's Powder River Basin (PRB). The accident occurred on the "Joint Line", which is an important 102-mile stretch of railroad track that is shared in ownership by the Burlington Northern Santa Fe (BNSF) and Union Pacific (UP) railways. "Subsequent investigation found that the derailments were caused by a weakening of the roadbed due to a combination of accumulated coal dust and significant rain and snow over a short time period" (Hamberger, 2006, p. 8). Coal deliveries out of the PRB were reduced to 80-85% of the norm, and some experts said in 2006 that they had still not fully recovered (English, 2006). As a result, some coal power plant customers across the nation were forced to reduce their stockpiles of coal down to uncomfortable levels. One of the more famous examples was that of the Laramie River Station in Wyoming, a plant that is just 170 miles from the PRB. Similarly, some utilities, like the Arkansas Electric Cooperative, were unable to get all of the coal that they planned on and, thus, were forced either to run their more expensive natural gas plants or to buy more expensive coal from overseas or coal that was higher in sulfur content. In total, it is estimated that the PRB coal shortages cost Arkansas ratepayers more than $100 million in higher electricity bills between 2005 and 2006 (Gallagher, 2006).

Had the train derailments occurred in almost any other part of the country besides the PRB, it might not have caused such a stir, but given America's increasing reliance on this one coal producing region, the concerns were well warranted indeed. The Joint Line provides rail access to ten of the biggest coal mines in the entire country. Thus, the amount of rail-coal traffic that the PRB rail lines see is astonishing. What makes PRB coal so attractive is its relatively lower cost and sulfur content compared to coal from other regions. In fact, the sulfur level is low enough that power plants can either avoid installing scrubbers or buying sulfur credits, two costs which add to the price of electricity. (On the other hand, it should be noted that the transportation costs of PRB coal are often higher than those of other coal types, depending on the location of the plant, and since PRB coal is lower in energy content than some other coals, more of it has to be purchased to supply the same amount of power that one would need with, for instance, Appalachian coal.) PRB coal production has seen explosive growth in the past couple of decades. In 1990, 200 million tons (19%) of U.S. coal production came from the PRB; in 2005, that number had risen to 429 million tons (38%), with 325 million tons (30%) from the 10 Joint Line mines alone (Hamberger, 2006). This rapid growth rate is not expected to slow down anytime soon: by 2030, the EIA projects that Wyoming PRB coal will contribute 657 million tons (39%) to the U.S. supply (EIA, 2006i). Whether or not the coal production and transportation infrastructure can handle this much coal is the subject of current debate and will be dealt with in later sections of this report.

The original rail lines out of the PRB were built in the 1980s in an effort to increase coal production in the area (AASHTO, 2003). Since that time, rail coal shipments have seen explosive growth. In 1985, for instance, the Joint Line handled 19 million tons of coal. But by 2005 the line’s capacity had risen to an astonishing 325 million tons (BNSF, 2006). It is reported that about 65-70 unit coal trains leave the PRB around the clock each and every day. (Note that this figure does not include an equivalent number of empty trains returning back to the PRB to pick up new loads.) The Joint Line is able to handle the high traffic because it is primarily double tracked, with many sections triple tracked. UP and BNSF are in the process of making substantial infrastructure investments in the Joint Line to increase the capacity to more than 400 million tons of coal per year. The investment may not ultimately stop there though. UP and BNSF decided to make the investments after commissioning a capacity planning study by the Montreal-based rail engineering firm CANAC. One of the eventual goals of the study is to identify how to increase the Joint Line capacity to between 500 and 600 million tons of coal per year (Hamel, 2006). The recent investments that UP and BNSF have announced for the Joint Line include triple tracking even more sections and laying down a fourth main line in certain spots. While some electric utilities and other organizations contend that the railroads have not been investing enough in recent years to keep up with the demand for PRB coal, a 2003 AASHTO study found quite the opposite: "Because of the volume and profitability of this market, there are no significant rail capacity constraints. From the building of the Powder River line, to triple tracking where the corridor shares assets with transcontinental flows, to upgrading of lines to handle 287,000-pound and 315,000-pound cars, the railroads have made the necessary investments" (AASHTO, 2003, p. 117). Investments cannot be made overnight, however; so what likely concerns coal producers and consumers the most is the railroads' short-term ability to respond to increases in coal demand.

It should also be noted that a new rail line out of the PRB is currently being proposed by the Dakota, Minnesota, and Eastern (DME) railroad. If built, the line would leave the PRB and head directly east to a point where it can connect with an already existing DME line in South Dakota. Along with DME's partner, the Iowa, Chicago, and Eastern (ICE) railway, more direct, and possibly less congested, shipping routes for coal could open up for a number of power plants in the Midwest and, perhaps, beyond.

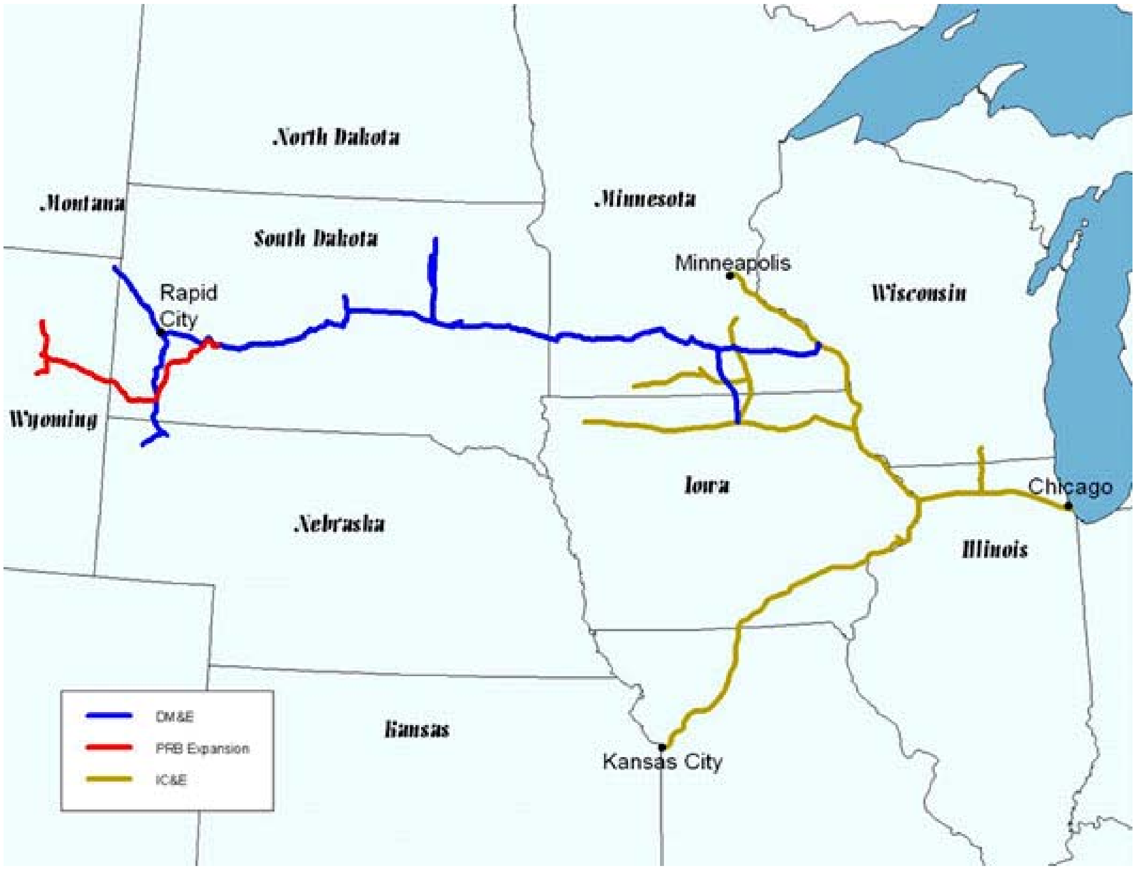

Figure 12: Proposed DME rail line out of the PRB (DME, 2006)

If the railroads are to be expected to carry a substantially greater amount of coal in the future, then they must have the capacity to do so. Yet, it is often stated that the railroads are reaching their capacity limits and certain rail corridors are becoming capacity constrained. Much of these fears rest on anecdotal accounts that have been widely reported in the literature, for example, some utilities in Wyoming, Texas, and Arkansas not being able to get enough coal to fulfill their contracts, or power plants whose stockpiles of coal have been running dangerously low (Gallagher, 2006; English, 2006). And in 2005 there were the two train derailments along the Joint Line out of the PRB, which reduced coal shipments by UP and BNSF (Gallagher, 2006). There are even some accounts of trains that have had to switch crews on the tracks, a few miles out from their switch yards, rather than at the switch yards, simply because the yards were already too congested with trains (Gill, 2006). The following statement by the Association of American Railroad's (AAR) President and CEO Edward Hamberger is typical: in 2005 the railroads experienced "…record overall demand for rail transportation that resulted in capacity constraints on important corridors and at critical locations on the rail network…" (Hamberger, 2006, p. 9).

But which "important corridors" are constrained? And where are these "critical locations" or bottlenecks? Definitive answers to these kinds of questions are hard to find, and there seems to be no publicly available literature that is able to answer them. According to Dan Keen, Principal Policy Analyst at the Association of American Railroads, nothing of the sort exists (Keen, 2006). By Keen's estimation, one of the reasons why no such list of bottlenecks currently exists is because of the inherent difficulty and uncertainty in putting one together. The railroads' situations are always changing; a line that may be capacity constrained at one moment in time may not be constrained just a few months later. In the meantime, new track might have been laid, or new crews hired—just two examples of how capacity can be increased. (Expanding the labor force means that more trains can be operated, which translates into more coal being shipped.) Another reason is that the railroads are wary of revealing any details of their operations that might compromise their competitive positions. But although no list of choke points is available, one way to approximate the locations of capacity constraints is simply to look at the places where the railroads are currently investing capital (Keen, 2006). Furthermore, Keen echoes the comments of other industry analysts that I have spoken to, as well as the general consensus in the trade press: the rail lines coming out of the PRB, particularly the Joint Line, are far and away the ones that are the most capacity constrained at the present time.

It is generally acknowledged that the rail industry continually operates certain lines at levels that are close to their maximum capacities. The reason for doing this is because capacity additions require substantial financial investment, and railroads face much risk if they build for future traffic that may never come. Hence, these are risks that the railroads simply cannot afford to take unless they are confident that adding capacity will result in more business. According to the Association of American Railroads (AAR) President and CEO Edward Hamberger, "…railroads cannot afford to keep—because their customers, including utilities, are not willing to pay for—spare capacity to have on hand 'just in case.' Thus, before investments in capacity enhancements are made, railroads must be confident that traffic and revenue will remain high enough in the long term to justify the enhancements, and that the investment will produce benefits greater than the scores of alternative possible investment projects" (Hamberger, 2006, p. 5). Therefore, rail companies work closely with their customers to ensure that there is enough capacity in the network to meet everyone's needs. This is why railroads are, basically, always operating at capacity; they do not make serious financial investments until they believe they really need to. But capacity additions cannot be made overnight. It can take a year or more for locomotives to be delivered following their orders. Six months might be required for new entry-level employees to get hired and trained and become qualified. And laying new track can easily take longer than a year. In spite of these inherent limitations, Hamberger states that "the fact that railroads are moving as much coal as they are today is a testament to the diligence with which they address the capacity issue" (Hamberger, 2006, p. 5).

Yet, over the course of the past year, the railroads have found themselves defending their operating and investment strategies in the face of criticism from electric utilities that claim that the railroads have not invested enough in their vast networks. In truth, up until a few years ago railroads were actually reducing the number of miles of track. There was excess capacity in the system, so in certain corridors railroads removed some of their redundant multiple mainline trackage. As an illustration, the amount of double track in the U.S. is less now than it was 50 years ago, despite the fact that the number of ton-miles has more than doubled since that time (Richards, 2006). Railroads were doing fine for much of the second half of the twentieth century, but then in the 1990s railroads saw explosive growth in Western coal demand and, especially, intermodal container traffic from Western ports. The railroads were forced to make capacity additions throughout their networks, even adding track in places where they had previously taken it away from. Hence, an important question has naturally been asked by many in the past several years: Will the railroads be able to invest enough over the coming years to handle the projected increases in freight traffic? The answer to this question has been offered by both proponents and critics. And while this study will attempt to answer a part of this question as it relates to coal, AAR President Hamberger already seems to think that railroads are up to the challenge. Regarding some of EIA's (now outdated) projections that total U.S. coal consumption would grow from 1.1 billion tons in 2003 to 1.5 billion tons in 2025—a 38% increase—Hamberger once said, “Railroads’ performance since 1985 strongly suggests that they will be able to handle the increased coal transportation demands commensurate with this increased consumption, as long as their ability to make the necessary investments in their networks is not constrained” (Hamberger, 2005, p.7). After all, U.S. coal consumption grew 34% between 1985 and 2003, and rail coal transportation (in ton-miles) grew by 98%. If the railroads were able to handle this significant increase in coal traffic over the past twenty years, what reason is there to believe that they will not be able to repeat this act over the next twenty? The National Coal Council (NCC) agrees that the railroads are up to the challenge. In their recent report, they state that their organization has “conducted an in-depth survey of existing data and finds that the mining industry and U.S. transportation infrastructure can be expanded to accommodate growth in coal production by over 1,300 million tons per year by 2025” (NCC, 2006, p. 96). This would result in a more than doubling of the current level of coal demand, from about 1.1 billion to 2.4 billion tons per year. Unfortunately, the NCC study does not go into specifics as to how the coal transportation infrastructure would be expanded—e.g., what routes will exceed their capacity and how much investment will be required to alleviate the resulting congestion. As I have found, this informational void is a recurring theme throughout the publicly available body of knowledge on rail transportation of coal.

To be sure, from 1980 to 2005, Class I railroads invested about $360 billion to maintain and improve their infrastructure and equipment; short line railroads also spent billions of dollars (Hamberger, 2006). Most of this spending, either directly or indirectly, was to the benefit of coal movements, because even investments on rail lines that do not carry much coal can have a positive impact on the coal-carrying capacity of rail lines in other parts of the system. The year 2006 was a big one for freight railroad investment. The $8.3 billion invested by the railroads was a marked increase from just $5.7 billion in 2002.

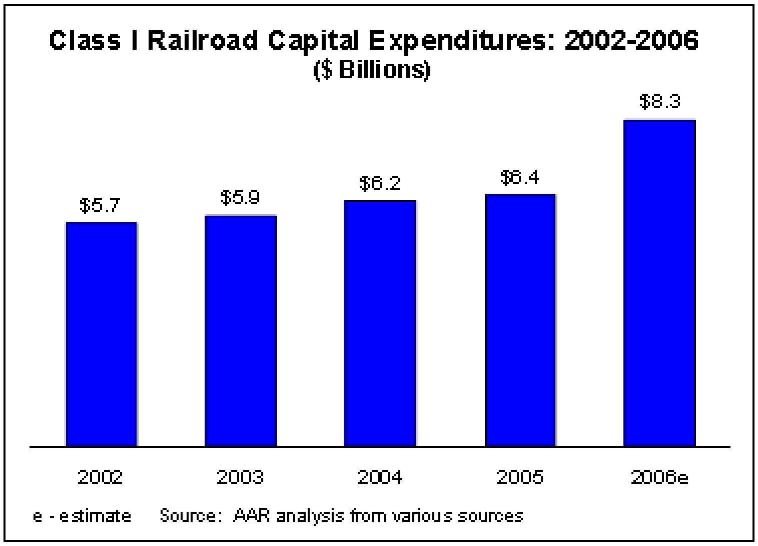

Figure 13: Class I railroad capital investment (Hamberger, 2006)

Much of this investment has been, or will be, used to increase the capacity of the rail coal transportation infrastructure. The following table highlights some of the more important rail investment projects for coal service that have been completed recently, or are planned for the near future. (Note that much of the text below is reproduced from an AAR statement by Ed Hamberger (2006).)

Railroad	Investments
Burlington Northern & Santa Fe (BNSF)	In 2005, BNSF purchased 1,300 coal cars, as well as 288 new locomotives, of which approximately 90 were assigned to coal service. The company plans to add 362 more locomotives in 2006, half of which will be used in coal service. Planned investments directly related to its coal business over the next couple of years include $500 million to $800 million on track and terminal expansions and well over $1 billion on new locomotives. Over the past decade, BNSF has spent more than $2.2 billion on investments specifically aimed at increasing coal-carrying capacity.
Union Pacific (UP)	Union Pacific has spent more than $1 billion over the past eight years on locomotives and another $1 billion on track capacity enhancements specifically for coal. Major projects include completing the $35 million Marysville, Kansas bypass to expedite PRB coal trains; completing a $40 million Denver bypass to ease the flow of eastbound trains; a new siding on the North Fork branch line in Colorado; several sidings in Southern Illinois to support coal growth; and continuing a multi-year effort to install centralized traffic control on the Central Corridor East/West mainline in Iowa. In 2006, UP will acquire more than 500 new coal cars and dozens of additional locomotives to support coal.
BNSF & UP	In May 2006, BNSF and UP agreed on plans to build more than 40 miles of third and fourth main line tracks, at a cost of about $100 million over the next two years, to meet current and future forecasted demand for PRB coal. This project is in addition to the construction of 14 miles of a third main line track completed last year and an additional 19 miles of the third main line currently under construction and scheduled to be fully operational in September 2006. The total cost of this nearly 75-mile capacity expansion will be about $200 million.
CSX	CSX plans to spend around $1.4 billion per year on capital expenditures in 2006 and 2007, up from $1 billion in the previous few years, with much of the spending benefiting coal. For example, major investments in the Southeast Express Corridor from Chicago to Florida will enhance coal movements to the growing Southeast market, and a new connection at Willows, Illinois provides a new route and improved capacity for western coal over the St. Louis gateway. In 2005, CSX rebodied 1,336 bottom-dump hoppers and repaired an additional 1,933 coal gondolas and bottom-dump hoppers. In 2006, CSX will rebuild 1,100 bottom dump hoppers and repair an additional 1,341 coal cars. From 2005-2007, CSX will acquire 300 new locomotives, many of which will be in coal service.
Norfolk Southern (NS)	Norfolk Southern (NS) will purchase more than 220 new locomotives from late 2005 through mid-2006 to augment the hundreds purchased over the past few years. Scores of these locomotives have been used in coal service. NS is also in the midst of its largest-ever locomotive rehabilitation program — in 2005, 491 locomotives were overhauled and 29 were rebuilt; another 420 will be overhauled and 52 rebuilt in 2006. NS is investing $60 million to add track capacity for coal movements between Memphis and Macon, Georgia, and $42 million to build five miles of new line to improve rail service at a coal-fired power plant.
Canadian National (CN)	In 2006, Canadian National will spend $1.2 billion to $1.3 billion on capital programs in the United States and Canada. Included are the reconfiguration of the key Johnston Yard in Memphis, a gateway for CN's rail operations in the Gulf of Mexico region; siding extensions in Western Canada; and investments in CN's Prince Rupert, British Columbia, corridor to capitalize on the Port of Prince Rupert's potential as an important traffic gateway between Asia and the North American heartland.

Canadian Pacific (CP)	In 2005, Canadian Pacific finished its biggest capacity enhancement project in more than 20 years by expanding its network from Canada's Prairie region to the Port of Vancouver. The project increased the capacity of CP's western network by 12 percent and improved the route structure from Canada's Pacific coast to the United States. Like other carriers, CP has added new sidings on congested corridors; taken delivery of dozens of new locomotives and newer, higher capacity freight cars; and hired and trained hundreds of new employees, many of whom will be in the United States.
Kansas City Southern (KCS)	Kansas City Southern (KCS) plans to continue to invest in its coal network to reduce cycle times, improve asset utilization, and increase velocity. To improve the coal network in 2005, the KCS Pittsburg, KS yard was modified to allow for distributed power (DP) to be added to coal trains more efficiently. Double track in Heavener, OK was added to improve fueling throughput at the new KCS main line fueling facility. Also in 2005, five sidings were extended to allow for longer coal trains. In 2006, a new siding opened for operation, and a DP setout track is being built to allow for the efficient removal of the DP power. From late 2005 through the first quarter of 2006, KCS received 30 new locomotives to bolster the fleet available to transport coal and to improve on-time coal train deliveries.

Table 2: Recent or planned rail investment projects for coal service

Although the focus of the investments highlighted above, rail capacity is not just a function of physical infrastructure alone. It also depends on personnel, and the railroads are currently on a hiring spree (Hamberger, 2006). More employees means that the railroads can run more trains, and the more trains they can run, the more tonnage they can haul. Rail employment had been falling steadily for decades up until 2004; but it is now on the upswing again.

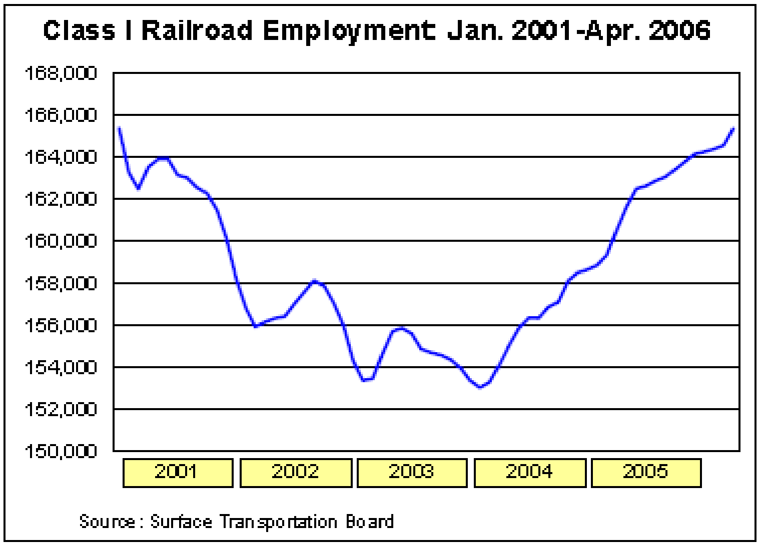

Figure 14: Class I railroad employment (Hamberger, 2006)

Furthermore, railroads are seeking other alternative ways to increase capacity. These include entering into innovative, mutually beneficial collaborations with each other—for example, to share rail lines; and developing/implementing complex computer models to optimize train movements. All of these efforts in tandem are helping, and will continue to help, ease the capacity constraints that are now being experienced. In the words of AAR's Hamberger, speaking of the coal transportation problems that the railroads experienced in 2005: "It is extremely gratifying that the nation's railroads have rebounded so robustly from the temporary delivery disruptions of the previous year" (Hamberger, 2006, p. 18). Others would probably disagree, however, by saying that the rail supply problems were just the start of something that will become more common in the future. The Federal Energy Regulatory Commission (FERC) took up this debate in June 2006, when it held a public meeting "to discuss railroad-delivery matters and their impact on markets and electric reliability" (FERC, 2006). On one side were representatives from the National Rural Electric Power Cooperative Association, American Public Power Association, and Edison Electric Institute voicing their concerns over the railroad’s inability to reliably meet future coal demands for power plant consumption. As Glenn English (2006, p. 2) of the National Rural Electric Power Cooperative Association put it, “Coal delivery by rail has been increasingly unreliable and expensive. Coal delivery problems by rail can impact the reliability of electric generation, the economics of electricity markets, and the economics of natural gas markets.” On the other side was the rail industry, trying to ease these fears by highlighting the railroads’ past successes and discussing their future plans. This debate is far from settled, and whether or not the railroads can handle future increases in freight traffic, particularly coal, remains to be seen.

II. COAL DEMAND GROWTH SCENARIOS

In the previous section, I highlighted some of the more important aspects of the U.S. coal production, consumption, and transportation industries. My task in this study is to analyze coal supply and demand, as well as the resulting rail coal traffic, that could potentially result from four different scenarios of growth in coal demand in the U.S. between now and 2050.

Scenario[10]	*Description*
BAU1	A baseline scenario using EIA projections for coal power demand, and assuming that all new coal plants will be pulverized coal (PC)
BAU2	*BAU2a and BAU2b*: A similar scenario to BAU1, but assuming that all new coal plants will be integrated gasification combined cycle (IGCC) (Same power demand as BAU1, but lower overall coal demand due to the higher efficiency of IGCC versus PC) *BAU2b only*: In addition to building new IGCC plants, all old PC plants are gradually retrofitted to IGCC
BAU2+LowH2	A similar scenario to BAU2b, except that in addition to IGCC plants being built, extra coal is used to supply a fleet of hydrogen fuel cell vehicles, which obtain a 50% share of the total vehicle market by the year 2050
BAU2+HighH2	A similar scenario to BAU2b, except that in addition to IGCC plants being built, extra coal is used to supply a fleet of hydrogen fuel cell vehicles, which obtain a 100% share of the total vehicle market by the year 2050

Table 3: Coal demand growth scenarios analyzed in this study

These four coal demand growth scenarios provide me with some extreme cases, depending on whether or not IGCC plants and hydrogen fuel cell vehicles are successful at penetrating the market, and whether coal is the sole feedstock of choice for producing

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[10] The reader should note that 'BAU' in this case refers to Business-As-Usual power demand, not the types of technologies that might be deployed in the future. For example, one could argue that IGCC plants are not BAU. But in this report BAU has to do with the EIA's AEO2006 Reference Case projections for power demand. The various scenarios all assume these same projected power demands; the power plant technologies used to meet those demands may be different across scenarios, however.

the hydrogen fuel. This section describes each scenario in detail, as well as the methods used for estimating the aggregate levels of coal demanded by the U.S. in each case. Key assumptions used in my modeling of coal demand growth are shown at the outset of this section. Then, each scenario is described in turn.

Assumptions	
Heat rate for conventional PC plants	10,750 Btu/kWh
Heat rate for a year 2005 modern PC plant	8844 Btu/kWh
Heat rate for a year 2030 modern PC plant	8600 Btu/kWh
Heat rate for a year 2005 IGCC plant	8309 Btu/kWh
Heat rate for a year 2030 IGCC plant	7200 Btu/kWh
Capacity factor for all types of coal plants	67%
Heat content of Eastern coal (LHV)	24 million Btu/ton
Heat content of Interior coal (LHV)	22 million Btu/ton
Heat content of Western coal (LHV)	16 million Btu/ton
Coal-to-Hydrogen Conversion Factor	8.179 kg coal / 1 kg H2 (~6540 Btu / kWh H2)[11]
Average fuel economy of conventional ICE car in 2006	22.3 mpg
Average fuel economy of conventional ICE truck/SUV in 2006	17.7 mpg
Average fuel economy of conventional diesel bus in 2006	3.0 mpg
Growth rate of fuel economy for each vehicle class	1% / year
Efficiency factor of H2FCVs to conventional ICEs (cars and trucks/SUVs)	2.4x
Efficiency factor of H2FCVs to conventional ICEs (buses)	1.67x
Annual distance traveled (cars and trucks/SUVs)	15,000 miles
Annual distance traveled (buses)	50,000 miles
Introduction of H2FCVs into the market (all vehicle classes)	1% of all vehicles in 2015

Table 4: Key assumptions used in modeling coal demand growth in the four scenarios

Scenario BAU1

BAU1 is a scenario in which all coal power is derived from conventional Pulverized Coal (PC) plants.[12] Thus, it is assumed that all new coal plant capacity

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[11] Using the lower heating value (LHV) of 120 MJ/kg (33 kWh/kg) for hydrogen, and a LHV of 20 million Btu/ton for eastern coal.

additions in the future are PC. As mentioned previously, there are currently 312.6 GW of coal power plant capacity in the U.S, a number which is expected to grow to 481 GW by 2030. Taking into account EIA's estimates of the amount of coal plant capacity that will be retired over the forecast horizon, I estimate that there will be 307.3 GW of old, conventional PC plant capacity in operation in both 2030 and 2050. (This assumes that most of today's coal plants will still be running 25 to 45 years from now, which is a reasonable assumption given the 50+ year lifetimes of some of today's coal plants.) Moreover, 173.7 GW and 257.2 GW, respectively, of new modern PC plant capacity will be added by 2030 and 2050. It should be noted that current EIA projections are only developed for the years up to 2030. I have forecast coal capacity out to 2050 by assuming that the growth rate in coal plant capacity per capita (GW/person) in the 2006-2030 timeframe will continue to be the same in the 2031-2050 timeframe.[13] Using population projections to 2050 come from the U.S. Census Bureau, I can estimate the total coal plant capacity installed in 2050 (see figure below).[14]

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[12] Since EIA's coal power projections in its Reference Case scenario of the AEO2006 assume that Integrated Gasification Combined Cycle (IGCC) plants will be built over the forecast horizon, the EIA projections must be slightly modified if they are to match BAU1—i.e., BAU1 is *not* the same scenario as the EIA's AEO2006 Reference Case, though it is similar.

[13] It is possible, however, that coal power plant capacity per person will not continue to grow in the years after 2030; it might level off, or even fall. This could happen if, for example, demand-side measures (such as greater efficiency standards for consumer electric products) are instituted so as to avoid building new coal plants altogether. With this in mind, I have carried out a sensitivity analysis on my assumption of growing coal capacity per capita (GW/person). In the sensitivity analysis, I have assumed that the value for GW/person in 2030 will be constant through 2050, as opposed to increasing based on the average 2006-2030 growth rate. This results in the installed coal plant capacity in 2050 being 553.6 GW, slightly less than the 564.5 GW that is projected if coal capacity per capita continues to grow. This result shows that coal capacity growth is more a function of the growing U.S. population rather than an increasing GW/person level. In other words, coal capacity per capita is relatively insensitive to my original assumption of increasing GW/person, as seen in the following graph. For this reason, I have decided to keep my assumption that the growth rate in coal capacity per capita from 2031-2050 will continue to grow at the same average rate that it did from 2006-2030. I have carried this assumption through all the scenarios in this study.

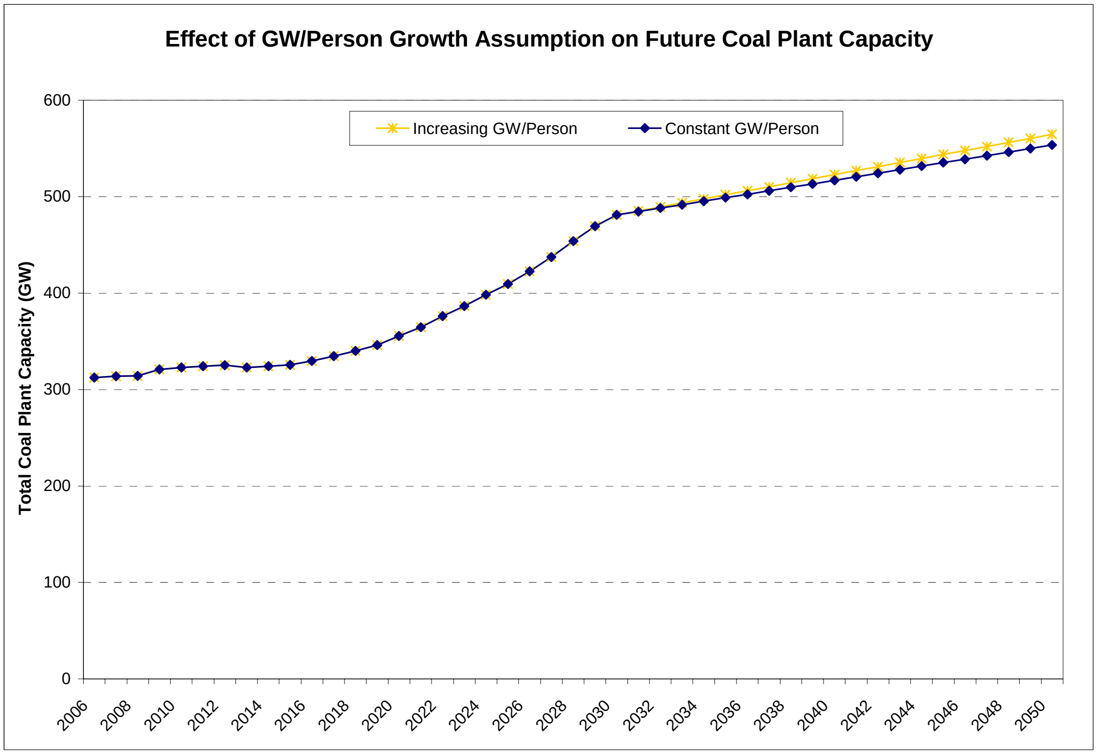

Figure 15: Effect of GW/person growth assumption on future coal plant capacity

The procedure for estimating coal demand for PC plants, both conventional and modern, is now described. First, I use values from the EIA's National Energy Modeling System (NEMS) documentation to estimate the heat rate (i.e., efficiency) of any modern PC plants that will be built in the future (EIA, 2006k). The heat rate for a year 2005 modern PC plant is 8844 Btu/kWh (i.e., efficiency of 38.6%). For the "nth" plant, the heat rate is 8600 (i.e., efficiency of 39.7%). I assume, like EIA, that an "nth" plant will be built in 2020 and that the plants gradually become more efficient over time. I model this by using linear interpolation for the heat rate in the years between 2005 and 2020; after that, it is assumed the heat rate stays the same between 2020 and 2050. In contrast, for

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[14] The U.S. population is projected to be 364,792,000 in 2030, and 419,854,000 in 2050 (U.S. Census, 2004; EIA, 2006j).

currently operating conventional PC plants I assume that the heat rate is 10,750 Btu/kWh, which is an average value for existing coal plants greater than 600 MW, as calculated from the EPA's eGRID database (eGRID, 2002). I also use eGRID to estimate what the average capacity factor currently is, and might be in the future, for a fleet of PC plants. It turns out the capacity factors for conventional coal plants vary widely, but for plants greater than 600 MW, the average capacity factor is about 65-70%. Thus, I assume that all conventional PC plants are utilized at 67% of their capacity, and since any new, modern PC plants will likely be quite large, I have also assumed that their capacity factor will be 67% as well.

I then estimate an average value for the heat content of generic coal based on the heat contents and relative share of coal coming from the different supply regions of the U.S. In 2006, 34.5% of U.S. coal supply came from Eastern (Appalachian) mines; 13.1% from Interior mines; and 52.4% from Western mines (EIA, 2006l). EIA forecasts these percentages to change gradually over time. In 2030, 24.2% will come from Eastern mines; 16.5% from Interior mines; and 59.3% from Western mines. To estimate the quantity of coal coming from the different supply regions—and thus, the fraction from each—in the 2031-2050 timeframe, I again use linear extrapolation based on per capita supply from 2006 to 2030. As more coal comes from the West in the future, the national average heat content of generic coal will decrease since the heat content of Western coal is lower than that of other regions. I assume the following values for the heat content of coal from the various supply regions: 24 million Btu/ton (27.9 MJ/kg) from the East; 22 million Btu/ton (25.5 MJ/kg) from the Interior; and 16 million Btu/ton (18.6 MJ/kg) from the West (EIA, 2006l). A weighted average of these values—based on the regional breakdown of coal supply—yields a generic coal heat content that decreases over time as Western coal gains market share. The average heat content is estimated to be 19.5 million Btu/ton in 2006 and 18.5 million Btu/ton in 2050.

Knowing the power plant heat rates and the heat content of coal, it is a straightforward procedure to estimate the amount of coal (tons) that each of the different types of coal plants (old, conventional PC; and new, modern PC) would demand in the years up to 2050.

$$D_i = \{ [(8760 * 10^6) * Cap_i * HR_i * CF] / HC_{gen\_coal} \} * SF_t$$

(where D_i = coal demand for plants of type *i* [tons]; 8760 = number of hours per year; 10^6 = number of kW per GW; Cap_i = installed capacity of *i*-type coal plants [GW]; HR_i = heat rate of plants [Btu/kWh]; CF = average capacity factor of plants; HC_{gen_coal} = heat content of generic coal [Btu/ton]; SF_t = Scaling Factor in year *t*)

The reason for including a scaling factor (SF) in the above equation for coal demand has to do with the inherent differences in my modeling relative to that of the EIA.

- Compared to NEMS, my model operates at a much more aggregated level.
- I base my projections of power plant coal demand on EIA's projections for total installed coal plant capacity. However, I have not attempted to replicate exactly the method that EIA uses to calculate coal demand based on coal plant capacity; to be sure, the method I use is much simpler.
- My modest effort at replicating the results from the NEMS model utilizes a number of assumptions, about generic coal heat content, plant heat rates, and capacity factors. Because of my assumptions and aggregation, the output from my model inevitably varies somewhat from the coal demand projections of EIA.

I am able to reconcile these differences, however, by use of a scaling factor (SF). A detailed discussion on the derivation of the scaling factor is described in the sidebar below.

Discussion: Scaling Factor Approach

To find the scaling factor, I used my method to simulate EIA's Reference Case as best I could, then compared my model's output to the actual EIA Reference Case projections. As input to my model, I assume the same types of coal plants as the EIA Reference Case: 55% of all new coal plant capacity additions are IGCC, the remaining 45% being modern PC. Based on the NEMS documentation, I assume values for the heat rates of the plants over time (EIA, 2006k).[15] As before, it is also assumed that the plant capacity factor of all coal plants is 67%, and that the same aggregated values for the heat content of generic coal are the same as those discussed previously. I now use my model to estimate coal power plant coal demand based on the same inputs of the EIA Reference Case scenario. The following graph compares projections for total annual coal demand (i.e., coal demand for all purposes) of the EIA Reference Case scenario with my attempt at replicating this scenario.

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[15] Modern PC plant heat rates are calculated in the same way that was described previously; then, an analogous method, is used for IGCC plants. The heat rate for a year 2005 IGCC plant (without CO_2 sequestration) is 8309 Btu/kWh (i.e., efficiency of 41.1%). For the "nth" plant, the heat rate is 7200 (i.e., efficiency of 47.4%). I assume, like EIA, that an "nth" plant will be built in 2020 and that the plants gradually become more efficient over time. I model this by using linear interpolation for the heat rate in the years between 2005 and 2020; then, it is assumed that the heat rate stays the same between 2020 and 2050.

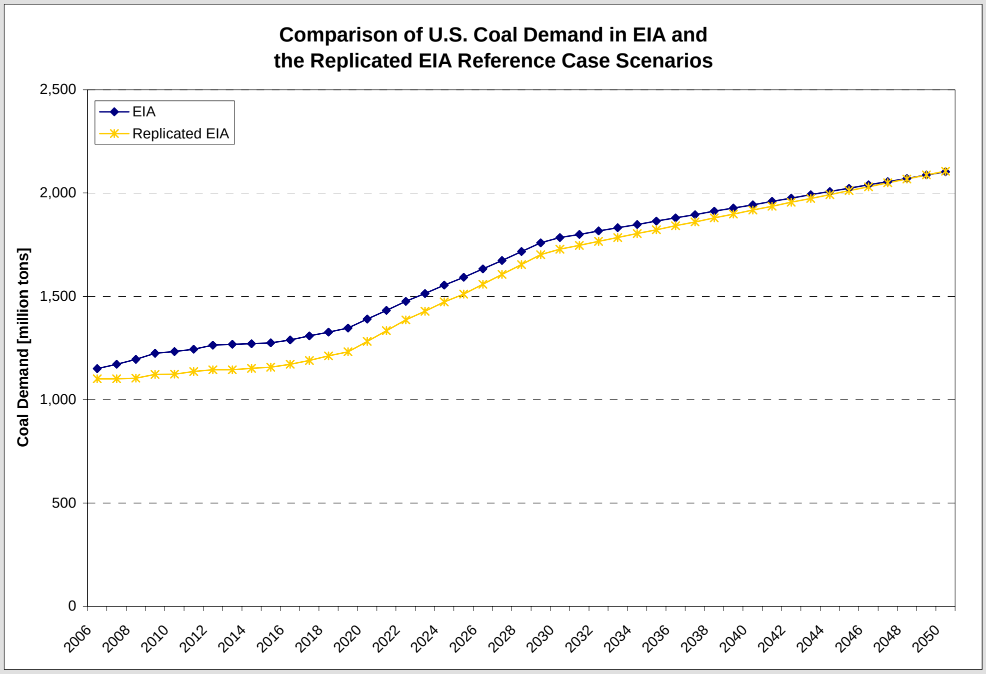

Figure 16: Comparison of U.S. coal demand in EIA and replicated EIA Reference Case scenarios

Obviously, when compared to the EIA Reference Case scenario, my modeling—as represented by the 'Replicated EIA' values—consistently underestimates coal demand in almost every year of the forecast period. The reason for this discrepancy, as discussed previously, is that my modeling methodology is inherently different from NEMS. To match the projections more closely, I can calculate the ratio between the power plant coal demand projected by EIA and that calculated by my model for each year of the forecast timeframe. This ratio is the scaling factor (SF).

$$SF = D_{EIA} / D_{rep\_EIA}$$

(where SF = scaling factor; D_{EIA} = coal power plant coal demand projections from the EIA Reference Case scenario [tons]; D_{rep_EIA} = coal power plant coal demand projections from my own modeling, which attemps to replicate the EIA Reference Case scenario [tons])

It turns out that the scaling factors that I calculate range from 1.0 to 1.12, depending on the particular year in question. This is the equivalent of saying that the EIA Reference Case scenario projections are anywhere from 0% to 12% greater than the projections that I obtain through my attempts at replication. If I multiply the scaling factor by the Replicated EIA coal demand projections for each year that I initially estimated, I would find projections that exactly match the EIA Reference Case scenario. The reader should note that later on in this paper, all of the coal demand projections that I report take the scaling factor into account. If this were not the case, then any of the coal demand projections that I would report for the various scenarios would consistently underestimate the level of coal demand.

Once the coal demands (D_i) for conventional and modern PC plants have been separately estimated, the two can be added together to arrive at the total annual coal demand for electric power in the U.S. in any future year. Adding this sum to EIA's Reference Case scenario projections of coal demand for non-electric power uses (e.g., industrial, coal-to-liquids production, and so on), which I have not changed, yields the total annual coal demand for all purposes. By my estimation, the total annual demand for coal in BAU1 will be 1828 million tons in 2030, and 2166 million tons in 2050, up from 1151 million tons in 2006. These projections can be compared to the corresponding levels of total coal demand for 2030 and 2050 from EIA's Reference Case scenario forecasts: 1784 million tonnes, and 2103 million tonnes, respectively.

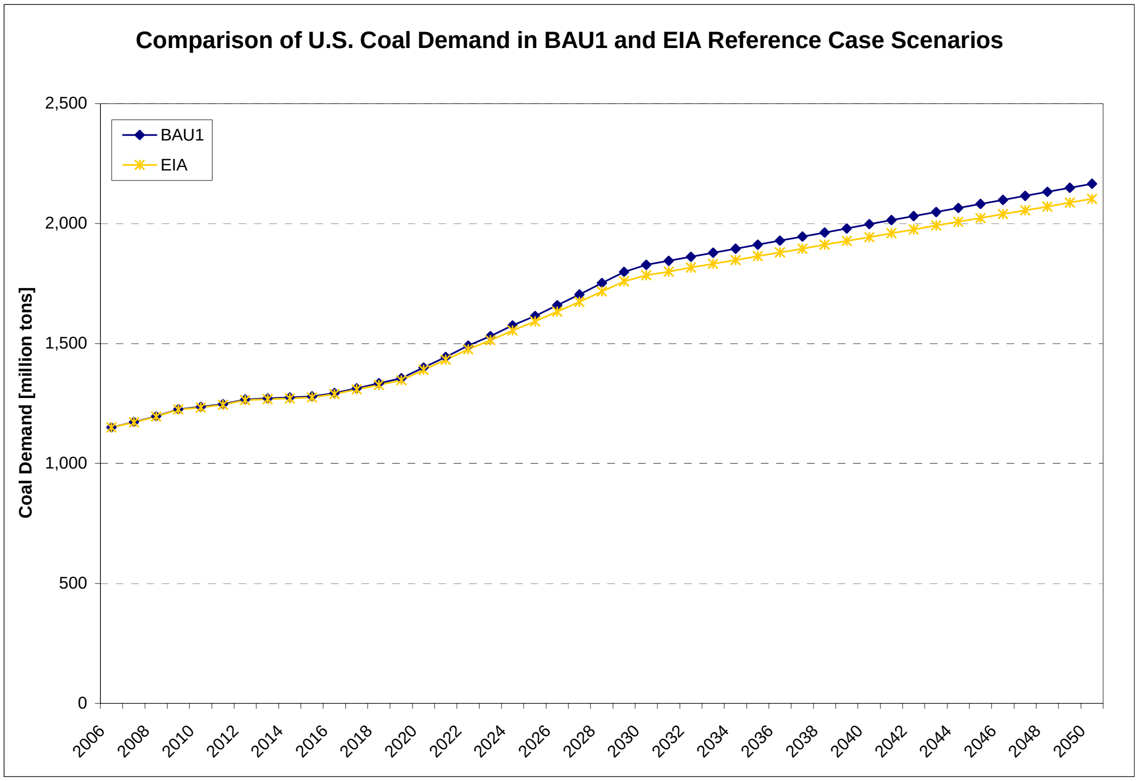

Figure 17: Comparison of U.S. coal demand projections in BAU1 and EIA Reference Case scenarios

On first thought, one might expect the BAU1 projections for coal demand to be substantially greater than the EIA Reference Case projections. After all, BAU1 is a scenario in which all new coal power plants are Pulverized Coal, whereas in the EIA Reference Case IGCC achieves some level of market penetration. Yet, coal demand in the EIA Reference Case is not markedly less than in the BAU1 scenario, especially in the early years before 2020. The main reason is that in the EIA Reference Case only 55% of the newly built power plant capacity is assumed to be IGCC, and newly built capacity will be just a fraction of the total installed capacity of coal power plants over the forecast horizon. IGCC plants do not really gain significant market share until about 2030, which is why they do not contribute to significant reductions in coal demand until later in the time period. In addition, the 16% improvement in heat rate (i.e., 16% reduction in plant coal use) for 2030 IGCC plants over 2030 PC plants, while significant, is not large enough to create wide margins in coal plant demand. It would seem as though building *new* IGCC plants to meet a fraction of the necessary coal plant capacity is simply not enough to significantly reduce the demand for coal from now to 2050. To achieve even greater benefits, it appears that it will also be necessary either to (a) meet all new coal plant capacity demand with IGCC plants, or (b) meet this demand with IGCC and in addition retrofit/repower the older, already-built conventional PC plants to IGCC over time. These potential futures form the basis of the BAU2a and BAU2b scenarios.

Scenario BAU2

BAU2 is a scenario in which Integrated Gasification Combined Cycle (IGCC) coal plants come to play an important role in the electricity generation mix between now and 2050. In actuality, BAU2 can be subdivided into two separate scenarios. First, in scenario BAU2a I assume that any new coal plant capacity that comes into the market is

IGCC; no new Pulverized Coal plants are built. In scenario BAU2b, I assume that not only are all new coal plants IGCC, but also that the already-built fleet of older, conventional PC plants is gradually retrofitted/repowered to IGCC over time. Thus, in BAU2b by 2050 all coal power plants in the U.S. are IGCC. Both the BAU2a and BAU2b scenarios are similar to BAU1 in that total demand for coal-derived power (i.e., newly installed coal plant capacity) is the same. (It is important to note that in both BAU2 scenarios, I assume that none of the IGCC plants are equipped with carbon capture and sequestration, a modification which would increase the plant heat rate—or decrease efficiency—thereby nullifying part of the attractiveness of IGCC over PC, at least purely on efficiency and coal demand bases.)

BAU2a

In BAU2a, it is assumed that all new coal plant capacity additions are IGCC. Since EIA's Reference Case coal demand projections assume that a 55/45% mix of IGCC/PC plants will be built over the forecast horizon, the EIA projections must be modified somewhat. The procedure for estimating coal demand for both new IGCC and conventional PC plants is similar to that described above for scenario BAU1. Plant heat rates, however, are assumed to be different, as shown in the assumptions table above. By my estimation procedure, the total demand for coal in BAU2a will be 1749 million tons in 2030, and 2053 million tons in 2050. These projections can be compared to the corresponding demands from the EIA Reference Case in 2030 and 2050: 1784 million tons and 2103 million tons, respectively. A comparison of the projections for total coal demand in both the BAU2a and EIA Reference Case scenarios is shown for the entire forecast period in the following graph.

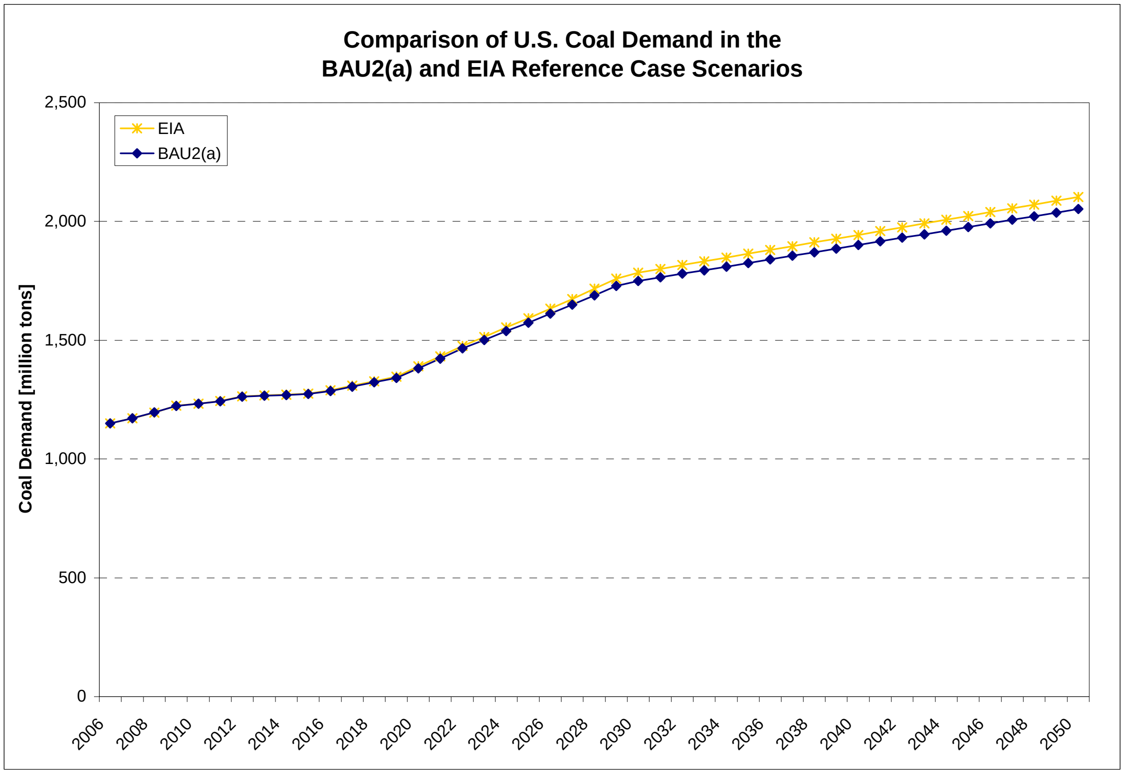

Figure 18: Comparison of U.S. coal demand projections in the BAU2a and EIA Reference Case scenarios

From the graph, it is clear that reductions in coal demand can be achieved by meeting new coal power plant capacity with IGCC plants instead of PC plants. However, the reductions are not particularly significant for several reasons. First, the EIA forecast already assumes that 55% of new coal capacity will be IGCC, whereas BAU2a assumes 100%. In essence, the only real difference between BAU2a and the EIA Reference Case scenarios is the remaining 45% of newly installed coal plant capacity, and whether it is modern PC or IGCC. Although PC plants are assumed to be less efficient than IGCC, the difference does not appear to be enough to significantly reduce the demand for coal over the forecast timeframe—at least when applied to the remaining 45% of new capacity, which in turn is just a small fraction of the total installed coal plant capacity that will exist in the future. A second reason is that even though a substantial amount of new, more-efficient IGCC coal plant capacity is added from 2006 to 2050, an even greater amount of less-efficient, already-built conventional PC capacity still remains in the fleet. Thus, it is difficult for new IGCC plants to significantly reduce overall coal demand, given that conventional PC plants are essentially weighing down the fleet-wide average coal plant efficiency.

A more interesting comparison may be to compare the BAU1 and BAU2a scenarios. Again, the total demand for coal in BAU2a is projected to be 1749 million tons in 2030, and 2053 million tons in 2050. The corresponding demands for BAU1 in 2030 and 2050 are projected to be 1828 million tons and 2166 million tons, respectively. A comparison of the estimated coal demand in both the BAU1 and BAU2a scenarios is shown for the entire forecast period in the following graph.

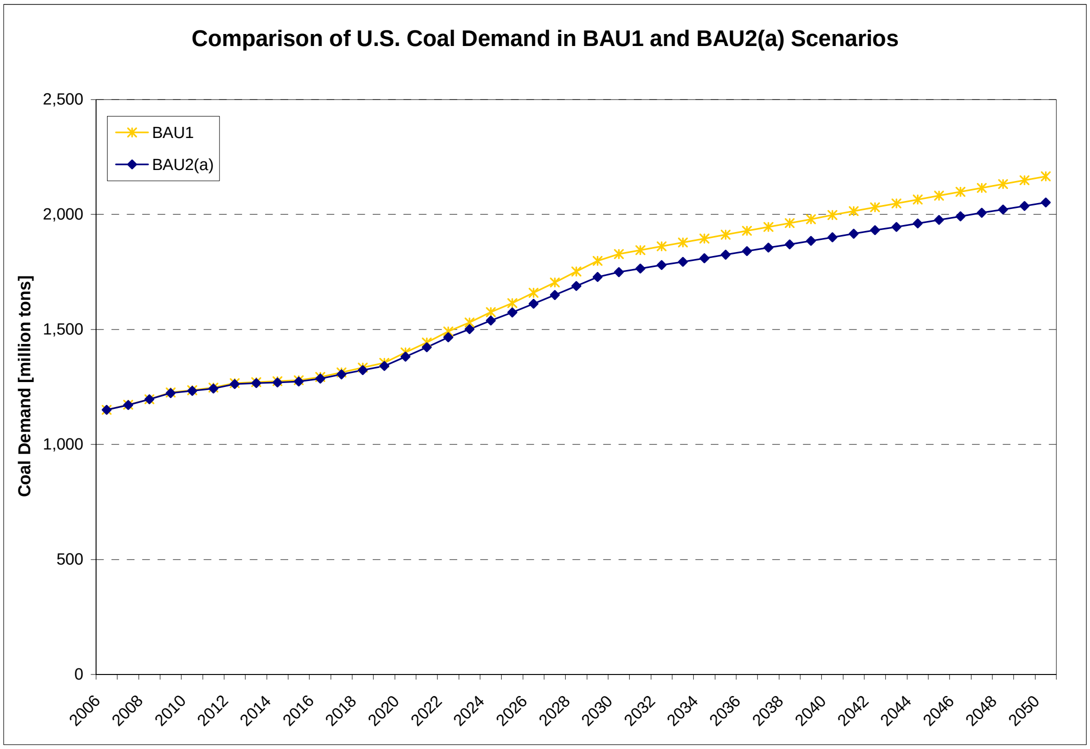

Figure 19: Comparison of U.S. coal demand projections in the BAU1 and BAU2a scenarios

<u>BAU2b</u>

Obviously, relatively significant reductions in coal demand can be achieved by choosing to meet all future coal plant capacity demand with IGCC plants rather than modern PC plants. However, the dominating presence of the already-built, less-efficient conventional PC plants means that, regardless of the adoption of IGCC, coal demand continues on its steep upward trajectory. To slow this rapid increase, it may be necessary to do more than just build new IGCC plants. For instance, currently-operating conventional PC plants could gradually be retrofitted/repowered to IGCC over time. The total demand for coal power in BAU2b over the forecast timeframe is the same as that described previously for both BAU1 and BAU2a—312.6 GW at present, increasing to 481 GW by 2030, and to 564.5 GW by 2050. The procedure for estimating coal demand in BAU2b is basically the same as that in BAU2a: coal demand is estimated separately for both new IGCC plants and conventional PC plants, and these demands are added together to arrive at the total coal demand for electric power. However, the main difference between the two BAU2 scenarios is that in BAU2b coal demand for conventional PC plants gradually decreases over time, since these older plants eventually get repowered to IGCC.[16]

I model the retrofitting of conventional PC plants to IGCC much like one would model the adoption and penetration of any other new technology into the market. I assume that IGCC retrofits will first start to occur in the year 2010, and that in this year, 5% of all conventional PC plant capacity will be retrofitted.[17] The growth of retrofitted IGCC coal plant capacity is modeled with an "s-shaped" market penetration curve. The structure of this type of logistic equation is the following:

$$\frac{dN_i}{di} = r\,N_i\left[\frac{K_i - N_i}{K_i}\right]$$

where:

"N_i" is the cumulative percentage of conventional PC plant capacity that has been retrofitted to IGCC by year "i";

"r" is the growth rate of this cumulative percentage; and

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[16] I have stated in a previous section that my work has been conducted at the aggregate level of the entire U.S., and this is surely the case with IGCC retrofits. I have made no attempt to model the exact timing of a retrofit for a given plant at a particular location; instead, I model retrofits on a nationwide basis.

[17] I do not take any regional or geographic considerations into account when determining which plants get retrofitted. Presumably, retrofits will take place at locations that are spread throughout the country, so the fact that this analysis is carried out at the aggregate level is probably sufficient. While it is possible that IGCC retrofits may take place on a region-by-region basis—something that my aggregate analysis would not capture—I do not anticipate this to be the case.

“K_i” is the maximum percentage of PC plant capacity in year “i” that can potentially be retrofitted.

i=0 refers to the year 2010, i=1 refers to 2011, and so on.

I can solve the equation to find the retrofitted vs. non-retrofitted capacity on a year-by-year basis (see figure below).[18]

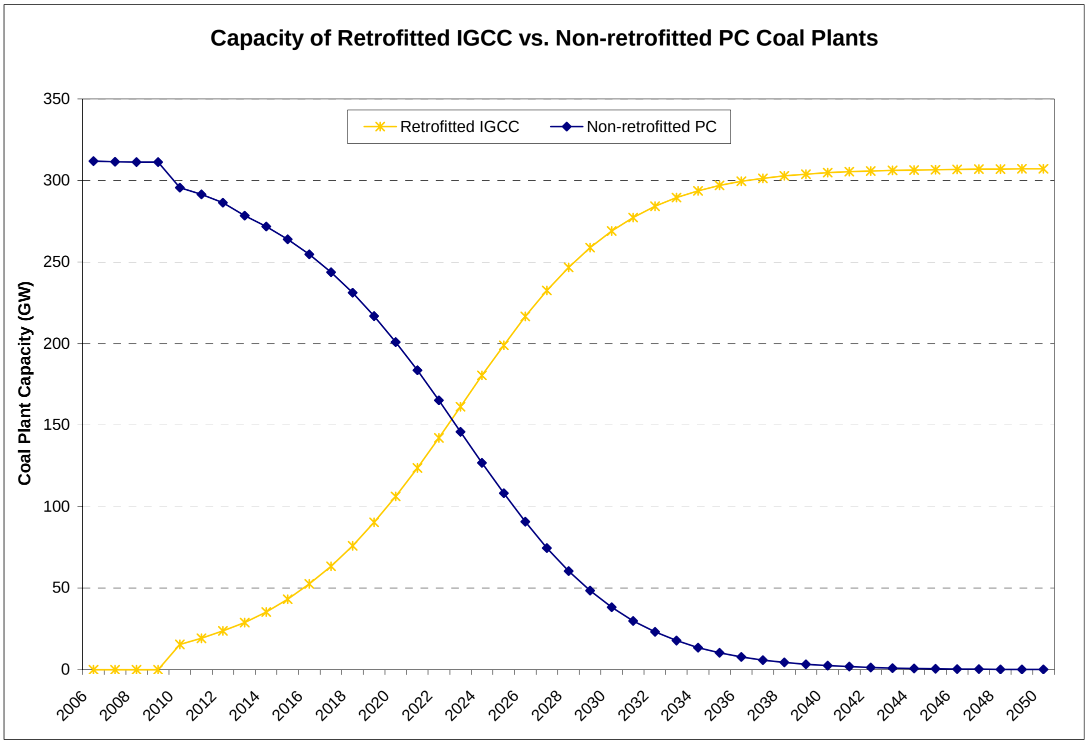

Figure 20: Comparison of retrofitted IGCC with non-retrofitted PC coal plant capacity

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[18] To solve this differential equation, I must assume values for both “N_1” and “r”; “K_1” is, of course, always 100%. Since “dN_1/di” is the change in the percentage of retrofitted IGCC plant capacity from i=0 to i=1, I can add this change to the initial percentage of retrofitted IGCC (“N_0”), which I have already assumed to be 5% of the total conventional PC plant capacity in 2010. This gives a value for “N_1”. The process can then be repeated for “N_2”, “N_3”, and so on, all the way up to “N_{40}”, corresponding to the year 2050. Next, the growth rate (“r”) can be varied until 100% of all conventional PC plant capacity has been retrofitted to IGCC by the year 2050. Once the cumulative percentage of retrofitted IGCC plant capacity has been estimated on an annual basis, it is a straightforward procedure to calculate the amount of capacity that has or has not been retrofitted up to that point in time. One must only multiply the percentage by the total amount of conventional PC plant capacity to arrive at the amount of capacity that has already been retrofitted; any remaining capacity has not yet been retrofitted.

The procedure for estimating coal demand for new IGCC, retrofitted IGCC, and conventional PC plants is similar to that which has already been described in previous sections.[19] By my estimation procedure, the total demand for coal in BAU2b will be 1442 million tons in 2030, and 1708 million tons in 2050.

Scenarios BAU2+LowH2 & BAU2+HighH2

The two scenarios, BAU2+LowH2 and BAU2+HighH2, describe cases where hydrogen becomes an important transportation fuel. In each, it is assumed that any new coal plants are IGCC and that all of the older, conventional Pulverized Coal plants are eventually repowered to IGCC over the forecast timeframe—i.e., BAU2b. But in addition to coal demand for electric power and other purposes, coal is also used as a feedstock for producing hydrogen, an alternative transportation fuel that can power hydrogen fuel cell vehicles (H2FCVs). BAU2+LowH2 is a low hydrogen demand scenario where the fleetwide vehicle market share of H2FCVs increases from 0% to 50% from now to 2050.[20] Similarly, BAU2+HighH2 is a high hydrogen demand scenario where the fleetwide vehicle market share of H2FCVs increases from 0% to 100% from now to 2050. In both scenarios, it is assumed that coal is the only feedstock that is used to produce hydrogen, which is probably not likely to be the case in the future, as one of hydrogen's most appealing attributes is that it can be made from a variety of feedstocks.

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[19] Note the simplifying assumption that the mix of coal (from different locations and of different heating values), will be the same for each of the scenarios. This assumption was made because there is really no easy way of estimating what it should be. One could imagine that the heating value of generic coal could potentially be different under different scenarios. For instance, high coal demand could lead to an increased quantity of coal coming from the west; this might lead to a more rapid decline in heating values.

[20] Note that the BAU2+LowH2 scenario could also be thought of as 100% market penetration of H2FCVs but only 50% of the H2 comes from coal, with the rest coming from natural gas, biomass, or other production technologies.

Nevertheless, these scenarios essentially provide me with some extreme cases of U.S. coal demand, which are valuable because they act as upper bounds for framing the range of potential futures.

To estimate the future demand of coal for hydrogen, one must first estimate the future demand for hydrogen, which depends on the anticipated growth in automobile energy use. Built into the EIA's NEMS energy model are projections of the future growth in passenger cars and light-duty trucks/SUVs up to the year 2030 (EIA, 2006m). The number of cars and trucks/SUVs in the U.S. in 2006 was 133,602,158 and 88,042,900, respectively. In 2030, these figures are expected to be 150,801,758 for cars and 167,023,254 for trucks/SUVs. But since I am interested in projecting hydrogen demand out to 2050 and since AEO2006 projections only go out to 2030, I need to make some assumptions about vehicle growth from 2031 to 2050. The number of light-duty vehicles (cars + trucks/SUVs) per capita has been on the rise for years and is expected to continue its upward trend into the future. The figure currently sits at about 0.74 vehicles per person, a number that the EIA projects will rise to 0.83 by 2030. To forecast the continued growth in vehicles per capita out past 2030, I assume that the 2031-2050 growth rate will be the same as that between 2020 and 2030; in other words, per capita vehicle growth after 2030 is assumed to increase linearly over time (out to 0.87 by 2050). Data and forecasts for the U.S. population come from the U.S. Census Bureau (U.S. Census, 2002; U.S. Census, 2004; U.S. Census, 2006) and the EIA (EIA, 2006m). It is estimated that in 2006 there are about 299,478,000 people living in the U.S., a number that is expected to grow to 364,792,000 by the year 2030 and to 419,854,000 by 2050. Similarly, when estimating the share of both cars and trucks/SUVs in future years, I also employ a linear extrapolation method based on historical trends. Cars currently make up 60% of the market, with trucks/SUVs accounting for the other 40%. EIA (2006m) projects that by the year 2030, the share of the market that is held by cars will drop to 47% while the trucks/SUV share will increase to 53%. By assuming that the trends from 2020 to 2030 will continue to be the same in the 2031-2050 timeframe, I estimate that in the year 2050 cars will only make up 39% of the market, and trucks/SUVs will account for 61%. (Obviously, this estimate is a bit questionable, given recent high gas prices and a gradual decline in sales of trucks/SUVs. Nevertheless, in spite of any knowledge about future gas prices and consumer purchasing behavior, I have chosen to base my estimates on EIA's Reference Case projections.) It is then a straightforward procedure to estimate the number of vehicles in the different vehicle classes based on the total number of vehicles in the U.S. in any given year. One must only multiply the total number of vehicles by the share of vehicles. By my calculations, there will be 156,683,717 cars and 240,285,925 trucks/SUVs in the year 2050. My projections closely match numbers generated by the base case of Argonne National Laboratory's 2005 "Vision Model", which predicts that there will be 159,087,830 cars and 241,410,708 trucks/SUVs in 2050 (Argonne, 2005).

In addition, I forecast the future growth in buses. Bus projections are treated a bit differently. The U.S. Department of Transportation (DOT) supplies historical data for the number of buses and other transportation modes in the U.S. between 1960 and 2004 (DOT, 2006). Similar to the method described above, I assume that the upward trend in the number of buses per capita between 1990 and 2004 continues to increase linearly from 2004 to 2050. I find that in 2004 there were 795,274 buses in operation, and that by 2030 and 2050 there will be 1,121,000 and 1,408,027, respectively.

The following graph shows the sum of cars, trucks/SUVs, and buses in each year of the forecast timeframe. This essentially represents the potential vehicle market for H2FCVs. (Note that I have not considered heavy-duty trucks or other modes of transportation in this analysis.)

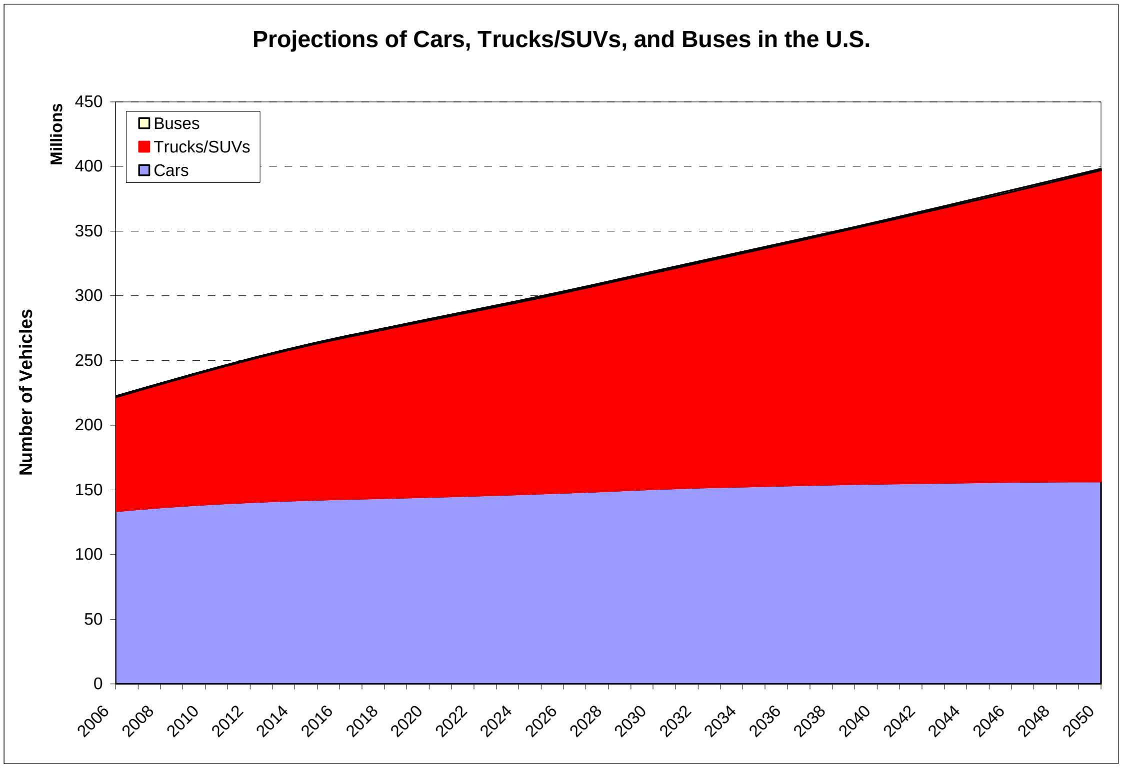

Figure 21: Projections of cars, trucks/SUVs, and buses in the U.S. over the forecast timeframe

The next step in estimating the future demand for hydrogen by the U.S. vehicle fleet is to model the penetration of H2FCVs into the market. To do this, I assume that H2FCVs of all vehicle classes will be introduced into the mainstream auto market in substantial numbers in the year 2015, at which point they instantly achieve 1.0% market share of the entire vehicle fleet. In the BAU2+LowH2 scenario, the market share of H2FCVs ultimately reaches 50%, while in the BAU2+HighH2 scenario the ultimate market share is 100%. The growth of H2FCVs is modeled with an “s-shaped” curve, and the methodology is similar that described above for market penetration of IGCC retrofits. After modeling the market penetration of H2FCVs on a percentage basis of the entire vehicle fleet, it is a straightforward procedure to calculate the number of H2FCVs in each vehicle class in each year. One need only multiply the market share of H2FCVs in a given year by the number of vehicles in the class in that same year. The following graphs show the growth rate of H2FCV market share (as a percentage of the entire vehicle fleet) and the total number of H2FCVs by class under each of the two hydrogen scenarios.

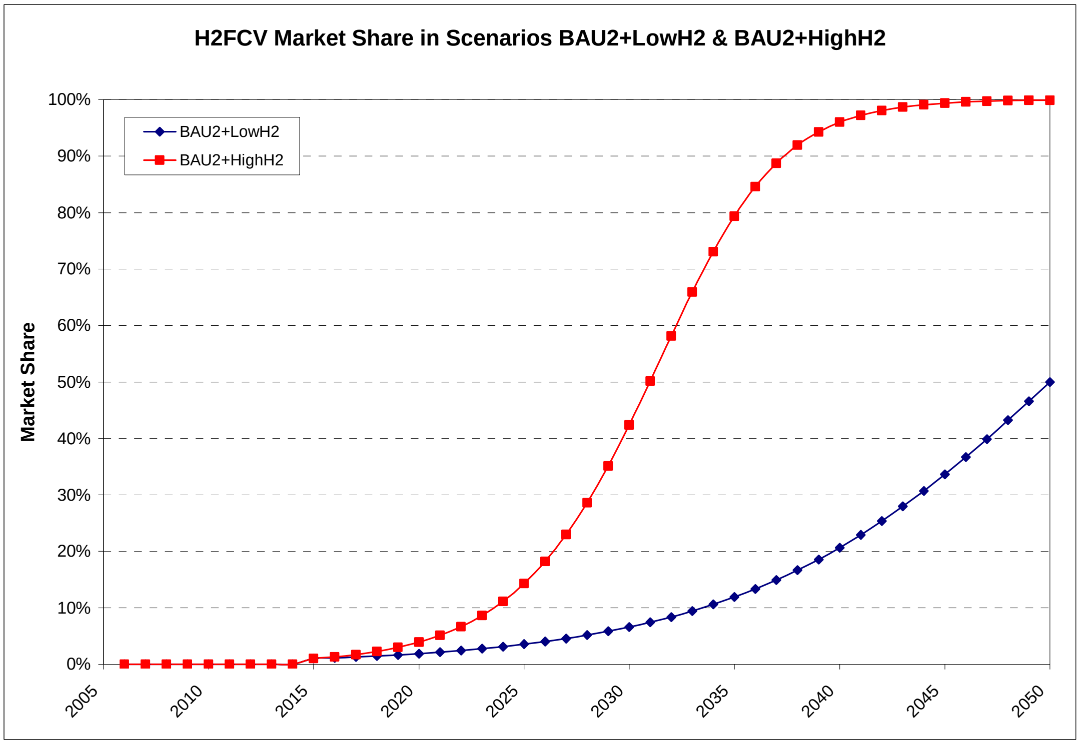

Figure 22: H2FCV market share in scenarios BAU2+LowH2 & BAU2+HighH2

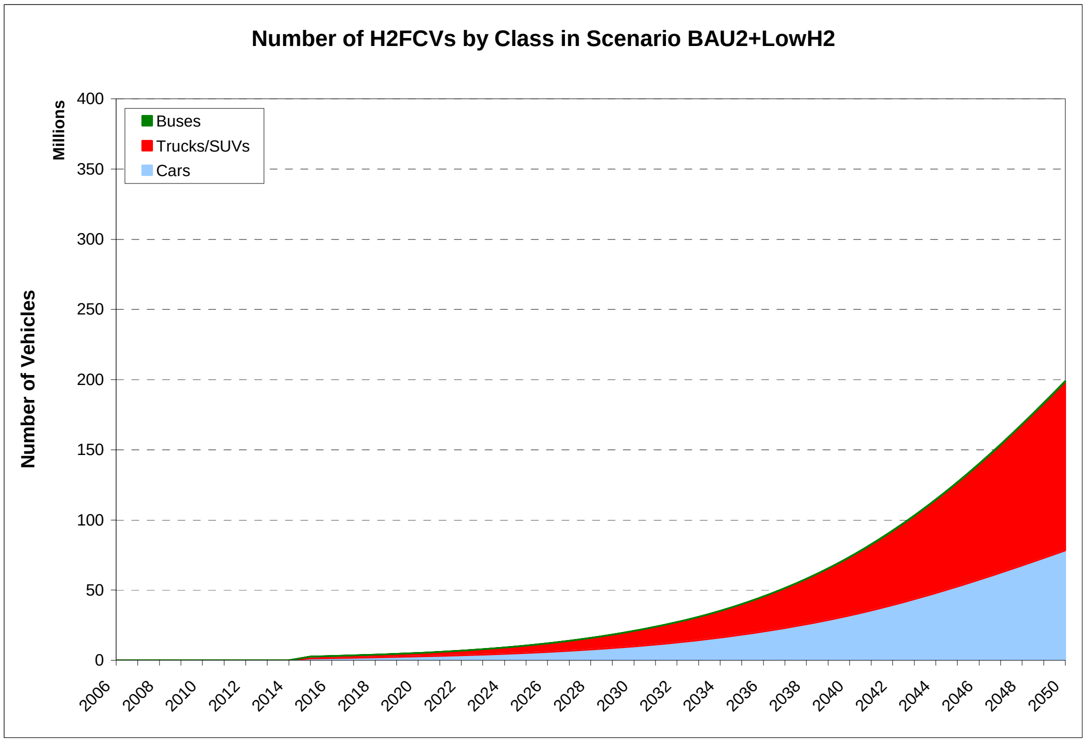

Figure 23: Number of H2FCVs by class in scenario BAU2+LowH2

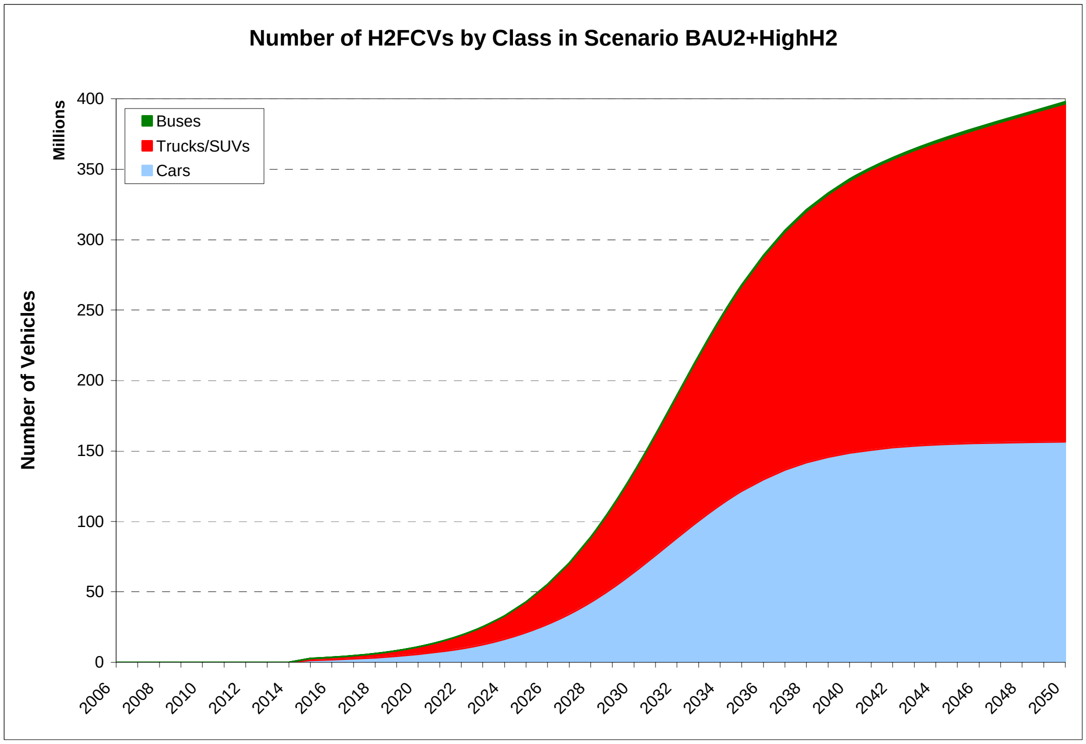

Figure 24: Number of H2FCVs by class in scenario BAU2+HighH2

Once the number of H2FCVs in each class and year has been estimated, the total amount of hydrogen that would be needed to fuel a fleet of these vehicles is calculated. First, I assume that the average fuel economies of conventional internal combustion engine (ICE) cars and trucks/SUVs in 2006 are 22.3 and 17.7 miles per gallon (mpg), respectively (ORNL, 2006a; ORNL, 2006b). For buses, I use a value of 3.0 mpg (Ogden, 2006). Then, based on a similar assumption in the National Research Council's 2004 report on the Hydrogen Economy, the fuel economies for each vehicle class are assumed to grow at a rate of 1% per year over the entire forecast timeframe (NRC, 2004). This translates into year 2050 ICE fuel economies of 34.5 mpg for cars, 27.4 mpg for trucks/SUVs, and 4.6 mpg for buses. The amount of energy contained in a gallon of gasoline is the same as that in a kilogram of hydrogen (~120 Megajoules on a lower heating value basis), and fuel cells are inherently 2-3 times more efficient at converting energy than spark ignition ICEs and 1.5-2 times more efficient than diesel ICEs. Picking mid-range values, I assume that the average fuel economy of H2FCV cars and trucks/SUVs in each year will be 2.4 times greater than that of conventional cars and trucks/SUVs, and 1.67 times greater for H2FCV buses compared to conventional buses (Ogden, 2006; NRC, 2004). Hence, from 2006 to 2050 the fuel economy of H2FCVs in the various vehicle classes ranges from 53.5 to 82.9 miles/kg H2 for cars, 42.5 to 65.8 for trucks/SUVs, and 5.0 to 7.7 for buses. Furthermore, by assuming that every car and truck/SUV travels an average distance of 15,000 miles per year, and every bus 50,000 miles per year, I am able to estimate the amount of hydrogen that a particular vehicle would need on an annual basis by simply dividing its annual average travel distance by its fuel economy (Ogden, 2006). Multiplying the individual vehicle hydrogen demand by the total number of vehicles in the particular class of that vehicle in a given year, and then summing across vehicle classes, the total annual hydrogen demand for a fleet of H2FCVs is calculated.

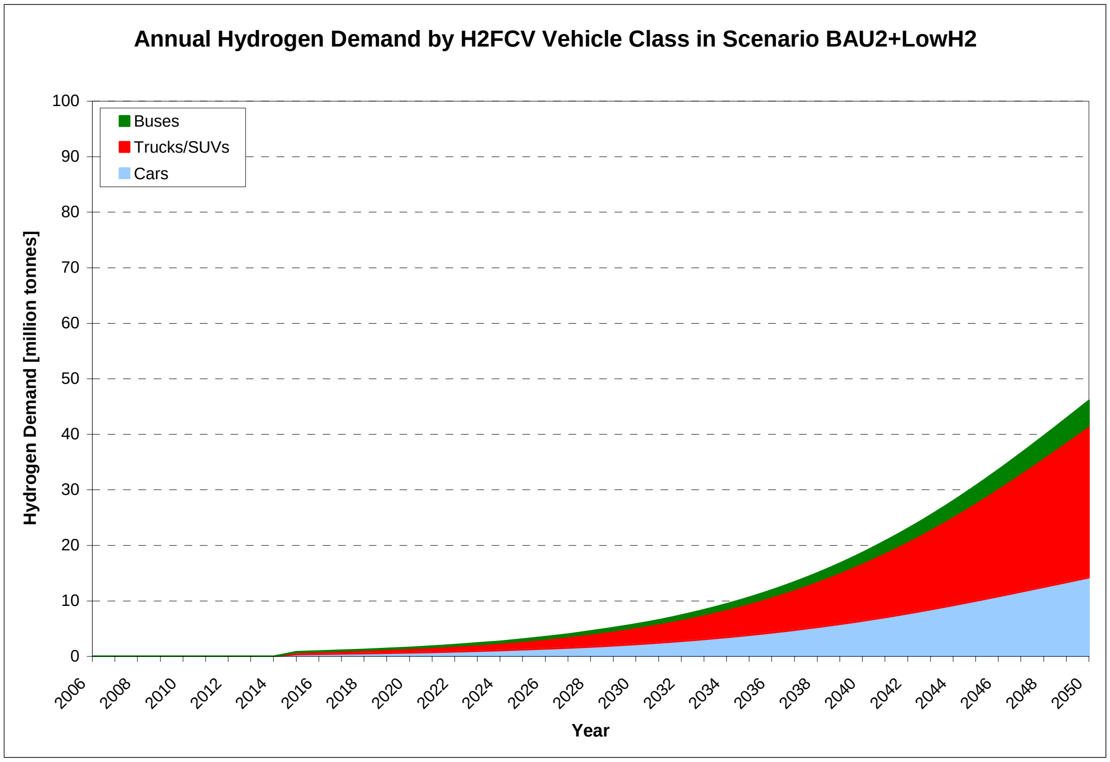

Figure 25: Annual hydrogen demand for the various H2FCV vehicle classes in scenario BAU2+LowH2

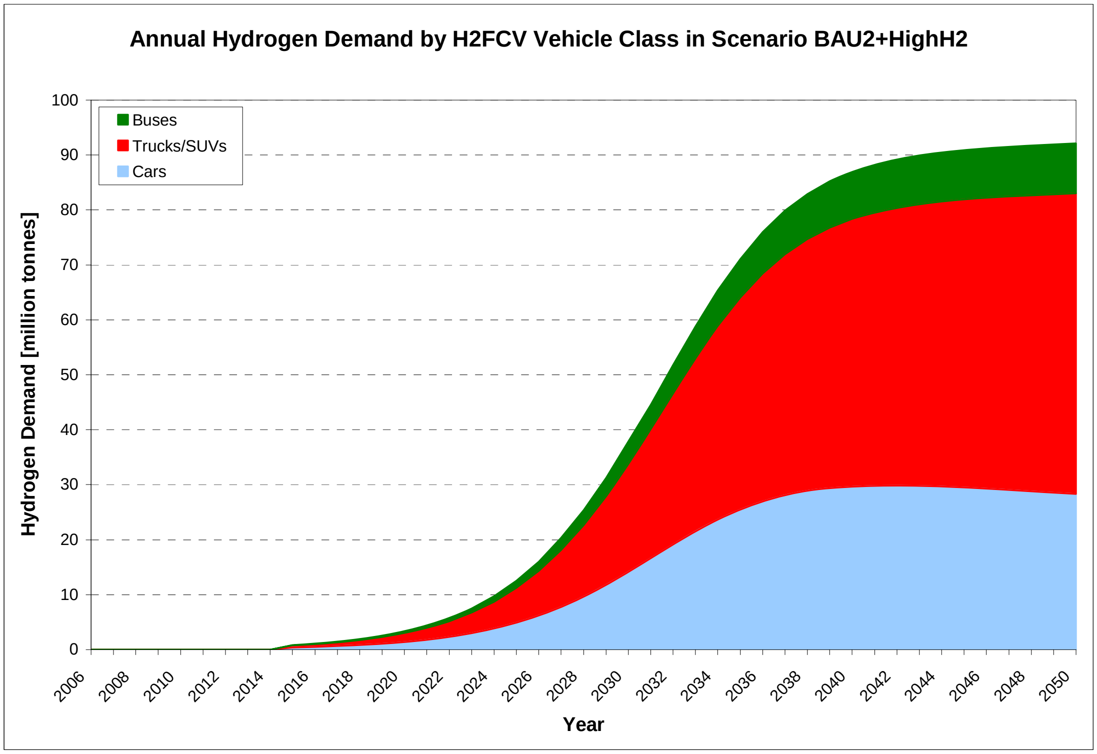

Figure 26: Annual hydrogen demand for the various H2FCV vehicle classes in scenario BAU2+HighH2

From this point it is a straightforward procedure to estimate the amount of coal that would be needed to meet these demands for hydrogen in each scenario. An average conversion factor of 8.179 kg coal to 1 kg hydrogen is used to represent a coal-to-hydrogen gasification process that does not employ CO_2 sequestration (DOE, 2006). The annual coal demand for hydrogen in each of the two scenarios is shown in the following graph.

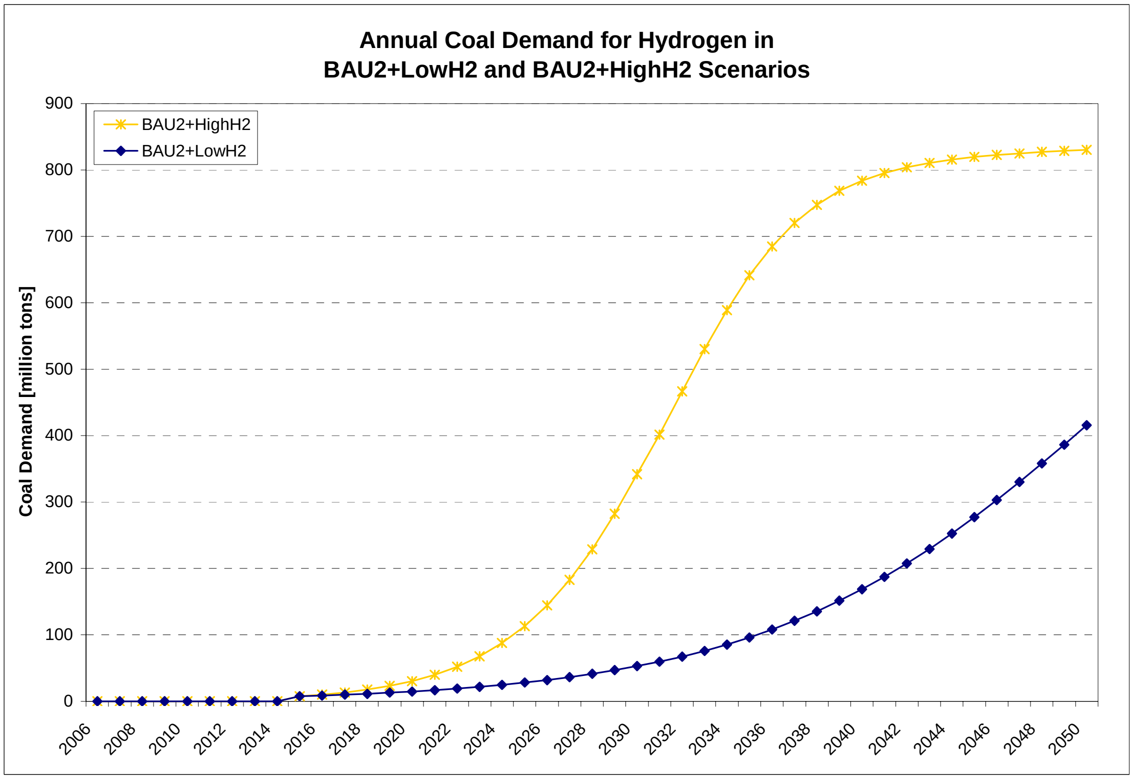

Figure 27: Annual coal demand for hydrogen in BAU2+LowH2 and BAU2+HighH2 scenarios

As mentioned previously, the BAU2+LowH2 and BAU2+HighH2 scenarios are similar to BAU2b in that all of the older, conventional Pulverized Coal plants are eventually repowered to IGCC over the forecast timeframe. Thus, the total coal demand in the two scenarios is simply the demand from BAU2b plus the extra demand resulting from coal-to-hydrogen production. By my calculations, the total amount of coal that will be demanded in the years 2030 and 2050, respectively, will be 1495 and 2124 million tons in scenario BAU2+LowH2, and 1784 and 2539 million tons in BAU2+HighH2. (These estimates are probably conservative since they only take into account coal needed for H2 production, and not the incremental amount of electricity needed for certain H2 delivery and refueling station pathways.[21])

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[21] Centralized H2 production pathways require electricity for H2 transmission and delivery, as well as for refueling stations. These needs could potentially add significant additional coal demands (depending upon

Scenario	2030 Demand	2050 Demand
EIA Reference Case	1784	2103
BAU1	1828	2166
BAU2a	1749	2053
BAU2b	1442	1708
BAU2+LowH2	1495	2124
BAU2+HighH2	1784	2539

Table 5: Comparison of coal demand for various scenarios [million tons]

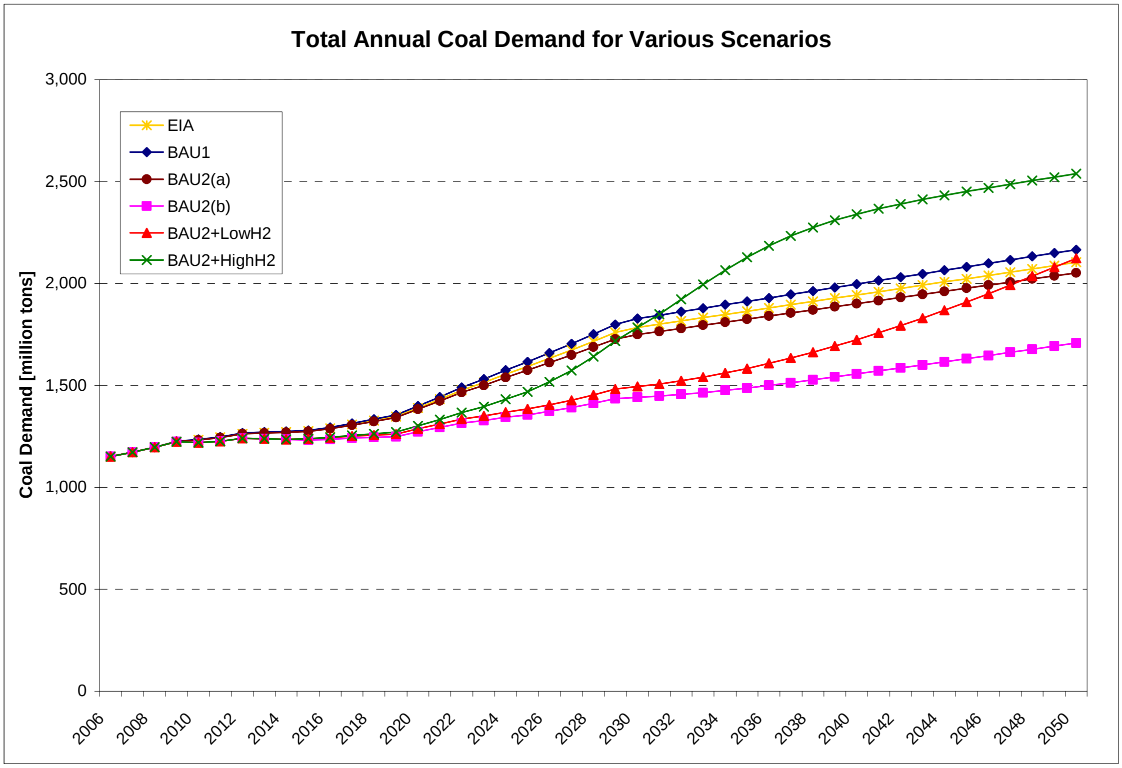

Figure 28: Total annual coal demand for various scenarios

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how much of the electricity to power these systems comes from coal). If one assumes that 50% of all electricity is generated from coal in 2050, then a delivery pathway such as liquefied H2 trucks could actually add approximately 50% more coal demand than the additional coal for H2 production. A pipeline pathway would be significantly less, but still substantial. The reader should acknowledge that these additions could be important, but have not been explicitly dealt with here.

There are several important conclusions that can immediately be drawn from the above comparisons. First, the scenario that results in the lowest overall coal demand in the long run is BAU2b. This says that building only new IGCC coal plants and repowering conventional PC plants to IGCC can slow the rate of coal demand growth. Conversely, BAU2+HighH2 results in the highest coal demand, mainly as a result of the significant amount of coal that is needed to produce hydrogen for a fleet of H2FCVs that reaches 100% market share by the year 2050. However, it is interesting that scenario BAU2+LowH2 results in a level of coal demand that is relatively low over the forecast timeframe, reaching approximately the same level as the EIA Reference Case forecast in 2050. Moreover, the following graph compares the level of coal demand in each of the scenarios with the demand that EIA projects in its Reference Case forecast. The building of and repowering to IGCC plants (BAU2b) can significantly reduce the annual demand for coal in the long term. And even after using extra coal to produce hydrogen for fueling 50% of the vehicle fleet (BAU2+LowH2), the level of coal demand is lower than the EIA forecast for nearly the entire time period. The difference gets smaller and smaller, however, in later years, as H2FCVs gain significant market share and the amount of coal needed to produce hydrogen sharply increases. In contrast, this is obviously not the case if 100% of vehicles are to be fueled by hydrogen (BAU2+HighH2). In this scenario, coal demand initially drops, as IGCC plants and retrofits contribute to reductions; but then, H2FCV market penetration sharply increases, and with it, so does coal demand. If conventional PC plants are not repowered to IGCC (BAU2a), however, only moderate, though sustained, reductions in coal demand can be achieved. On the other hand, building only new PC plants (BAU1) would lead to a moderate and sustained increase in coal demand.

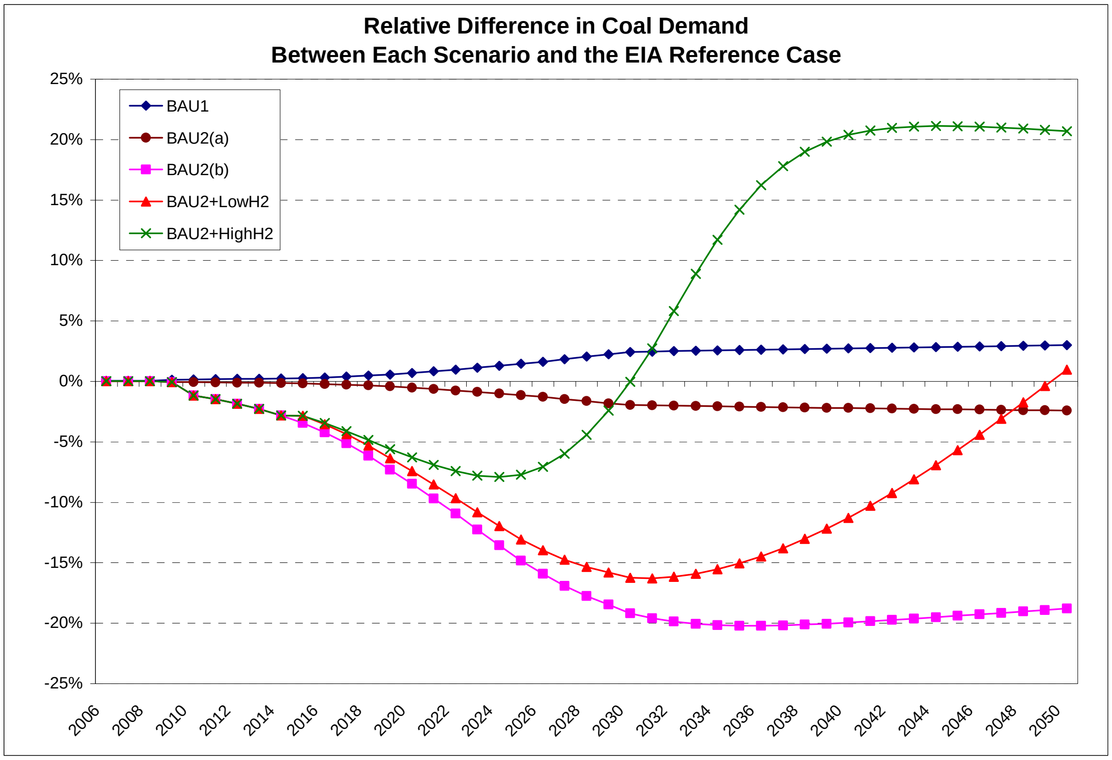

Figure 29: Relative differences in coal demand between each scenario and the EIA Reference Case

III. PROJECTIONS OF FREIGHT TRAFFIC ON THE RAIL NETWORK

Using the projections of total national coal demand under the various scenarios, I attempt to disaggregate and spatially distribute these demands over the rail-coal transportation network, thereby projecting coal traffic on each and every rail line. To do this modeling, I make use of an extensive confidential data set known as the Carload Waybill Sample. The Waybill Sample is considered to be the best data set available for providing detailed information on the various types of railroad freight shipments transported between a multitude of origins and destinations on the rail network and consists of a record of approximately 600,000 railroad shipments made within, to, or from the United States in a given year (STB, 2007).

To project future rail traffic flows, I tie the highly disaggregated Waybill Sample (year 2004) to the much more aggregated projections of the Freight Analysis Framework 2 (FAF2) program, which provide estimates of freight commodity flows between U.S. states, sub-state regions, and international gateways, with projections to 2035 (DOT, 2007). I divide FAF2 projections for the various commodities into two categories: coal and non-coal. Non-coal projections are taken directly from FAF2, but coal projections are modified to reflect the varying levels of growth in each of the different coal demand scenarios. After generating hypothetical versions of the Waybill Sample for future years and various scenarios, I worked with ALK Technologies, a consulting firm in Princeton, NJ, to assign/route the current and projected freight traffic onto the rail network. In addition to the base case year 2004, I develop "static snapshots" of the freight rail system in the years 2030 and 2050 for each of the coal demand growth scenarios.

Description of the Carload Waybill Sample

The Carload Waybill Sample is an annual record of approximately 600,000 railroad shipments made within, to, or from the United States (STB, 2007). It is compiled by the U.S. Department of Transportation (DOT), Surface Transportation Board (STB), with the help of ALK Technologies, a transportation consulting firm in Princeton, NJ, collaborating with me on this project. STB has contracted ALK to process and enhance the Waybill Sample since 1979. Contained in the confidential 900-byte Master Record File version of the Waybill Sample, which is different from the publicly available 247-byte Public Use File, is detailed information on various types of railroad freight shipments between a multitude of origins and destinations.[22] The Waybill Sample is essentially an enormous text file, and every single line in the file corresponds to one shipment that was made by a given rail carrier on a particular date during the year. For each shipment, there is information on where the shipment originated and terminated; junction interchanges and bridge carriers used in multi-carrier routes (i.e., the intermediate locations that a particular shipment passed through on its way from origin to destination); total distance of the trip; type of commodity; amount (tonnage) of commodity; number of carloads on the train; rail carrier name; revenue information; and a number of other items of interest. Many rail shipments are repeated more than once during the year—perhaps daily, weekly, or monthly—so there is considerable repetition

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[22] Note that the number of bytes refers to the number of data entries on each line/record of the Waybill Sample. The total file size of the data set is over 600 MB.

in the data set. For the purposes of data manipulation and analysis, it is helpful to aggregate the repeated shipments into one record for the entire year, essentially adding up the tonnage estimates for individual shipments that, otherwise, have the same attributes. Special software can be used expressly for this purpose, and I enlisted the help of ALK in carrying out this procedure. Interestingly, the aggregated 2004 Waybill Sample contains approximately 90,000 unique shipments, a significant reduction from the original 600,000. In addition to aggregating the Waybill data set, I also had ALK reduce the amount of information contained therein. For example, in this study I am not particularly interested in railroad revenues (probably the most confidential information contained in the data set), so I had these and other similar fields removed. In general, I am most interested in information regarding the details on shipment routing, commodity type, and tonnage estimates, so this is the basic information that I elected to retain in the Waybill Sample.

After ALK's processing of the 2004 Waybill Sample data, I was left with a Microsoft Access database of 89,935 railroad shipments that occurred at least once during the year 2004. Each of these shipments contains valuable information on the U.S. freight railroad industry, but further analysis has to be carried out if I am to fully utilize the data set. For this reason, ALK's transportation modeling expertise was requested. Over the years, as ALK has helped the STB compile the Waybill Sample, they have developed railroad routing models that can seamlessly use the Waybill data as an input. Their proprietary software utilizes complex, operations research-based algorithms. While the Waybill data does not spell out exactly how shipments are routed between origins and destinations, ALK's models attempt to come up with a "best-guess." What is important is that the routing models enable one to graphically represent on a map the huge database of information on railroad shipments that is contained in the Carload Waybill Sample. An example of one of these maps is shown below; later, the methods for generating the map will be discussed more fully. ALK created this map based on the 2004 Waybill Sample data. Notice that the types of rail traffic have been divided into two groups—coal and non-coal commodities. Notice also that the amount of traffic on rail lines is represented by bandwidths of varying thickness.

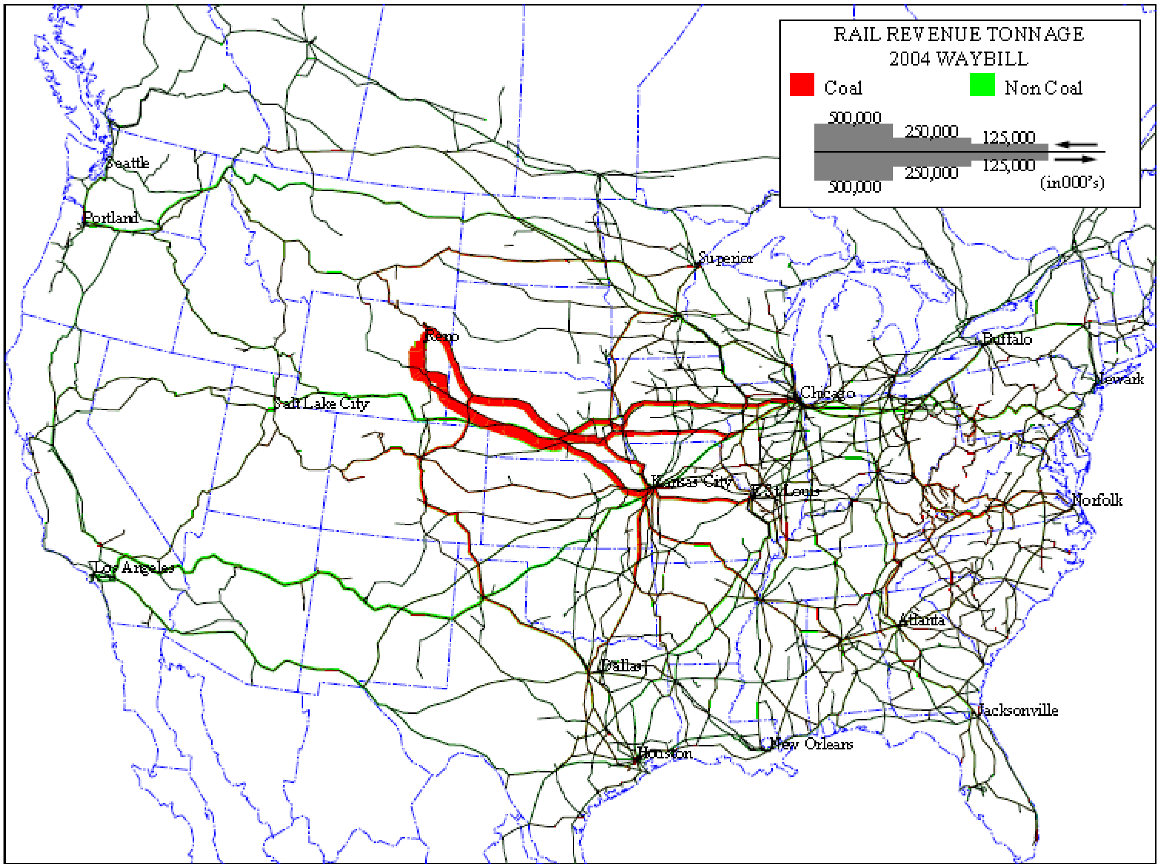


Figure 30: Graphical representation of 2004 Carload Waybill Sample data

Using FAF2 Projections to Modify the Carload Waybill Sample

One of the primary goals of this project is to study how the nation's railroad network will be affected by future increases in rail transportation of coal. Of course, coal is not the only rail commodity that will experience growth in the future. The transportation of other rail commodities, from agricultural products to electronics, will also continue to increase. The subsequent growth in rail traffic will not be uniformly spread throughout the country, however: commodity traffic of certain commodities may grow more in some places than others. Since the Waybill Sample is the best data available for representing traffic flows on the rail network, I would like to somehow utilize it in projecting future rail traffic flows. I take the 2004 tonnage estimates contained in each shipment record of the Waybill Sample and modify them over time to reflect future changes in traffic. I then work with ALK to produce new rail traffic maps for the future—similar to the base case map shown above—which are built upon the modified data. Finally, I can analyze how the rail transportation situation might change in the future if it is to accommodate the growth in traffic. However, for reasons discussed previously, I cannot simply scale up the year 2004 tonnage estimates for each Waybill record by some arbitrary, uniform growth rates. I have to consider (1) the type of commodity being shipped, and (2) the origin and destination of the shipment.

Fortunately, the regionally-based freight projections that I seek have recently become available as part of the U.S. DOT Federal Highway Administration's (FHWA) Freight Analysis Framework 2 (FAF2) program (DOT, 2007). FAF2 provides estimates of freight commodity flows between U.S. states, sub-state regions, and international gateways. Essentially, it is an origin-destination database with tonnage and monetary value estimates for commodity movements between various regions. Commodity flows are also broken down by transportation mode—e.g., truck, rail, air, sea, and so on. The base case data is for the year 2002, but there are forecasts for the years between 2010 and 2035 at 5-year intervals. While the base case estimates are transparent and built on public data sources, the forecasts are built on the proprietary economic modeling packages of Global Insight, a consulting firm. According to FAF2 staff, technical documentation regarding the forecast methods will be available sometime in 2007. I have used the FAF2 forecasts in conjunction with the base case 2004 Waybill Sample data to project future rail traffic flows.

My fundamental methodology can be easily summarized. First, I treat each record in the Waybill data set as a unique shipment. Second, I determine the origin, destination, commodity, and tonnage of that shipment. Then, I look at the FAF2 forecasts and match up the origin, destination, commodity, and transportation mode (which is, of course, always rail). Next, I determine the FAF2's projected growth rate for a shipment with those particular attributes in a given future year. Finally, I apply the FAF2 growth rates to the base case 2004 Waybill tonnage estimate to project Waybill tonnages in future years. The following flow diagram graphically depicts my methodology.

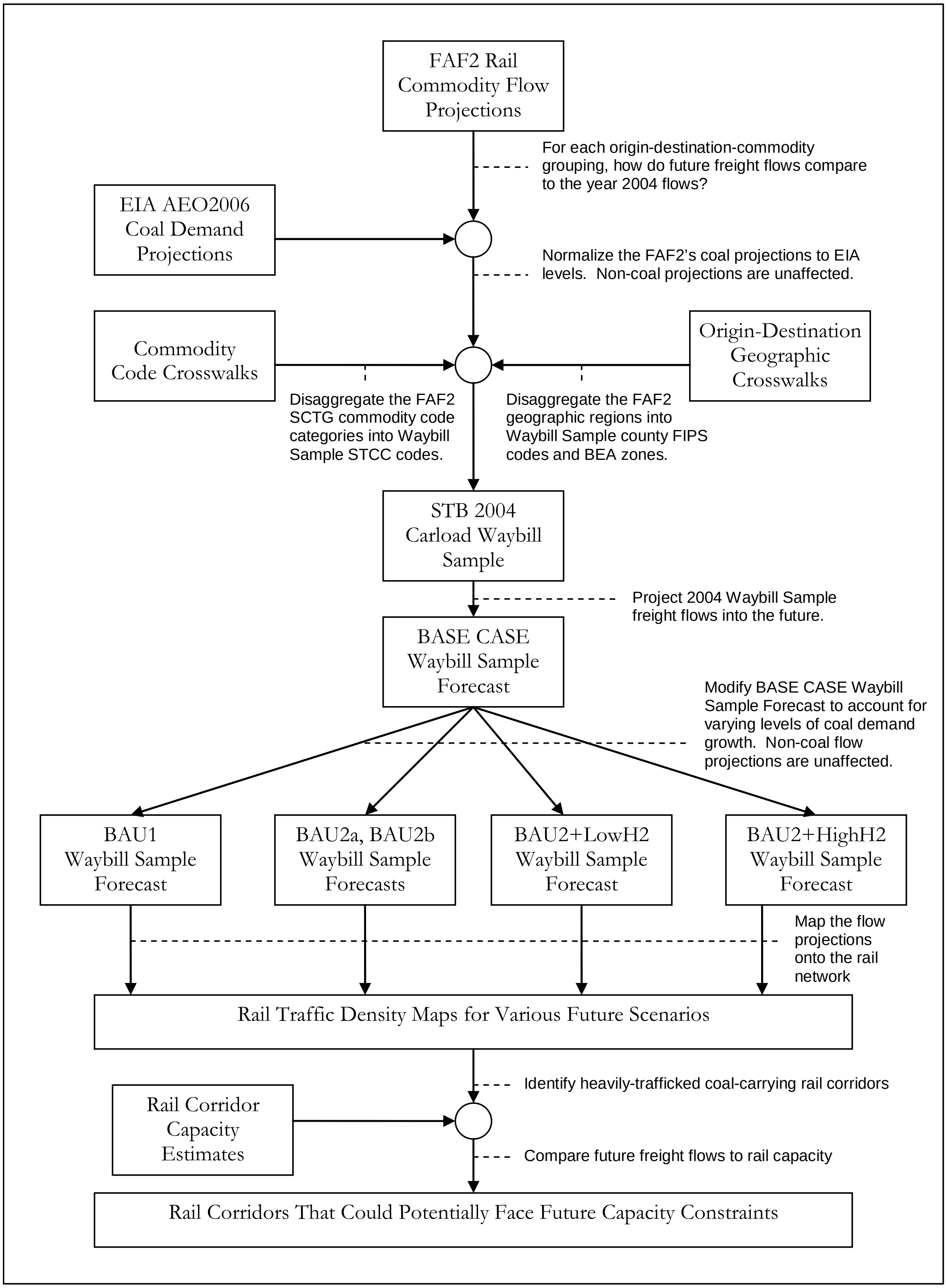


Figure 31: Flow diagram depicting major steps in rail flow modeling methodology

While the logic underlying this process seems quite straightforward, in practice it is a bit more complicated. To start, the Waybill Sample and FAF2 utilize different commodity classification systems. Waybill shipments are classified under the 7-digit Standard Transportation Commodity Code (STCC) system, of which there are more than 15,000 unique codes. FAF2, on the other hand, uses the 2-digit Standard Classification of Transported Goods (SCTG) system; there are only 43 of these codes. Obviously, the SCTG system is a much more aggregated set of codes than the STCC set, and most STCC codes can fit into the more general SCTG categories. What is needed then is a so-called “cross-walk” to assign STCC codes to SCTG codes/categories. This crosswalk was made available by FAF2 staff (Southworth, 2006). The following table lists the SCTG commodity classifications used in FAF2, along with a short description of the types of commodities that fit into the various categories.

SCTG	Commodity Class Description	FAF Abbreviation
1	Live animals and live fish	Live animals/fish
2	Cereal grains	Cereal grains
3	Other agricultural products	Other ag prods.
4	Animal feed and products of animal origin, n.e.c.[1]	Animal feed
5	Meat, fish, seafood, and their preparations	Meat/seafood
6	Milled grain products and preparations, bakery products	Milled grain prods.
7	Other prepared foodstuffs and fats and oils	Other foodstuffs
8	Alcoholic beverages	Alcoholic beverages
9	Tobacco products	Tobacco prods.
10	Monumental or building stone	Building stone
11	Natural sands	Natural sands
12	Gravel and crushed stone	Gravel
13	Nonmetallic minerals n.e.c.[1]	Nonmetallic minerals
14	Metallic ores and concentrates	Metallic ores
15	Coal	Coal
16	Crude Petroleum	Crude petroleum
17	Gasoline and aviation turbine fuel	Gasoline
18	Fuel oils	Fuel oils
19	Coal and petroleum products, n.e.c.[1] (Note: primarily natural gas, selected coal products, and products of petroleum refining, excluding gasoline, aviation fuel, and fuel oil.)	Coal-n.e.c.[1]
20	Basic chemicals	Basic chemicals
21	Pharmaceutical products	Pharmaceuticals
22	Fertilizers	Fertilizers
23	Chemical products and preparations, n.e.c.[1]	Chemical prods.
24	Plastics and rubber	Plastics/rubber
25	Logs and other wood in the rough	Logs
26	Wood products	Wood prods.
27	Pulp, newsprint, paper, and paperboard	Newsprint/paper
28	Paper or paperboard articles	Paper articles
29	Printed products	Printed prods.
30	Textiles, leather, and articles of textiles or leather	Textiles/leather
31	Nonmetallic mineral products	Nonmetal min. prods.
32	Base metal in primary or semi-finished forms and in finished basic shapes	Base metals
33	Articles of base metal	Articles-base metal
34	Machinery	Machinery
35	Electronic and other electrical equipment and components and office equipment	Electronics
36	Motorized and other vehicles (including parts)	Motorized vehicles
37	Transportation equipment, n.e.c.[1]	Transport equip.
38	Precision instruments and apparatus	Precision instruments

39	Furniture, mattresses and mattress supports, lamps, lighting fittings	Furniture
40	Miscellaneous manufactured products	Misc. mfg. prods.
41	Waste and scrap	Waste/scrap
43	Mixed freight	Mixed freight
42	Commodity unknown	Unknown
	[1] n.e.c. = not elsewhere classified.	

Table 6: SCTG commodity code classifications used in FAF2 (DOT, 2007)

Another discrepancy between the Waybill and FAF2 data relates to the level of geographic resolution. For each shipment record in the Waybill Sample, there is information on the origin and destination, down to the county level, in the form of 5-digit Federal Information Processing Standards (FIPS) codes. In addition, more aggregate geographic information is also listed for each origin and destination, such as 2-digit state abbreviations, Standard Metropolitan Statistical Area (SMSA) codes, and Bureau of Economic Analysis (BEA) zones. The BEA codes are especially helpful for shipments to or from Canada and Mexico, since these countries, being outside the U.S., do not have FIPS codes associated with any of their municipalities. In contrast to the Waybill Sample, FAF2 groups origins and destinations into much larger regions, which consist of Metropolitan Statistical Areas (MeSAs), Consolidated Statistical Areas (CSAs), and states or remainders of states. In total, there are 138 FAF2 regions, most of which are shown on the map below. Metropolitan areas are shown in green; states and remainders of states in white; and international gateways in blue.

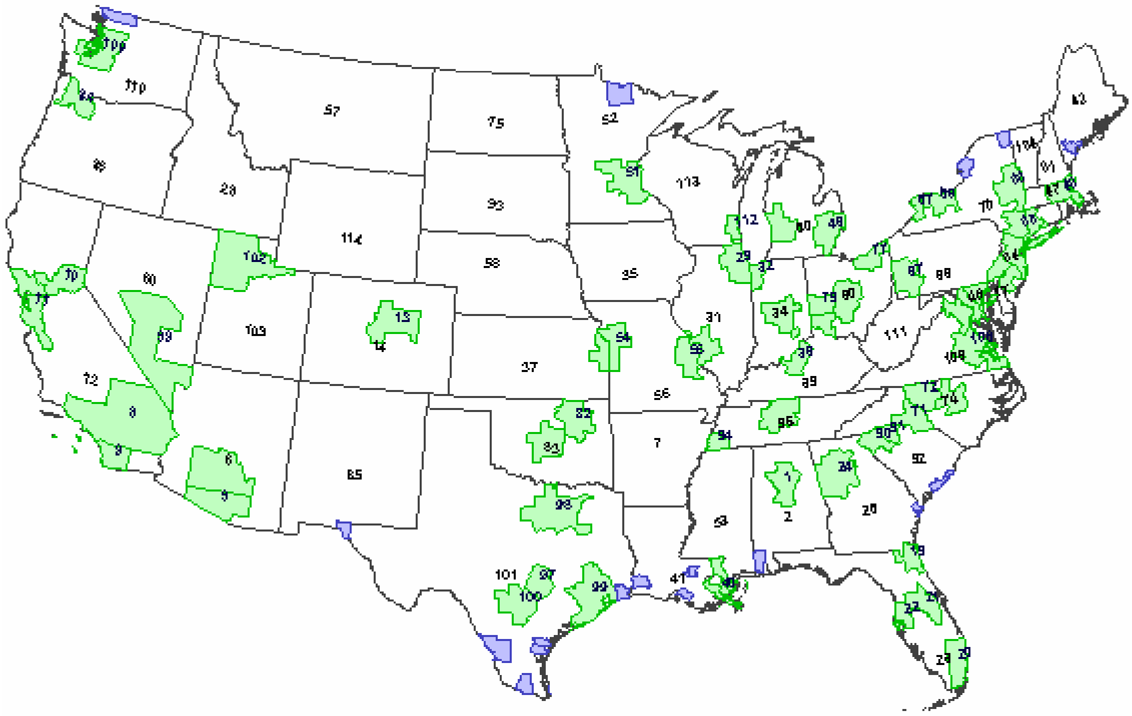


Figure 32: Geographic regions used in FAF2 (DOT, 2007)

According to FAF2 staff, no cross-walk exists for relating the aggregated FAF2 regions to more disaggregated geographic entities like county FIPS codes or BEA zones. Therefore, I had to carry out this process manually. As stated before, each domestic shipment in the Waybill Sample has FIPS codes associated with its origin and destination locations. In turn, each of the 3000+ FIPS codes in the U.S. can be sorted into one of the 114 domestic FAF2 regions. For foreign origins/destinations, BEA zones had to be assigned to a FAF2 country code.

Via the above-mentioned procedures, it is possible to manipulate the original 2004 Waybill Sample data so that it is more aligned with the FAF2 freight flow database and forecasts. More precisely, the Waybill Sample can be modified so that for each shipment the original commodity code and origin and destination locations are assigned corresponding FAF2 values. With this key information, along with the original tonnage estimates for each Waybill shipment, it is possible to coordinate with the FAF2 freight forecasts and make hypothetical tonnage projections for each shipment record in the Waybill data. Waybill projections that have been based directly on the FAF2 forecasts, as has been described in the preceding discussion, are known as the BASE CASE in my terminology. In turn, the BASE CASE projections can be further modified to account for varying levels of coal demand growth; these other scenarios are in line with the total coal demand projections outlined in a previous section of this report. The names I give to these Waybill projections are similar to the ones before: BAU1, BAU2a, BAU2b, BAU2+LowH2, and BAU2+HighH2.

The first step in the rail freight projection modeling process was to download the FAF2's extensive "Commodity Origin-Destination Database 2002-2035" (faf2_v22.mdb) from the FAF2 website (DOT, 2007). Since railroads are the primary focus of my study, I was able to quickly reduce the size of the data set by filtering only for entries where the transportation mode is rail. The years in which freight flows are estimated are 2002, 2010, 2015, 2020, 2025, 2030, and 2035. My Waybill Sample data is for 2004, however. Thus, for each entry in the FAF2 database, I have used linear interpolation between the years 2002 and 2010 to estimate the freight flows in 2004. A small portion of the FAF2 Commodity Origin-Destination Database has been reproduced below. Note how the "Origin" and "Destination" columns correspond to abbreviated names of FAF2 regions. Note also that the commodity flows for each entry are in units of thousand short tons.

Origin	Ost	Destination	Dst	Commodity	Mode	2002	2004	2010	2015	2020	2025	2030	2035
AK	AK	AK	AK	Alcoholic beverages	Rail	1.77	1.85	2.09	2.13	2.22	2.43	2.66	2.89
AK	AK	AK	AK	Basic chemicals	Rail	1143.7	1242.503	1538.91	1457.94	1413.47	1422.81	1442.55	1472.53
AK	AK	AK	AK	Coal	Rail	977.22	857.2025	497.15	457.7	465.32	501.93	558.69	642.85
AK	AK	AK	AK	Coal-n.e.c.	Rail	543.57	599.6425	767.86	766.09	746.37	762.78	792.42	838.94
AK	AK	AK	AK	Fuel oils	Rail	661.14	761.7825	1063.71	1074.53	1074.44	1130.7	1205.72	1306.44
AK	AK	AK	AK	Gasoline	Rail	4090.27	4715.793	6592.36	6645.72	6623.65	6956.39	7399.07	7998
AK	AK	AK	AK	Gravel	Rail	10027.23	10992.82	13889.59	13585.93	13954.45	14427.32	14868.53	15418.66
AK	AK	AK	AK	Mixed freight	Rail	37.31	41.89	55.63	61.17	68.42	79.11	91.65	107.82
AK	AK	AK	AK	Other foodstuffs	Rail	13.67	18.325	32.29	41.73	53.11	67.04	80.58	98.08
AL Birmi	AL	AL Birmi	AL	Coal	Rail	1915.49	1769.72	1332.41	1189.79	833.24	575.09	412.42	304.9
AL Birmi	AL	AL Birmi	AL	Coal-n.e.c.	Rail	51.07	47.4025	36.4	27.91	21.86	18.96	17.41	16.77
AL Birmi	AL	AL Birmi	AL	Gravel	Rail	151.81	147.495	134.55	202.91	225.1	236.6	260.13	272.11
AL Birmi	AL	AL rem	AL	Base metals	Rail	173.38	173.9125	175.51	173.13	172.73	181.14	195.08	207.18
AL Birmi	AL	AL rem	AL	Electronics	Rail	7.39	7.4475	7.62	9.54	11.67	15.09	19.57	25.27
AL Birmi	AL	AL rem	AL	Gravel	Rail	122.24	110.1575	73.91	141.49	165.42	175.13	198.74	207.21
AL Birmi	AL	AL rem	AL	Unknown	Rail	85.64	84.81	82.32	95.18	107.91	127.31	151.08	175.6
AL Birmi	AL	CA San J	CA	Base metals	Rail	128.63	110.31	55.35	46.73	41.85	40.15	39.93	39.4
AL Birmi	AL	CA San J	CA	Nonmetal min. prods.	Rail	173.13	169.535	158.75	157.71	154.72	155.75	156.86	150

Table 7: Snapshot of FAF2 "Commodity Origin-Destination Database 2002-2035" (DOT, 2007)

In my study, I am interested in projecting freight rail traffic out to the year 2050. Therefore, if I am to make full use of the FAF2 forecasts, I need to further modify them to include post-2035 projections. I do this by using linear extrapolation tied to population growth. Population projections to the year 2050 have been published by the U.S. Census Bureau (U.S. Census, 2004). For each entry in the FAF2 database, I calculate the ratio between the commodity flow and population in each year out to 2035. I then assume that the rate of change in the flow-to-population ratio between the years 2030 and 2035 will continue to be the same out to 2050. This yields flow-to-population ratios for 2040, 2045, and 2050. Next, I multiply these projected ratios by the Census population projections for those same post-2035 years, thereby obtaining commodity flow projections for those years—i.e., (tons/person) x (# of people) = (tons). For each entry in the FAF2 database I then calculate a scaling ratio between the commodity flow in a future year to the flow in 2004. These scaling ratios are subsequently applied to the 2004 Waybill Sample tonnage estimates. For example, if it was found from the FAF2 database forecasts that the year 2030-to-2004 scaling ratio for coal transported between Wyoming and Dallas, TX, was 2.0, then for any shipment records in the Waybill Sample that correspond to this entry (Commodity = coal, Origin = Wyoming, Destination = Dallas, TX), I would multiply the base case 2004 Waybill tonnage by the scaling ratio of 2.0 to project how large the shipment might be in the year 2030. If I do this for each shipment in the Waybill Sample and for each forecast year from 2010 to 2050, I can start to develop a large database of projected Waybill rail shipments for future years. Since these projections are based directly on the FAF2 forecasts, this first set of modeling results is known as the BASE CASE Waybill forecast.

The methodology described above for projecting future Waybill tonnages works well for nearly all commodities, but coal is a little different. In section 2, I have described my methods and results for projecting total national coal demand under each of the four coal demand growth scenarios. Much of that modeling is built upon EIA Reference Case forecasts, as published in the AEO2006. In contrast, the FAF2 forecasts are based upon Global Insight's proprietary freight demand and economic models, the methods and assumptions for which have not yet been made available to the public. If I assume that the Global Insight and EIA projections for coal demand growth are different, then there will inevitably be some discrepancies between the EIA-based national coal demand growth scenario projections and the FAF2-based coal demand modeling that has been described above for projecting future Waybill shipments. Fortunately, I can resolve these differences.

The first step is to calculate the total coal demand delivered via all transportation modes from either domestic or foreign destinations that FAF2 estimates for 2002 and projects for future years. Since FAF2 only projects commodity flows at 5-year intervals, and since the last forecast year is 2035, I use linear interpolation and extrapolation, respectively, to estimate the total forecasted coal demand between the 5-year intervals and after 2035. The FAF2 and EIA Reference Case national coal demand projections are then compared to see how well they correlate with each other. The following plot shows that the FAF2 forecasts are consistently higher than those of the EIA; interestingly, they start out at a higher level and continue their upward climb at a more rapid pace.

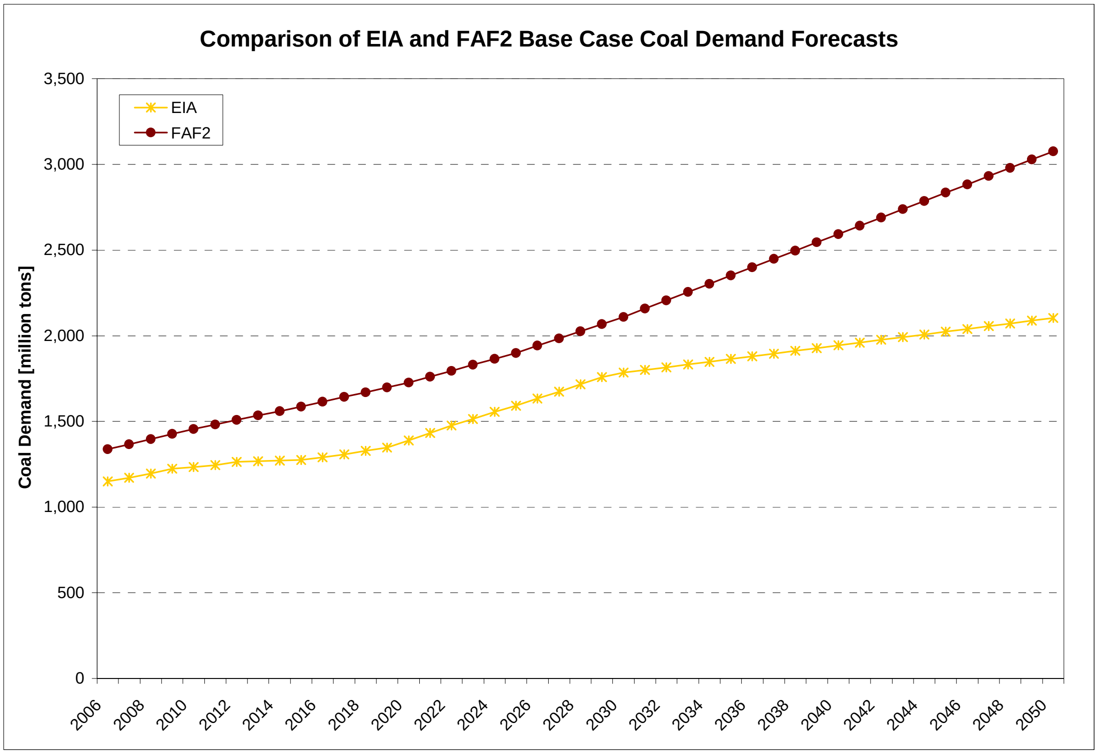


Figure 33: Comparison of EIA and FAF2 Reference Case coal demand projections

Because of these differences, it becomes necessary to modify either the FAF2 or EIA coal forecasts if I am to remain consistent within my own modeling framework. Since the methods and assumptions underlying the EIA forecasts are more well-documented and transparent, I have opted to keep them the way they are and, in turn, normalize the FAF2 coal demand projections to EIA levels. This is quite easily done with another type of scaling ratio, an EIA-to-FAF2 ratio. As the name suggests, to calculate the ratio I simply take the total coal demand projected by EIA in a given year and then divide it by the FAF2 projection for that same year. Because of the discrepancies in the two forecasts, this ratio ranges between 0.68 and 0.86, depending on the year. The EIA-to-FAF2 ratio is then used in conjunction with the BASE CASE Waybill projections—the coal projections of which were themselves based on the FAF2 coal projections, as described previously—to normalize the tonnage estimates to EIA levels. In other words, whereas originally the total coal demand in a given year in the BASE CASE Waybill forecast would have been overestimated, at least compared to EIA's forecast, this is no longer the case, since the tonnage projection for each coal shipment has been normalized by the EIA-to-FAF2 scaling ratio. In sum, my methodology has essentially utilized the EIA's coal demand projections, which are given at the aggregated level of the entire United States, and then spatially distributed the demands around the country with the help of the FAF2 forecasts.

My coal demand modeling for each of the coal demand growth scenarios—BAU1, BAU2a, BAU2b, BAU2+LowH2, and BAU2+HighH2—is carried out in much the same as described above for the BASE CASE. In these new forecasts, I simply scale up or scale down the Waybill tonnage projections that have already been estimated in the BASE CASE. As mentioned previously, the BASE CASE Waybill forecast at this point contains about 90,000 records, each of which corresponds to a single shipment of a certain commodity that is made at least once during the year between the specified origin and destination. The commodities included are of both the coal and non-coal variety. In the coal demand growth scenarios, only the coal flows are assumed to be different from the BASE CASE; in other words, non-coal commodity flows are exactly the same for all of the different scenarios. Then, to adjust the coal flows to reflect the varying levels of total national coal demand across the different scenarios, I use another scaling ratio, known as a scenario-to-EIA ratio (where "scenario" denotes one of the coal demand growth scenarios, e.g. BAU1, and so on). This is calculated as the total coal demand in a given scenario in a particular year divided by the EIA Reference Case estimate for the same year. I use the scenario-to-EIA ratios to go into the BASE CASE Waybill forecast database and apply the ratios to all shipments of coal. After doing this, I am left with five more Waybill forecast databases—one corresponding to each of the BAU1, BAU2a, BAU2b, BAU2+LowH2, and BAU2+HighH2 scenarios. All of the forecasts are similar in that non-coal commodity flows are the same; they are different in that the tonnage estimates for related coal shipments vary. ("Related" means that, except for the tonnage estimates, the shipment record is the same in the Waybill BASE CASE forecast and all other scenarios. For instance, the origin, destination, and routing of the shipment are identical.)

Summing up all the coal shipments in a given scenario for a particular year yields the total annual amount of coal shipped on the rail network. These totals are shown in the following graph. The trends are similar to those shown previously for total national coal demand growth. Note, however, that quantities of coal shipped by rail are a bit smaller; this is because only about two-thirds of U.S. coal is transported by rail.

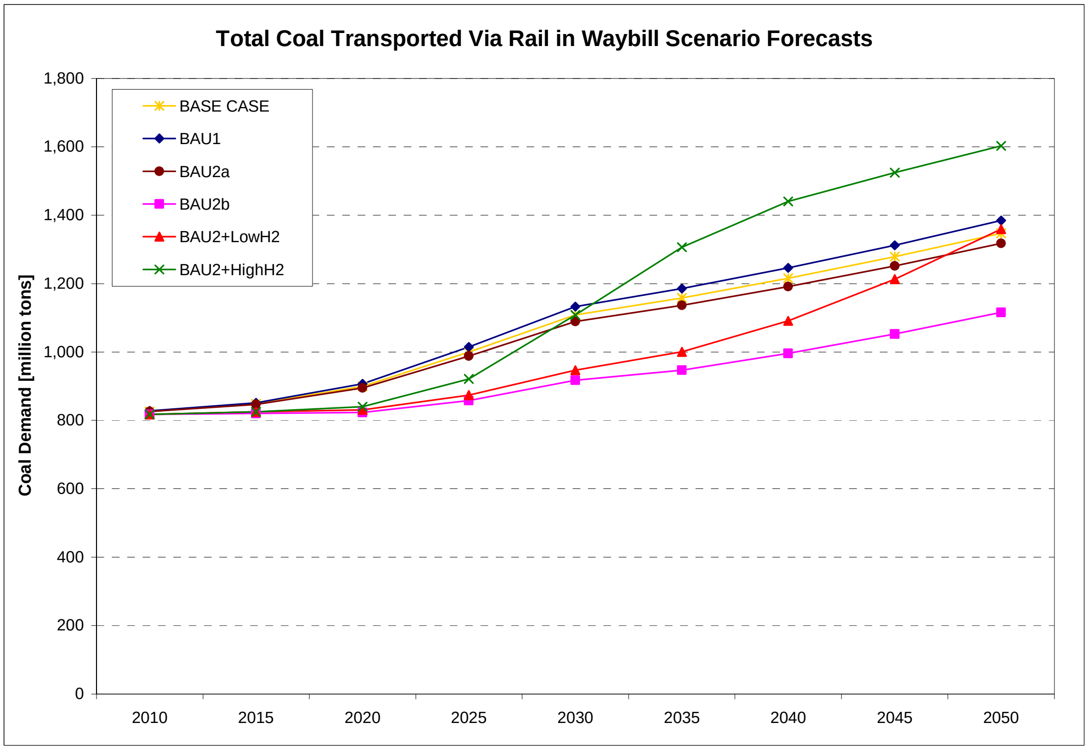


Figure 34: Total amount of coal transported via rail in various Waybill forecast scenarios

Freight Rail Traffic Assignment

While estimates of the total amount of coal transported via rail are interesting, I need to estimate how the coal shipments might actually be routed around the country in the future, namely which rail lines will bear the brunt of the increased coal traffic—not to mention increased traffic of other non-coal commodities. In a sense, the work that has been previously described in this report comprises the first three of four steps in the traditional transportation network modeling process—trip generation, trip distribution, and mode choice. Although I have not progressed sequentially from one step to another in my study, I have touched upon each one at least partially and at some point during my work. For instance, from the start I made an explicit choice to model only freight rail traffic, thus choosing the transportation mode. Then, I combined the trip generation and trip distribution steps by assuming that future rail flows would be scaled versions of current flows. I did this by taking projections of coal and non-coal commodity growth (via FAF2, EIA, and my own analyses) and then applying these projections to the 2004 Carload Waybill Sample. In other words, I model the future mix of rail traffic as being distributed in much the same way that it is today, albeit with differing traffic volumes because the generation of "trips" is not the same. Therefore, if my analogy to transportation network modeling is in fact true, then the fourth and final step in the process, trip/traffic assignment, is represented by the work that ALK Technologies has done in "flowing the traffic"—i.e., assigning traffic flows between particular rail stations to specific links on the rail network and then generating maps and databases that provide the traffic flows on each of the links.

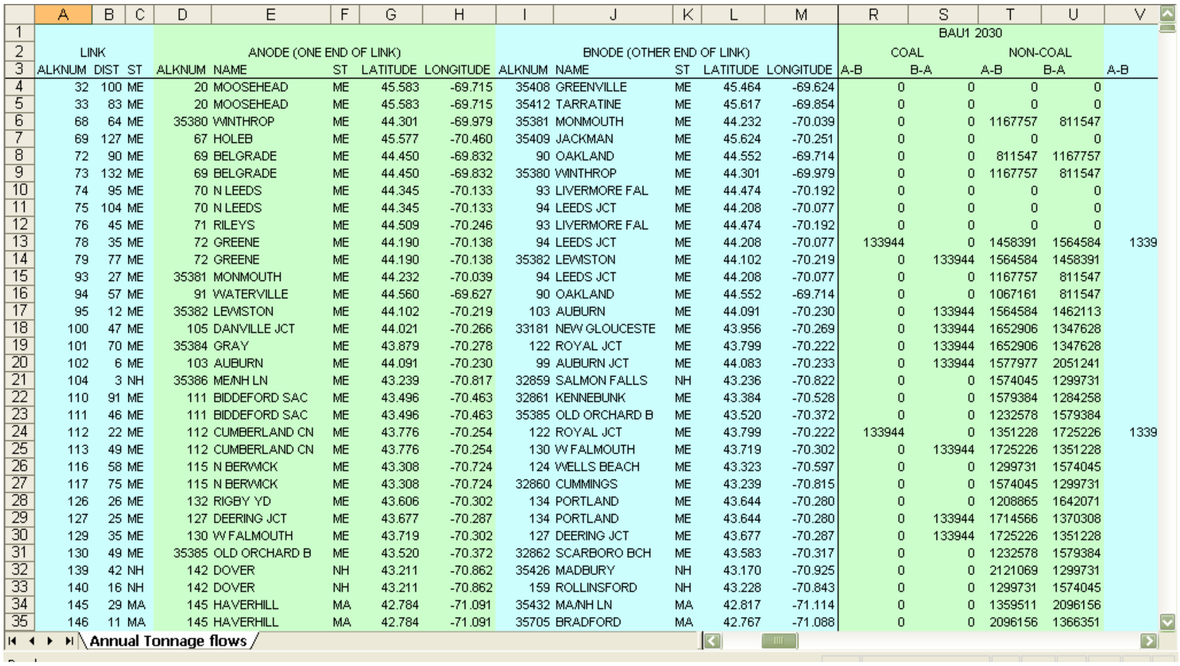
To carry out the traffic assignment step, ALK used its Princeton Transportation Network Model and Graphic Information System (PTNM). Specifically, two components of the model were utilized—ALKFLOW and TRGRAPH. ALKFLOW (2003) is used primarily for doing calculations and producing output that can be used as input to TRGRAPH (2003) to make traffic flow maps. The two main data needs for ALKFLOW are a representation of the rail network and a set of traffic volume data typically referred to as "AB pairs." The PTNM possesses its own model of the North American rail network. It represents the continent's 50,000 freight stations with roughly 43,000 nodes, and the 250,000 route miles of rail lines with about 44,000 links. The second data input is exogenous to the model and depends on the problem being analyzed. In my case, the traffic volume data that I supplied to ALK were the modified Waybill

Sample forecasts that reflected my projections of future freight flows in the years 2030 and 2050 under the different scenarios—BAU1, BAU2a, BAU2b, BAU2+LowH2, and BAU2+HighH2. As discussed previously, the Waybill forecasts that I created for each scenario project freight traffic at 5-year intervals out to the year 2050. However, due to temporal and financial limitations, ALK was only commissioned to run its traffic assignment software on only a subset of these projections, namely the traffic in 2030 and 2050 under each of the scenarios for coal demand growth. Since ALK has a great deal of experience in working with the format of the Waybill data set, it was a relatively straightforward process for them to assign my estimates of future freight traffic flows between regions onto specific links of the nation's rail network.

One of the biggest challenges of traffic assignment is figuring out the best way to route a particular shipment from point A to point B if there exist a number of alternative routes. In the typical traffic assignment process, as traditionally taught to transportation students, a mathematical algorithm is used to determine the most likely traffic flows on routes based on factors such as travel times, volumes, route capacities, costs, and other impedance factors (ITE, 1992). For example, one possibility might be to route traffic based solely on the shortest distance between the AB pairs. Another possibility might be to consider the travel times involved, as well as the quality of the trackage on rail line and its ability to transport the types of commodities and carloads in question. In the real world, a railroad considers all of these factors, and probably others, in deciding how best to route its traffic. For this reason, ALKFLOW attempts to represent reality as much as possible (Karthikeyan, 2007). ALK staff conduct extensive research—talking to railroads, consulting the trade literature, and so on—in an effort to ensure that the routing formulas in their models are consistent with industry practices for train routing. To a certain extent, routing depends on the types of trains involved (e.g., intermodal, coal, automobile racks, and general merchandise), so different formulas are used in each of the different cases. Furthermore, one of the advantages to using data derived from the Waybill Sample is that, in addition to the origin and destination locations for shipments, the data set contains information on the junction interchanges and bridge carriers used in multi-carrier routes (i.e., the intermediate locations that a particular shipment passes through on its way from origin to destination). This makes the traffic assignment process simpler and more reliable than it would otherwise be in the absence of detailed route information.

The output from ALKFLOW is both a final product in and of itself, as well as an intermediate data file to be used as an input into TRGRAPH. ALKFLOW produces a "Total Flow File" in which each record/line of the file corresponds to a link in the PTNM rail network that carries a non-zero quantity of traffic. A single record contains information on the characteristics of that particular link (e.g., origin city and state, destination city and state, link distance, and so on) and the volumes of traffic flowing over that link. In my case, I am interested in link-specific flow volumes, such as annual tonnages and annual carloads, both of which are readily available in the Waybill data set and, thus, my modifications of it. The traffic volumes on links are aggregated over railroad companies, meaning that if two different railroads use a route to transport goods, the volumes of the two railroads are summed together to get a total flow on that link. (This also serves the dual purpose of protecting confidentiality.) The only disaggregation that is done is to distinguish between the shipments of coal and non-coal commodities;

though, no distinction is made between individual commodities within the non-coal category. The reason for separating the commodities into these two categories is because in my study I have wanted to focus only on the rail corridors that will be responsible for transporting a large share of the nation's coal in the future. The following figure is a screenshot of what the output file for total link flows looks like once it has been imported into MS Excel. The traffic volumes shown are in units of annual tonnages, but the file for annual carloads is very similar. Link-specific traffic volume files, like the one shown above, have proven to be very useful in my analyses since they have allowed me to obtain more exact estimates of the traffic volumes on routes than can otherwise be obtained with the traffic flow maps.



	A	B	C	D	E	F	G	H	I	J	K	L	M	R	S	T	U	V
1														BAU1 2030				
2	LINK			ANODE (ONE END OF LINK)					BNODE (OTHER END OF LINK)					COAL		NON-COAL		
3	ALKNUM	DIST	ST	ALKNUM	NAME	ST	LATITUDE	LONGITUDE	ALKNUM	NAME	ST	LATITUDE	LONGITUDE	A-B	B-A	A-B	B-A	A-B
4	32	100	ME	20	MOOSEHEAD	ME	45.583	-69.715	35408	GREENVILLE	ME	45.464	-69.624	0	0	0	0	
5	33	83	ME	20	MOOSEHEAD	ME	45.583	-69.715	35412	TARRATINE	ME	45.617	-69.854	0	0	0	0	
6	68	64	ME	35380	WINTHROP	ME	44.301	-69.979	35381	MONMOUTH	ME	44.232	-70.039	0	0	1167757	811547	
7	69	127	ME	67	HOLEB	ME	45.577	-70.460	35409	JACKMAN	ME	45.624	-70.251	0	0	0	0	
8	72	90	ME	69	BELGRADE	ME	44.450	-69.832	90	OAKLAND	ME	44.552	-69.714	0	0	811547	1167757	
9	73	132	ME	69	BELGRADE	ME	44.450	-69.832	35380	WINTHROP	ME	44.301	-69.979	0	0	1167757	811547	
10	74	95	ME	70	N LEEDS	ME	44.345	-70.133	93	LIVERMORE FAL	ME	44.474	-70.192	0	0	0	0	
11	75	104	ME	70	N LEEDS	ME	44.345	-70.133	94	LEEDS JCT	ME	44.208	-70.077	0	0	0	0	
12	76	45	ME	71	RILEYS	ME	44.509	-70.246	93	LIVERMORE FAL	ME	44.474	-70.192	0	0	0	0	
13	78	35	ME	72	GREENE	ME	44.190	-70.138	94	LEEDS JCT	ME	44.208	-70.077	133944	0	1458391	1564584	1339
14	79	77	ME	72	GREENE	ME	44.190	-70.138	35382	LEWISTON	ME	44.102	-70.219	0	133944	1564584	1458391	
15	93	27	ME	35381	MONMOUTH	ME	44.232	-70.039	94	LEEDS JCT	ME	44.208	-70.077	0	0	1167757	811547	
16	94	57	ME	91	WATERVILLE	ME	44.560	-69.627	90	OAKLAND	ME	44.552	-69.714	0	0	1067161	811547	
17	95	12	ME	35382	LEWISTON	ME	44.102	-70.219	103	AUBURN	ME	44.091	-70.230	0	133944	1564584	1462113	
18	100	47	ME	105	DANVILLE JCT	ME	44.021	-70.266	33181	NEW GLOUCESTE	ME	43.956	-70.269	0	133944	1652906	1347628	
19	101	70	ME	35384	GRAY	ME	43.879	-70.278	122	ROYAL JCT	ME	43.799	-70.222	0	133944	1652906	1347628	
20	102	6	ME	103	AUBURN	ME	44.091	-70.230	99	AUBURN JCT	ME	44.083	-70.233	0	133944	1577977	2051241	
21	104	3	NH	35386	ME/NH LN	ME	43.239	-70.817	32859	SALMON FALLS	NH	43.236	-70.822	0	0	1574045	1299731	
22	110	91	ME	111	BIDDEFORD SAC	ME	43.496	-70.463	32861	KENNEBUNK	ME	43.384	-70.528	0	0	1579384	1284258	
23	111	46	ME	111	BIDDEFORD SAC	ME	43.496	-70.463	35385	OLD ORCHARD B	ME	43.520	-70.372	0	0	1232578	1579384	
24	112	22	ME	112	CUMBERLAND CN	ME	43.776	-70.254	122	ROYAL JCT	ME	43.799	-70.222	133944	0	1351228	1725226	1339
25	113	49	ME	112	CUMBERLAND CN	ME	43.776	-70.254	130	W FALMOUTH	ME	43.719	-70.302	0	133944	1725226	1351228	
26	116	58	ME	115	N BERWICK	ME	43.308	-70.724	124	WELLS BEACH	ME	43.323	-70.597	0	0	1299731	1574045	
27	117	75	ME	115	N BERWICK	ME	43.308	-70.724	32860	CUMMINGS	ME	43.239	-70.815	0	0	1574045	1299731	
28	126	26	ME	132	RIGBY YD	ME	43.606	-70.302	134	PORTLAND	ME	43.644	-70.280	0	0	1208865	1642071	
29	127	25	ME	127	DEERING JCT	ME	43.677	-70.287	134	PORTLAND	ME	43.644	-70.280	0	133944	1714566	1370308	
30	129	35	ME	130	W FALMOUTH	ME	43.719	-70.302	127	DEERING JCT	ME	43.677	-70.287	0	133944	1725226	1351228	
31	130	49	ME	35385	OLD ORCHARD B	ME	43.520	-70.372	32862	SCARBORO BCH	ME	43.583	-70.317	0	0	1232578	1579384	
32	139	42	NH	142	DOVER	NH	43.211	-70.862	35426	MADBURY	NH	43.170	-70.925	0	0	2121069	1299731	
33	140	16	NH	142	DOVER	NH	43.211	-70.862	159	ROLLINSFORD	NH	43.228	-70.843	0	0	1299731	1574045	
34	145	29	MA	145	HAVERHILL	MA	42.784	-71.091	35432	MA/NH LN	MA	42.817	-71.114	0	0	1359511	2096156	
35	146	11	MA	145	HAVERHILL	MA	42.784	-71.091	35705	BRADFORD	MA	42.767	-71.088	0	0	2096156	1366351	

Figure 35: Screenshot of ALKFLOW output file showing the traffic volumes on individual rail links

The creation of traffic flow volume maps was done with the second component of ALK's PTNM. TRGRAPH is a workspace that contains functions and variables that allow the user to access, edit, manipulate, and display geopolitical and network data. Most of this data is already available within TRGRAPH. The important exogenous data are the link-specific flow volume files, i.e. the outputs from ALKFLOW. Within the TRGRAPH component, the software tool that is used for graphing and mapping is called MapMaker. The process of creating a map is fairly straightforward since the output from ALKFLOW contains information on the traffic flow volumes for each link in the network. MapMaker simply represents these flows graphically by showing the amount of traffic on each link as a bandwidth around the link. On links with bi-directional flows, the bandwidth is shown on both sides of the link, and the relative proportion of the traffic in each direction can be identified by the thickness of the bandwidth on each side. In addition, different colors can be used to represent different types of shipments, e.g. coal and non-coal commodities. Examples of these maps are shown elsewhere in this report.

IV. MODELING OF INCREMENTAL RAIL CAPACITY

Identification of Major Coal-Carrying Rail Corridors

One of the central goals of this study is to identify the rail corridors that will be responsible for carrying large quantities of coal in the future and to estimate the amount of capital investment in rail infrastructure that might be needed to alleviate the potential capacity constraints on those routes. The output from ALK's traffic assignment modeling, which was based on my projections of future freight rail flows, provided me with a modeled representation of the quantities and types of traffic on virtually every single major rail line in the U.S. Of course, coal is only transported on a fraction of those lines, and the bulk of coal traffic is found on only a small fraction of these. Therefore, I focus my analysis on these major coal-carrying rail corridors. For manageability I subdivide the corridors into 42 sections, or routes. Most of these routes are found in the Midwest and East and primarily transport coal out of the Powder River Basin and Appalachian coal mining regions, respectively. The following three maps, in a sense, depict my sequential process of narrowing down the coal-carrying corridors to a reasonable number. The third map—simply a modification of the one before it—is color-coded and labeled with numbers (1 to 42) to help identify specific rail routes.

By my estimation, the 42 routes accounted for about 80% of all coal shipped by rail in 2004 (on a ton-mile basis). The total distance of these routes is about 12,500 miles, which accounts for roughly 5% of all route mileage in the North American rail network, or 10% of the total mileage of the five Class I carriers (BNSF, UP, NS, CSX, and CN) who operate these 42 routes.

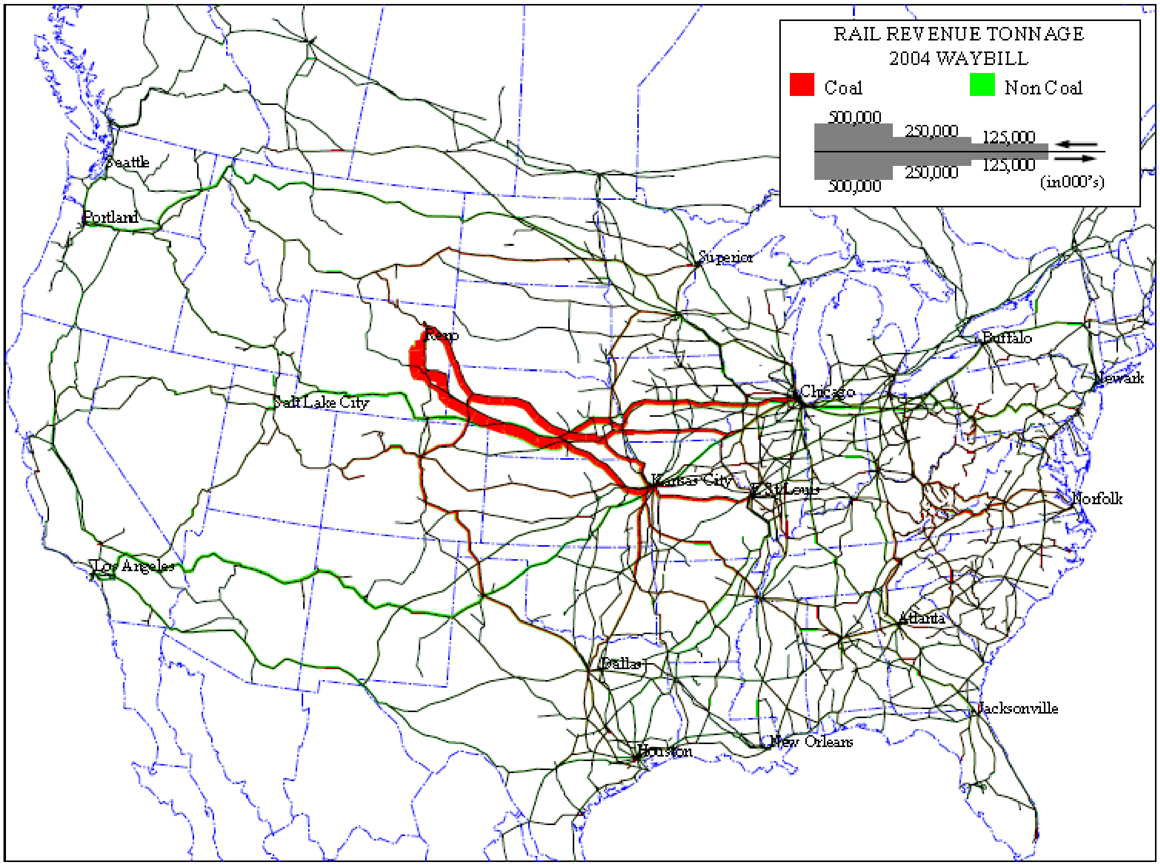


Figure 36: Freight rail traffic on the U.S. rail network in 2004 (using 2004 Waybill Sample data)

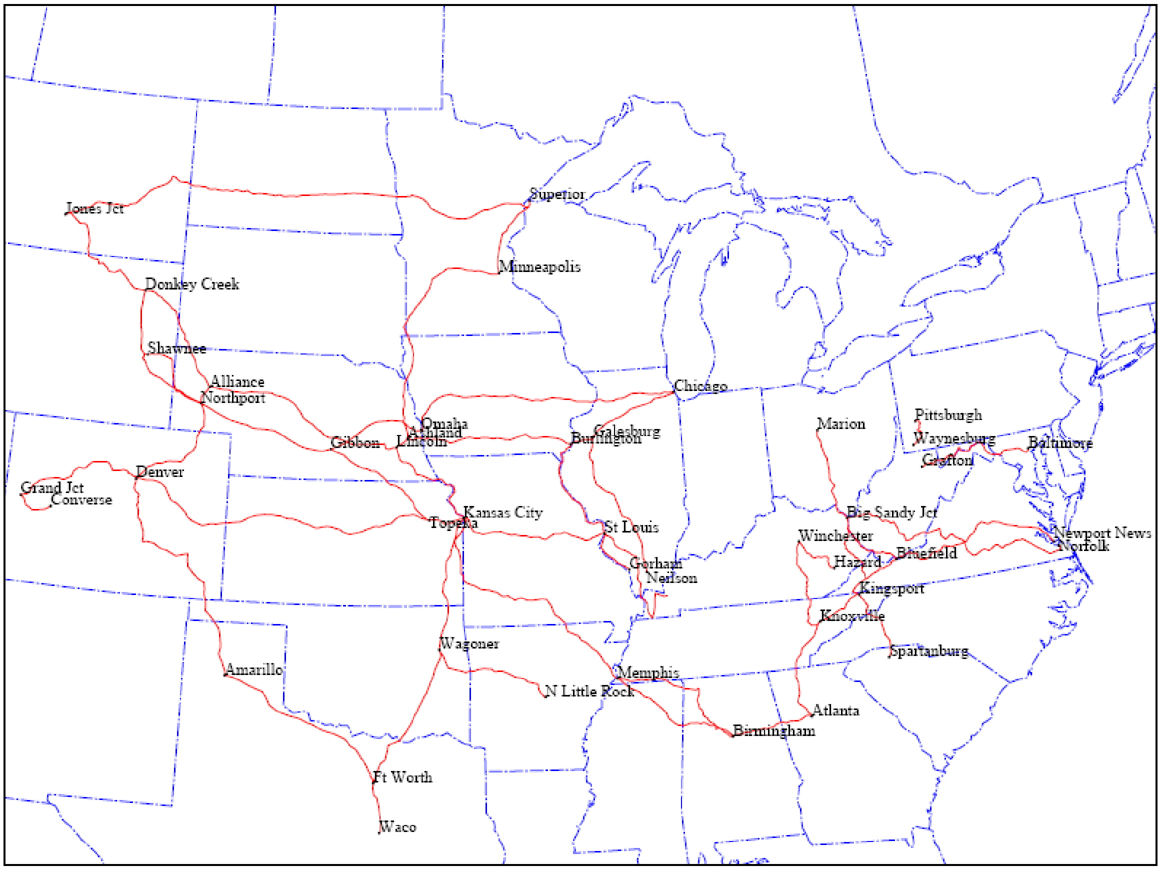


Figure 37: Major coal-carrying rail corridors that have been focused upon in this study

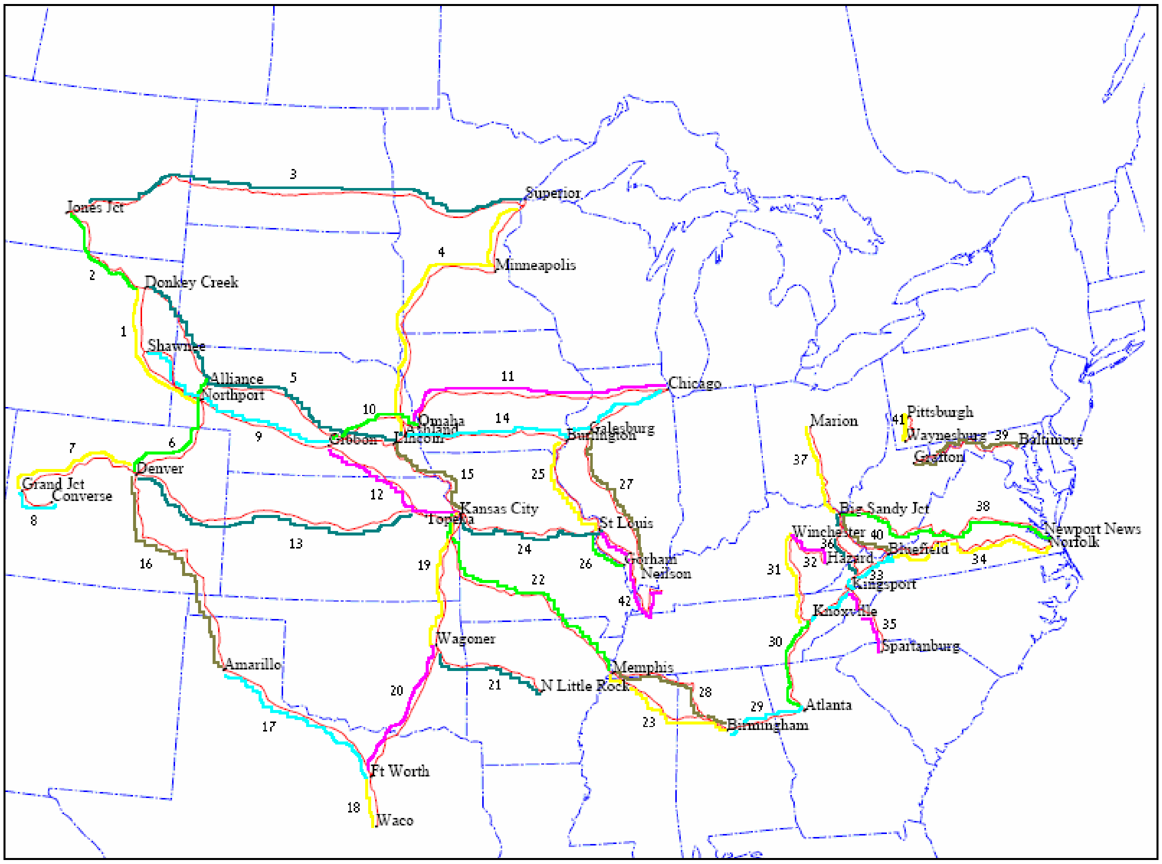


Figure 38: Major coal-carrying rail corridors subdivided into individual routes

In order to carry out a capacity analysis of the 42 selected rail routes, my first task was to collect information on each of them. As discussed previously, I worked with ALK to obtain reasonably accurate numerical values for the annual tonnage and carload flows transported over each route. I also strived to obtain accurate information on the physical characteristics of the rail lines that comprise each of the routes. This second task proved to be quite difficult, but fairly reliable information was eventually obtained for most routes. Route-specific information is primarily found in the employee timetables for each of the railroad companies. Employee timetables are not “timetables” in the conventional sense of the word. For instance, they do not contain information on the times that trains arrive at or depart from a particular station. Rather, the timetables contain valuable information on the characteristics of rail lines, such as the number of mainline tracks, types of signaling systems, and number/length of sidings, among many other things. For my purposes, this information is helpful for estimating route capacities, and the impacts that future capacity-enhancing rail infrastructure investments might have. At the most fundamental level, line capacity is a function of the number of mainline tracks, types of signaling systems, trains speeds, and freight car sizes along a particular route. Thus, this is the kind of information that I attempted to gather from the employee timetables of BNSF, UP, and CSX; these timetables were found on the World Wide Web. Fortunately, the timetables of BNSF, UP, and CSX cover 35 of the 42 selected rail routes. Unfortunately, however, I was not able to obtain timetables for NS and CN.

Estimation of Incremental Capacity Needs

While an attempt at estimating the total capacity (say, in tons/year, carloads/year, or trains/day) of a particular rail route, or even the entire rail network, is theoretically possible if one possesses all the necessary data, in practice this proves to be a difficult task that often leads to inaccurate estimates. On one hand, a detailed analysis of every route in the rail system could potentially reveal the capacity of each and every route. An analysis of this type would require a great deal of time and effort, however, as well as cooperation on the part of the railroad companies; and it is not improbable that by the time the study was completed, the situation would have already changed in some important way. Thus, to complete an analysis at the national scale, like I have attempted to do, I must resort to some level of aggregation and assumption.

Route capacity depends on a number of route-specific factors, such as the number of parallel tracks, distance between and length of sidings (i.e., tracks for slower trains to pull onto so that faster trains can pass), length of trains, block length (i.e., distance between trains), speed limits, sizes of rail cars, horsepower of locomotives, geography, weather, and types of signaling systems, to name a few. The combination of all of these factors together determines the capacity of a route at a particular moment in time. Some, like Prokopy and Rubin (1975), have attempted to quantify the varying effects that each of these factors has on capacity. Yet, the inherent problem that one faces is that I do not always know, or am unable to determine, the values for some of the critical factors in the capacity calculation, for example, the distance between and length of sidings and the type of signaling system along certain rail lines.

Fortunately, it is possible to simplify this process by making some generic assumptions as to track capacity. This is exactly what researchers at the Electric Power Research Institute (EPRI) did in their 1976 study on the coal transportation capability of the rail network to meet future increases in coal demand (EPRI, 1976). In their report, the EPRI researchers also found it difficult to quantify rail route capacity: "The capacity of a railroad link, let alone the capacity along a route or of the U.S. railroad network, appears to defy definition" (EPRI, 1976, p. 41). They also state that in their report "…the emphasis is on through trains. I recognize that there are significant delays at terminals and switching yards, and other delays may occur at refueling points or crew change locations; these delays are not significant to my analysis of link capacity" (EPRI, 1976, p. 42). As described previously, unit (i.e., through) trains shuttle back and forth from origin to destination. They typically bypass terminals and switch yards and, thus, can avoid getting hung up in the inherent delay. This is not to say that a unit train does not feel the ripple effects of delay at terminals and yards as congestion builds up and spills over onto the throughway rail lines; but this only happens in the most extreme cases. Therefore, I have borrowed EPRI's assumption to help define the boundaries of my study: I focus on rail traffic and capacity along the routes themselves, and not necessarily at rail terminals and yards.

Due to the inherent difficulties in estimating the total capacity of a network of rail routes, I simply assume that the 42 selected rail routes, given that they are all heavily-trafficked corridors, are already at or near their upper capacity limits in the base year, 2004. This assumption is consistent with the literature, press accounts, and the comments of rail industry professionals, as discussed in a previous section of this report. Based on my knowledge, it seems reasonable to assume that the average annual capacity factors (CF) of the selected routes (i.e., the actual annual traffic volume as a fraction of the maximum amount of annual traffic that could possibly traverse the route without significant delay) might be in the range of 0.85 – 1.0. Then, to roughly estimate the current capacity limit of a particular route, I take the estimated number of annual carloads transported over the route and divide by the capacity factor. Thus, an estimate of annual carloads must first be obtained by multiplying the number of revenue carloads (i.e., the number of non-empty carloads actually transporting a commodity), which is provided by ALK's traffic flow modeling, by 1 (one) plus the empty-return-ratio (ERR) for carloads on that route. These equations are shown below.

$$Annual\ Carloads \quad = \quad (Annual\ \mathrm{Re}venue\ Carloads) \times (1 + ERR)$$

$$Maximum\ Route\ Capacity = \frac{(Annual\ Carloads)}{CF}$$

While the ERR depends on the type of commodity and the particular route, I simply assume that generic ERRs can be applied across all routes—e.g., 1.0 for coal shipments and 0.75 for non-coal shipments. In other words, after delivering their loads, 100% of coal trains/carloads return to their points of origin via the same routes that they used to initially make the delivery. This assumption is generally true for coal unit train service. Non-coal carloads, on the other hand, are not always transported in unit trains. Therefore, based on discussions with rail industry professionals, the assumption that 75% of non-coal trains/carloads return to their origins along the same routes seems reasonable (BNSF, 2007).

The approach I take in my modeling is to estimate the amount of incremental capacity that could potentially be obtained by improving the physical infrastructure of a given route, e.g. upgrading the signaling system or laying new main track. With information from the timetables on the characteristics of the selected routes in 2004, I am able to estimate how much more capacity might be added to the route in the future if certain infrastructure investments are made. To do this, I borrow and modify methods from Burton (1998). Through studying a large number of rail routes in the U.S. in the 1990s, Burton was able to develop an econometric equation that relates the maximum capacity of a rail route to a number of the physical and operating characteristics of that particular route. This equation is reproduced from Burton's report below. His methods employed Waybill Sample data, employee timetables, and other information.

$$\begin{aligned}\mathrm{MAXCARM}_i = \beta_0 \; + \; & \beta_1(\mathrm{TIMETBLS}_i) + \beta_2(\mathrm{CTCSPEED}_i) + \beta_3(\mathrm{SPEEDRAT}_i) + \\ & \beta_4(\mathrm{TRAINLEN}_i) + \beta_5(\mathrm{MAINS}_i) + \beta_6(\mathrm{CTCMAIN}_i) + \beta_7(\mathrm{SIDSIZ}_i) + \\ & \beta_8(\mathrm{SIDINGS}_i) + \beta_9(\mathrm{SIDINT}_i) + \beta_{10}(\mathrm{ABS}_i) + \beta_{11}(\mathrm{CTC}_i) + \beta_{12}(\mathrm{SWITCH}_i) + \\ & \beta_{13}(\mathrm{SWITCH2}_i) + \beta_{14}(\mathrm{ROUTLEN}_i) + \\ & \beta_{15}(\mathrm{ROUTLN2}_i) + \sum\gamma(\mathrm{CD}_i) + \varepsilon_i\end{aligned}$$

For my purposes, not all of the variables in the above equation are important. The ones that are pertinent are described briefly here.

- **MAXCARM** = “The dependent variable is defined as the natural log of the number of gross carloads accommodated by the i^{th} route link in the busiest 1995 calendar quarter. The log-linear specification was adopted to help capture any non-linear relationships between the dependent variable and explanatory variables. Gross carloads reflect the sum of revenue carloads and estimated empties” (Burton, 1998, p. 9).
- **CTC** = “The percentage of the route link that is controlled by centralized traffic control (CTC).”
- **TIMETBLS** = “Average timetable speed on the route link was calculated by averaging the timetable speed at highway grade crossings. This variable helps capture track component quality.”
- **CTCSPEED** = “The product of TIMETBLS and CTC, a measure of centralized traffic control”…“This interaction term is included to capture substitutability / complementarities between signal quality and track component quality.”
- **MAINS** = “The estimated proportion of mainline tracks within the route estimated by combi[ni]ng the number of mainline tracks at grade crossings throughout the link in question and the carrier-specific ratio of additional mainline miles to total route miles operated.” In other words, MAINS equals the length of mainline track along a given route divided by the route distance. For example, if points A and B are separated by 100 miles, and the rail route between the two points is fully double-tracked so that there are 200 (= 2 x 100) miles of mainline track on the route, then MAINS = 2.0.
- **CTCMAIN** = “The product of CTC and MAINS. This term is included to reflect substitutability or complementarity between signal quality and the amount of mainline trackage.”

By taking partial derivatives of the dependent variable in the regression equation with respect to certain variables of interest, I can estimate the impact that a change in one of these independent (explanatory) variables might have on the dependent variable, *ceteris paribus*. Ordinarily, in a simple regression equation the partial derivative of the dependent variable with respect to a particular independent variable is simply the regression coefficient on the independent variable. Burton's regression equation is slightly more complicated, however, since he includes interaction terms (e.g., CTCSPEED, CTCMAIN) between some of the independent variables. Therefore, the partial derivatives include more than just one regression coefficient term. For instance, I show below the partial derivatives of maximum quarterly carload capacity (i.e., the dependent variable) with respect to (1) the number of mainline tracks, and (2) the amount of CTC on the route.

$$\frac{\partial \, MAXCARM}{\partial \, MAINS} \quad = \quad \beta_5 + \beta_6(CTC)$$

In the regression equation above, β_5 is the coefficient on MAINS, and β_6 is the coefficient on CTCMAIN. Since the CTC and MAIN variables are multiplied together to generate the variable CTCMAIN, then, when taking the partial derivative, the CTC term is treated as a constant and must also be considered along with β_6. This rationale is per the advice of Burton (1998, p. 9).

$$\frac{\partial \, MAXCARM}{\partial \, CTC} \quad = \quad \beta_2(TIMETBLS) + \beta_6(MAINS) + \beta_{11}$$

In the regression equation β_2 is the coefficient on CTCSPEED, β_6 is the coefficient on CTCMAIN, and β_{11} is the coefficient on CTC. Again, since CTC and MAIN are multiplied together to generate CTCMAIN, then, when taking the partial derivative, the MAINS term is treated as a constant and must also be considered along with β_6. Similarly, the TIMETBLS term is treated as a constant in the interaction term CTCSPEED and must also be considered along with β_2. The values of the regression coefficients used in the equations, as suggested by Burton, are shown below.

Regression Coefficient	Value
β_2	-0.017
β_5	0.7272
β_6	-0.41692
β_{11}	1.854777

Table 8: Values of regression coefficients used in modeling of incremental rail route capacity

The partial derivative equations can be modified and rearranged to obtain other equations that lend themselves better to the data that I am using in my analyses. For instance, the data on route capacities are in terms of carloads per year, not maximum carloads per quarter. Therefore, I modify the dependent variable in the regression equation (MAXCARM) to be more consistent with the dependent variable that I would like to use (MAXCARLOADS) and that I have data on.

MAXCARM = ln [maximum carloads per quarter]
= ln [(maximum carloads per year) / 4]
= ln [(MAXCARLOADS) / 4]

Of course, the maximum number of carloads per year is not exactly the same as four times the maximum carloads per quarter. But since I do not have quarterly data, I assume for my purposes that the approximation is close enough. Also, I invoke the definition that the partial derivative is an infinitesimal change in MAXCARM divided by an infinitesimal change in one of the independent variables (MAINS, CTC). In my analyses, I stretch this definition a little further and apply it to situations where the changes are larger than infinitesimal. As an example, I carry out this derivation in full for the partial derivative of MAXCARM with respect to MAINS.

$$\frac{\partial\, MAXCARM}{\partial\, MAINS} = \frac{\Delta\, MAXCARM}{\Delta\, MAINS} = \beta_5 + \beta_6(CTC)$$

$$\downarrow$$

$$\frac{\Delta\, MAXCARM}{\Delta\, MAINS} = \frac{\Delta \ln[(MAXCARLOADS\ /\ 4\,]}{\Delta\, MAINS} = \beta_5 + \beta_6(CTC)$$

$$\downarrow$$

$$\frac{\ln[(MAXCARLOADS\ /\ 4\,]_f - \ln[(MAXCARLOADS\ /\ 4\,]_i}{\beta_5 + \beta_6(CTC)} = MAINS_f - MAINS_i$$

(where *f* indicates ‘final’ and *i* indicates ‘initial’)

$$\downarrow$$

$$\frac{\{\ln[MAXCARLOADS_f] - \ln[4]\} - \{\ln[MAXCARLOADS_i] - \ln[4]\}}{\beta_5 + \beta_6(CTC)} = MAINS_f - MAINS_i$$

$$\downarrow$$

$$\frac{\ln[MAXCARLOADS_f] - \ln[MAXCARLOADS_i]}{\beta_5 + \beta_6(CTC)} = MAINS_f - MAINS_i$$

This final expression is quite useful because it allows one to estimate the incremental number of mainline tracks that must be installed on a route in order to increase the capacity from $\text{MAXCARLOADS}_\text{i}$ to $\text{MAXCARLOADS}_\text{f}$. Of course, if one knows the initial number of mainline tracks on a route (MAINS_i), then he/she can then calculate the final number of mainline tracks (MAINS_f) that will ultimately be needed to meet the future capacity levels. (Note that the value of CTC to use in the equation is a constant and represents the percentage of CTC installed on the route at the time the new tracks are added.)

Following the same methodology, a similar expression can be derived from the partial derivative of MAXCARM with respect to CTC.

$$\frac{\ln[MAXCARLOADS_f] - \ln[MAXCARLOADS_i]}{\beta_2(TIMETBLS) + \beta_6(MAINS) + \beta_{11}} = CTC_f - CTC_i$$

(The variables TIMETBLS and MAINS are constants and represent the values at the time new CTC is installed.)

Costs of Capacity Enhancements and Infrastructure Investments

After estimating the incremental amount of either CTC signaling or mainline track additions that are needed to meet future capacity levels, costs are assigned to these infrastructure upgrades in an effort to estimate the total capital costs of rail capacity enhancement. Cost assumptions are shown in the following table. Where applicable, I include high and low values to show the ranges of uncertainty. To account for these uncertainties, I carry out Monte Carlo simulation to span the possibilities of assumed values.

Assumption	Value Used	Units	Low	High	Source
Mainline Track (Light Density)	573,650	$/mile	-10%	+10%	(Zeta-Tech, 2004), (Burton, 2007)
Mainline Track (Medium Density)	637,514	$/mile	-10%	+10%	(Zeta-Tech, 2004), (Burton, 2007)
Mainline Track (High Density)	683,307	$/mile	-10%	+10%	(Zeta-Tech, 2004), (Burton, 2007)
Extra Cost of Laying Track in Flat Terrain (existing ROW)	0	$/mile	-10%	+10%	(Burton, 2007)
Extra Cost of Laying Track in Flat Terrain (new ROW)	144,681	$/mile	-10%	+10%	(Burton, 2007)
Extra Cost of Laying Track in Rolling Terrain (existing ROW)	198,484	$/mile	-10%	+10%	(Burton, 2007)
Extra Cost of Laying Track in Rolling Terrain (new ROW)	953,820	$/mile	-10%	+10%	(Burton, 2007)
Extra Cost of Laying Track in Mountainous Terrain (existing ROW)	663,019	$/mile	-10%	+10%	(Burton, 2007)
Extra Cost of Laying Track in Mountainous Terrain (new ROW)	4,604,972	$/mile	-10%	+10%	(Burton, 2007)
CTC Signal Upgrades	65,000	$/mile	40,000	80,000	(Zeta-Tech, 2004)

Table 9: Cost assumptions used in capacity-enhancing rail infrastructure modeling

First, I determine the type of new trackage needed on each of the 42 rail route selected for this study: light density, medium density of high density. Light-density rail trackage is usually found on long industrial tracks, small branch-lines, and Class III railroad mainlines (Burton, 1998). It is capable of carrying modest tonnages at moderate speeds and is not found very often on the 42 selected rail routes of this study. Medium density trackage, on the other hand, is the type of trackage found most often on the selected routes. This type of trackage is designed to handle moderate to heavy traffic at train speeds up to 60 mph or so. High density, or heavy-haul, trackage is able to support continuously moving heavy traffic, like that found on some of the busiest rail lines in the country. High density trackage exists on several of the selected rail routes of this study. In my modeling I classify each route by the type of trackage that is found on it. This information is obtained from data provided by ALK, which they have collected over a number of years. The trackage classification dictates the type of new mainline trackage that will be laid on the route in the future and, thus, the cost of mainline track additions. In many cases, different types of track currently exist on routes. Therefore, on routes that have high density trackage on more than half of their links, I assume that any new mainline track additions will be of the high density type. Similarly, on routes that have medium density trackage on more than half of their links, I assume that any new mainline track additions will be of the medium density type. Light density trackage is found in significant quantities on only one of the 42 selected rail routes; therefore, I assume that any new mainline trackage installed on this route in the future will be of the light density type.

All of this said, my cost model includes an option for assuming that any new trackage laid on any part of the rail network will be of the high-density type in the future. This is not an unreasonable assumption on heavily trafficked corridors (Gill, 2007). High density trackage can potentially increase the carrying capacity of routes because it allows for heavier rail cars and faster moving traffic.

Furthermore, the existence, or absence, of railroad right-of-way (ROW), as well as the geographic terrain present on the route, impacts the cost of laying new mainline track. In my modeling, I have attempted to analyze every single route with regard to the types of terrain that the route traverses. For example, a route with mixed terrain might be 25% flat, 25% rolling hill, and 50% mountainous. I consulted railroad timetables and topographical/relief maps to carry out this part of the analysis. Breaking down routes by the existence of ROW was a difficult task, however, and in fact one that I did not attempt to complete. Instead, I parameterize this variable in my model—either the route has ROW to accommodate all new capacity expansions in the future, or it does not. There is a 50/50% probability of either occurrence. The ROW parameter is then varied during Monte Carlo simulation.

In addition to upgrading rail infrastructure to accommodate future increases in freight traffic, railroads will also be required to invest in new rolling stock (i.e., rail cars and locomotives). To estimate the number of new coal-rail cars needed on a particular route, I take the number of annual revenue carloads of coal traversing the route and divide by the number of roundtrips that each car can make on the route in a given year. For estimation purposes only, I make an imaginary assumption that coal trains/cars are used exclusively on a single route—i.e., they shuttle back and forth from one end of the route to the other, and are not used on other routes. While this is certainly not a true assumption in reality, since trains typically traverse one route, then go to the next, and so on, this simplifying assumption allows me to isolate the number of rail cars that might be devoted exclusively to a single route, which is useful for cost accounting purposes. For instance, if it takes 3.5 days for a coal train to make a roundtrip on a particular route (i.e., start at point A, go to point B, then come back to point A), then roughly 100 roundtrips can be made within a year (= 365 / 3.5 = ~100). This reduces the number of new rail cars that must be acquired since a given rail car can be used on 100 different trips throughout the year. To estimate the roundtrip delivery time, the total roundtrip route distance is divided by the distance that a typical coal train travels in a given day. After estimating the incremental number of coal-rail cars that are needed on a route, I estimate the corresponding number of new locomotives needed by dividing the number of new coal-rail cars by the number of coal-rail cars that one locomotive can pull on its own. These equations are shown below.

$$RDT = \frac{2 \times RD}{ATS \times HO}$$

where RDT = Roundtrip Delivery Time (days); RD = Route Distance (miles); ATS = Average coal Train Speed (mph); HO = Average Hours of Train Operation per Day (hours)

$$CCN = \frac{ARC}{(365.25 / RDT)}$$

where CCN = Coal Cars Needed; ARC = Annual Revenue Carloads of coal; RDT = Roundtrip Delivery Time (days); 365.25 = average number of days in a year

$$CLN = \frac{CCN}{1/(LPT/100)}$$

where CLN = Coal Locomotives Needed; CCN = Coal Cars Needed; LPT = number of Locomotives Per 100-car coal unit Train; 100 = number of coal cars on a 100-car coal unit train

The variables RD and ARC are specific to each individual rail route. The other variables are either calculated by the above equations or are generic assumptions that are applied to all routes. The assumed values for these variables are shown in the table below. Also shown are the assumptions used for the estimating the costs of rolling stock—coal-rail cars and locomotives.

Assumption	Value Used	Units	Low	High	Source
ATS	17.5	mph	15.5	22.0	(RPM, 2007)
HO	16	hours	12.48	19.2	(Zeta-Tech, 2004), (Gill, 2007)
LPT	4	locomotives	3	6	(Gill, 2007)
Cost of Coal-Rail Car	75,000	$	60,000	90,000	(RTF, 2007)
Cost of Locomotive	2,500,000	$	2,000,000	3,000,000	(Zeta-Tech, 2004), (Gill, 2007)

Table 10: Assumptions used in incremental rolling stock calculations

Due to the “snapshot” nature of the freight rail traffic projections, my modeling of rail infrastructure investments is restricted to two distinct time frames: 2004 – 2030 and 2030 – 2050. In other words, since for each of the coal demand scenarios, I only project the traffic flows (both coal and non-coal) on the 42 selected routes in the years 2030 and 2050, I am limited in my estimates of when the capacity investments might actually be made. Therefore, I first model the investments that might be made in the 2004 – 2030 timeframe to achieve the necessary levels of capacity in 2030. Then, I do the same for the 2030 – 2050 timeframe in an effort to meet the necessary capacity levels in 2050. In my modeling structure, CTC signal upgrades are always the first choice for enhancing route capacity since installing signals is generally cheaper than installing new mainline trackage. Thus, it is assumed that signal upgrading would be the logical first choice for a railroad in a competitive business environment. However, if CTC signal upgrading does not allow a particular route to meet the necessary capacity levels, new mainline track is then added. This methodology is applied to both timeframes, and the total costs are computed for each.

In order to estimate the present value of all future costs, as well as the annualized costs ($/year) and levelized costs ($/ton-mile), I employ two different costing methods that should span the range of possibilities. In the first method, I assume that all the necessary capital investment for a given time period occurs in the first year of the period (i.e., 2004 for the 2004-2030 period, and 2030 for 2030-2050 period). To account for underutilization of the route in the early years after the investment is made, I then also assume a relatively low average capacity factor for future rail traffic on the route. In the second method, I divide up the total capital investment over the time period by the length of that time period and assume that the costs are spread out in equal annual installments. Due to the high upfront costs of the first method, I can expect that the cost estimates derived from it will be higher than those derived from the second method. In fact, the first method's costs will likely be overestimated while the second method's costs will likely be underestimated. These extremes give an upper and lower bound for costs that I can use to bracket my estimates. The financial parameters used for annualizing and levelizing capital costs are shown in the following table. The economic analysis is done in real terms (no inflation) in constant 2005$.

Assumption	Value Used	Units	Low	High	Source
Lifetime of Railroad Infrastructure (track, signals)	30	years	---	---	(Burton, 1998)
Lifetime of Locomotives and Rail Cars	30	years	---	---	(Zeta-Tech, 2004)
Salvage Value of Equipment at End of Lifetime (% of initial capital)	10	%	5	15	---
Real Discount Rate	10	%	7	12	(Burton, 1998), (Zeta-Tech, 2004)
Reference Dollar Year	2005	---	---	---	---

Table 11: Assumptions for financial parameters

Positive Train Control: An Alternative Capacity Enhancement Strategy

Another potential rail capacity enhancement strategy that I model as an alternative to CTC signal upgrading and installation of mainline trackage is positive train control (PTC). PTC is a collection of technologies that some believe could be used to increase the speed and safety of train operations. The technologies involved are global positioning systems (GPS) on board the locomotive and wayside detectors along the track, the combination of which would establish a direct data link to a central command center for railroad operations (Zeta-Tech). Trains would automatically be able to detect their exact geographic location on the rail network at any given time and then send this information to the railroad's central command center where train operations could be more effectively managed. Under this regime, trains would, theoretically, be able to follow each other more closely than under the guidance of conventional control systems, such as CTC, thereby increasing the throughput and capacity of rail lines. But although the concept of PTC has been around for a couple decades now, there has been little experience with it in practice, outside of a handful of pilot projects; and nothing has been attempted on a system-wide scale. Therefore, the capacity benefits of PTC are not yet known. In my modeling of PTC, I assume that the technology will be available and implemented sometime within the 2004 – 2030 timeframe and that it offers a capacity enhancement benefit of 0 – 20% over conventional CTC. I base this assumption partly on a Zeta-Tech (2004) report, which discusses the line-haul speed benefits of PTC, and on the fact that PTC is essentially a technological improvement over conventional CTC. Hence, on routes that are not already fully CTC in 2004, I assume that PTC offers the same benefits that could be achieved by making the line 100% CTC plus an additional 0 – 20% capacity increase over this. The equation used to model the incremental capacity benefit of PTC is based on a similar one shown previously for estimating the incremental proportion of CTC to add to a route in order to increase the capacity to a certain level. This equation is shown again below.

$$\frac{\ln[MAXCARLOADS_f] - \ln[MAXCARLOADS_i]}{\beta_2(TIMETBLS) + \beta_6(MAINS) + \beta_{11}} = CTC_f - CTC_i$$

Assuming that PTC offers an increase in final route capacity over CTC, an equation for the route capacity after PTC installation can be derived, after slight modification and rearrangement, from the one above.

$$MAXCARLOADS_f = (1+CB)\times\exp\{[\beta_2(TIMETBLS) + \beta_6(MAINS) + \beta_{11}]\times(CTC_f - CTC_i) + \ln[MAXCARLOADS_i]\}$$

where CB = % capacity benefit of PTC over CTC; $CTC_f = 1.0$; All other variables as above

It is assumed that PTC will be fully installed on a given route essentially all at once. In other words, there is no partial installation of PTC since it would be inefficient if some parts of a route were PTC while others were not. Just as with CTC, I model PTC upgrading as occurring before the installation of mainline trackage, which is again based on the assumption that PTC will be a cheaper alternative than laying new track. After the capacity benefits of fully installing PTC on a route are realized, the only other choice for increasing capacity is new mainline track additions. The potential advantage of PTC over CTC is, perhaps, the need for new, expensive mainline trackage might be reduced, thereby reducing the total capital costs of enhancing the capacity of a particular rail route.

After estimating the capacity benefits of PTC and the amount of new mainline track that would be needed in a PTC scenario, the capital and levelized costs can be calculated just as they were described above for the CTC scenario. The only differences in this case are that the costs of CTC signal upgrades are not incurred; instead, the costs of PTC are incurred. These additional costs include installing instrumentation and equipment on board the locomotive, upgrading the signaling devices and detectors along the track, and the cost of the central command center facility, as well as all the computers and equipment that would be required for it. The PTC-related assumptions are summarized in the following table.

Assumption	Value Used	Units	Low	High	Source
Capacity Benefit of PTC over CTC	10	%	0	20	(Zeta-Tech, 2004)
Cost of Locomotive Instrumentation	50,000	$/locomotive	30,000	75,000	(Zeta-Tech, 2004)
Cost of Track/Signal Upgrades	20,000	$/mile	16,000	24,000	(Zeta-Tech, 2004)
Cost of Central Command Center	300,000,000	$/center	100,000,000	500,000,000	(Zeta-Tech, 2004)

Table 12: Assumptions used in modeling positive train control (PTC)

Description of Capacity Enhancement and Infrastructure Investment Spreadsheet Model

I have incorporated the methodologies described above into a model that estimates the infrastructure requirements and capital investments necessary to increase the capacities of the selected rail routes under the various scenarios of coal demand growth. Because the model is built on a number of variable and uncertain assumptions, most of which were highlighted above, Monte Carlo simulation techniques are employed to estimate final results. The MS Excel add-on software Crystal Ball is used to develop and run the Monte Carlo simulations. First, the user defines which assumptions of the model are variable and uncertain. Then, a probability distribution or range of likely values is specified for each assumption. Next, Crystal Ball calculates the model several hundred, or even thousands, of times, in each case using a different value for each assumption based on the input probability distribution. The value selected is randomly drawn from the range of possible values. After the model has been calculated a large number of times, a probability distribution is created to represent the likelihood of seeing a particular outcome. In my opinion, this procedure is preferable to a single point estimate that would be entirely dependent on the restrictive set of assumptions that goes into producing it.

V. HISTORICAL COSTS OF RAIL TRANSPORTATION OF COAL

The Federal Energy Regulatory Commission (FERC) conducts a survey called the "Interrogatory on Fuel and Energy Purchase Practices", in which it uses Form 580 to collect "among many other data elements, information on cost, quantity, quality, and origin of coal purchased under contract by investor-owned, interstate electric utility plants with steam-electric generating stations of more than 50 megawatts, and on the transportation rate, mode, and distance of the contract coal shipments" (EIA, 2007). The EIA then organizes this information into a database known as the Coal Transportation Rate Database (CTRDB), the most recent of which contains data from 1979 to 2002. Railroad transportation of coal is well represented in the survey data: more than 70% of the coal used by the surveyed plants was delivered by rail. The EIA breaks down the survey data into coal supply and demand regions, since coal transportation rates are dependent on the origin and destination of the particular coal shipment.

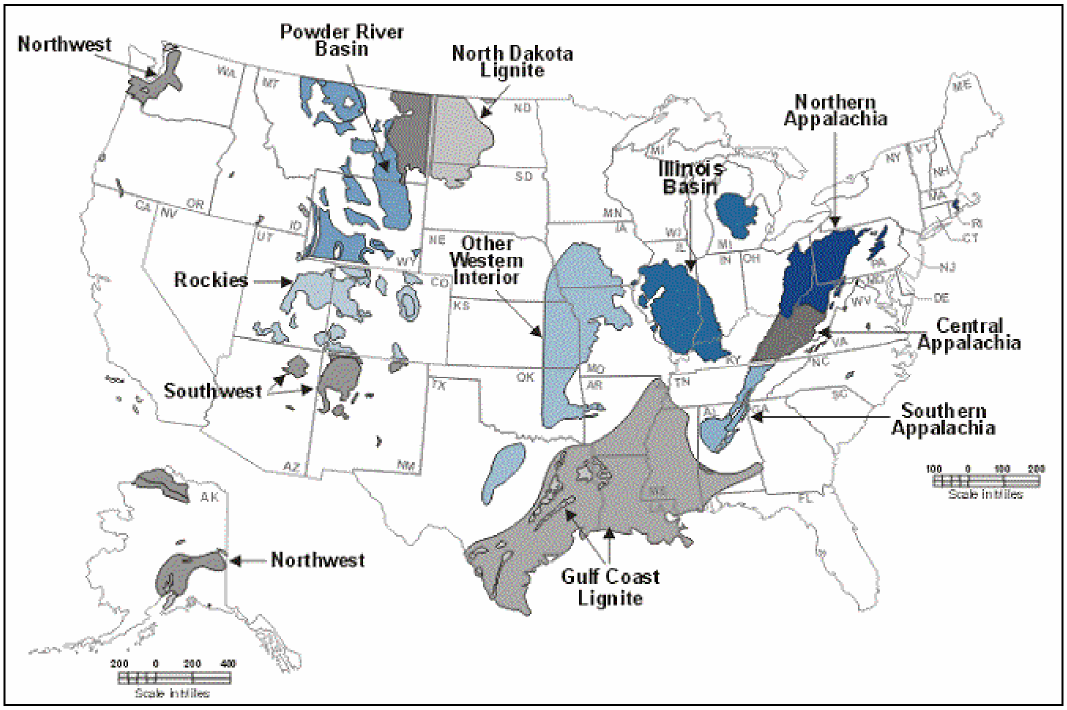
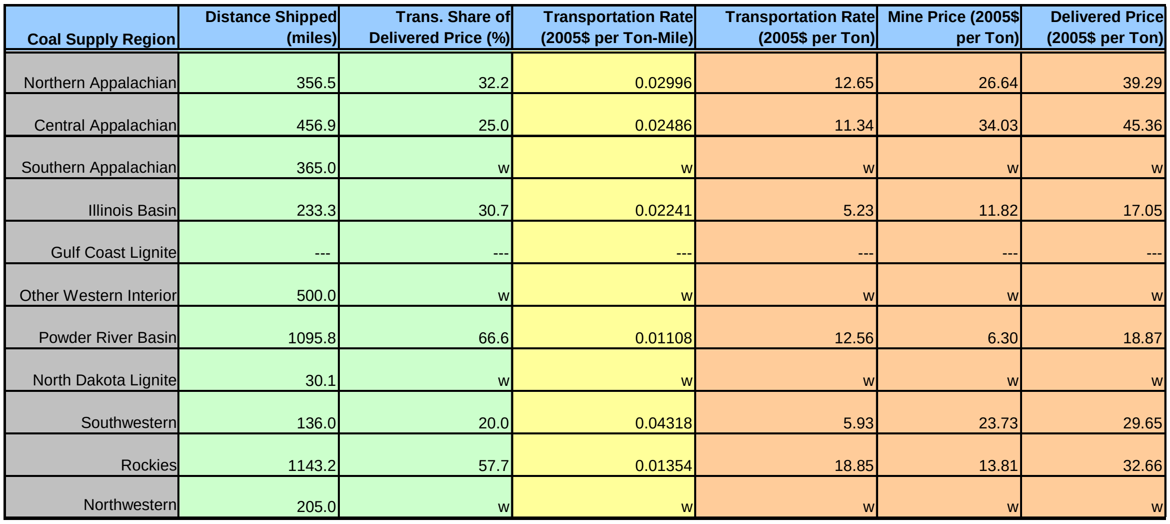


Figure 39: Coal regions and coal fields (EIA, 2007)

Coal Regions	Coal Fields	States
APPALACHIA	Northern Appalachia	MD, OH, PA, Northern WV
	Central Appalachia	Eastern KY, VA, Southern WV
	Southern Appalachia	AL, TN
INTERIOR	Illinois Basin	Western KY, IL, IN
	Gulf Coast Lignite	TX, LA, MS
	Other Western Interior	AR, IA, KS, MO, OK
WEST	Powder River Basin	WY, MT
	North Dakota Lignite	ND
	Southwest	AZ, NM
	Rockies	CO, UT
	Northwest	AK, WA

Table 13: Coal regions, coal fields, and states (EIA, 2007)

The EIA data are useful in comparing average mine prices and rail shipping rates from the different coal fields and supply regions. These are the two components that make up the delivered price of coal that electric plants are responsible for paying. The table and chart below show these average prices and rates in 2001 (where available), along with other information, for coal originating from the various coal fields.



Coal Supply Region	Distance Shipped (miles)	Trans. Share of Delivered Price (%)	Transportation Rate (2005$ per Ton-Mile)	Transportation Rate (2005$ per Ton)	Mine Price (2005$ per Ton)	Delivered Price (2005$ per Ton)
Northern Appalachian	356.5	32.2	0.02996	12.65	26.64	39.29
Central Appalachian	456.9	25.0	0.02486	11.34	34.03	45.36
Southern Appalachian	365.0	w	w	w	w	w
Illinois Basin	233.3	30.7	0.02241	5.23	11.82	17.05
Gulf Coast Lignite	---	---	---	---	---	---
Other Western Interior	500.0	w	w	w	w	w
Powder River Basin	1095.8	66.6	0.01108	12.56	6.30	18.87
North Dakota Lignite	30.1	w	w	w	w	w
Southwestern	136.0	20.0	0.04318	5.93	23.73	29.65
Rockies	1143.2	57.7	0.01354	18.85	13.81	32.66
Northwestern	205.0	w	w	w	w	w

"w" = withheld to protect the confidentiality of shippers
"---" = no data available

Table 14: Coal shipment data for the various coal fields (EIA, 2007)

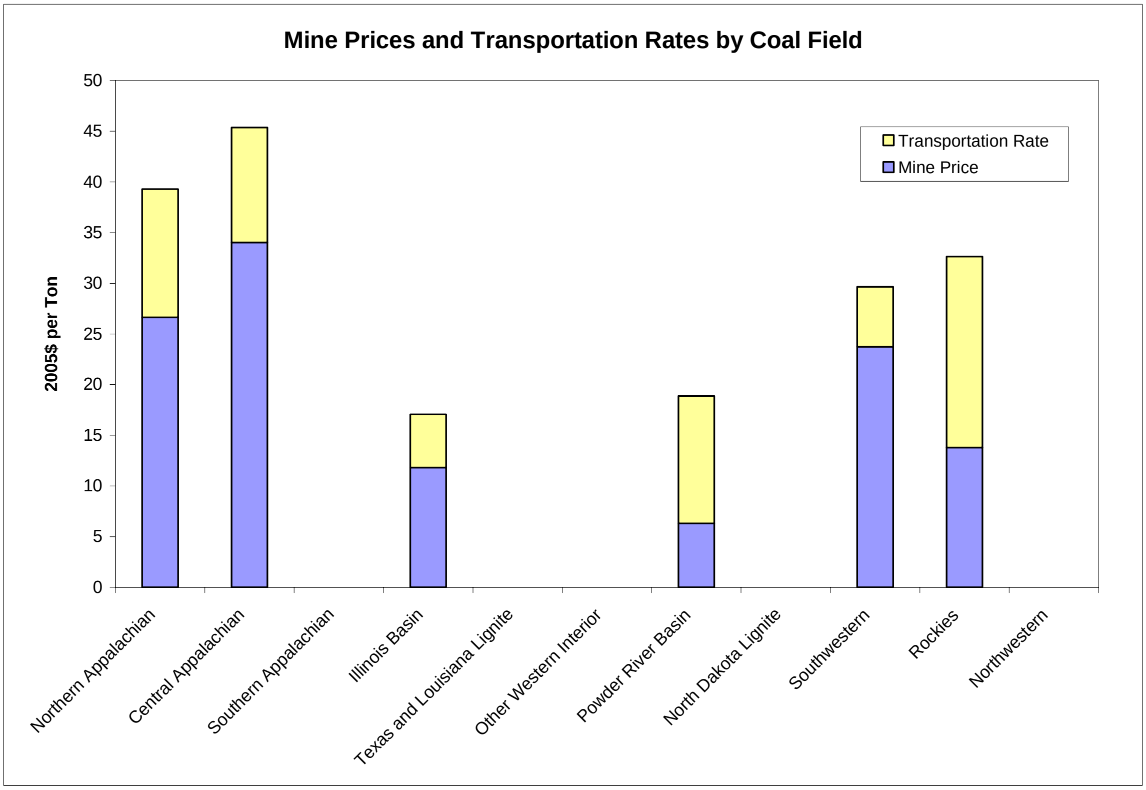
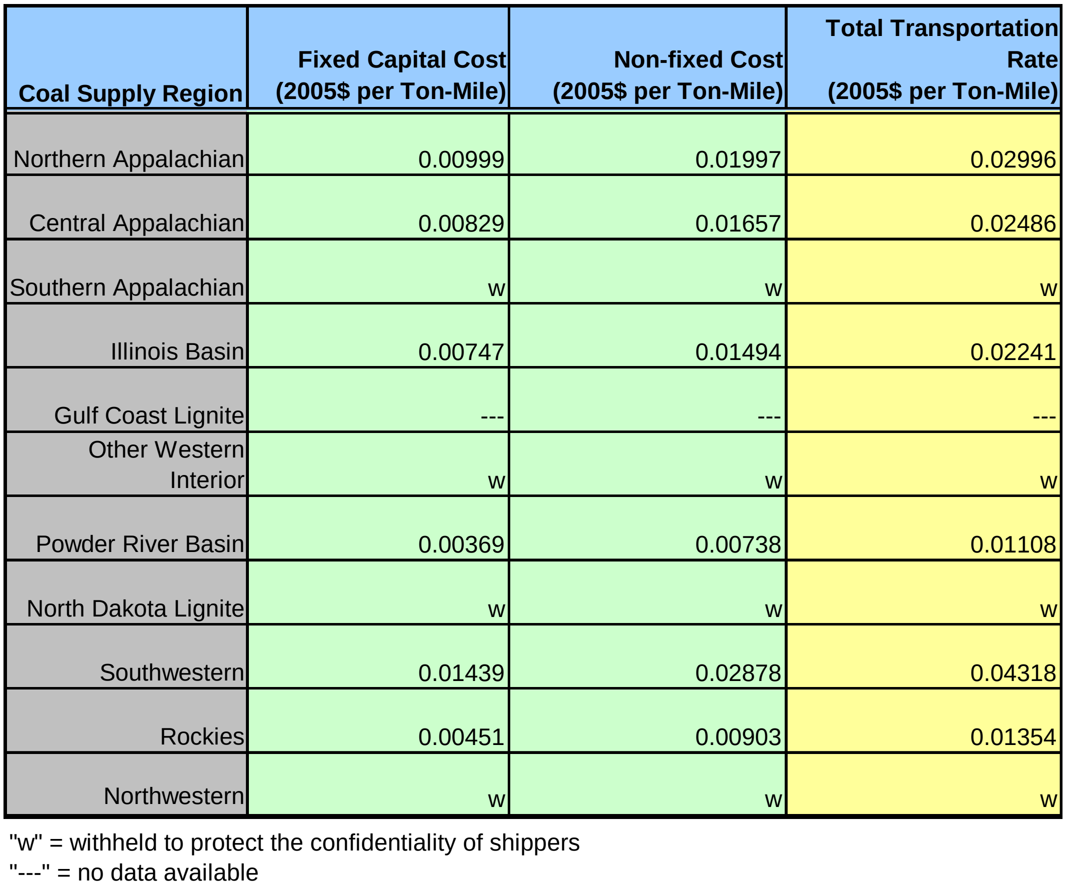


Figure 40: Mine prices and transportation rates by coal field (EIA, 2007)

The total delivered price of coal is greatest in the Appalachian region, but this is due more to the relatively expensive underground mining techniques employed than to the transportation of the coal. In contrast, mine prices of coal are least expensive when produced from the Powder River Basin region, where cheaper surface mining methods are employed. In terms of transportation rates, the situation is for the most part reversed. Coal originating from some Western mines, such as those in the Powder River Basin and the Rockies, is transported a much further distance than coal originating in the Appalachian and Interior regions. The greater shipping distances drive down the distance-based transportation rate, however. On a $/ton-mile basis, the transportation rate associated with Powder River Basin and Rockies coal is the lowest.

It is this distance-based transportation rate that becomes important when discussing the railroads’ costs of doing business. First, it is assumed that rail rates are competitively determined, i.e. they are set at a level just above the railroads’ costs of providing service. If this is indeed true, then a further assumption can be made that approximately two-thirds of the rate is attributable to non-fixed costs (e.g., rolling stock and variable costs), with the remaining one-third attributable to fixed capital costs (e.g., trackage and signaling systems) (TVA, 1998). This assumption is one that is often made by traditional railroad costing models. Therefore, I can decompose the distance-based transportation rates for each region into their fixed and variable cost components.



Coal Supply Region	**Fixed Capital Cost (2005$ per Ton-Mile)**	**Non-fixed Cost (2005$ per Ton-Mile)**	**Total Transportation Rate (2005$ per Ton-Mile)**
Northern Appalachian	0.00999	0.01997	0.02996
Central Appalachian	0.00829	0.01657	0.02486
Southern Appalachian	w	w	w
Illinois Basin	0.00747	0.01494	0.02241
Gulf Coast Lignite	---	---	---
Other Western Interior	w	w	w
Powder River Basin	0.00369	0.00738	0.01108
North Dakota Lignite	w	w	w
Southwestern	0.01439	0.02878	0.04318
Rockies	0.00451	0.00903	0.01354
Northwestern	w	w	w

"w" = withheld to protect the confidentiality of shippers
"---" = no data available

Table 15: Decomposition of coal transportation rates into fixed and non-fixed cost components

The fixed capital cost component can be thought of as the capacity cost that is embedded in the observed transportation rate. As rail capacity is added over time, new incremental capital costs are incurred. If the incremental capital cost for a particular route is greater than the currently observed capacity cost on that same route, then the future average capacity cost will necessarily increase (TVA, 1998). This, in turn, will lead to an increase in the total transportation rate, assuming it is competitively determined and based on cost. On the other hand, if the incremental capital cost is lower than the currently observed capacity cost, then the future average capacity cost and total transportation rate will both decrease.

An increase or decrease in the distance-based transportation rate (on a $/ton-mile basis) will ultimately affect the transportation component of the delivered price of coal (on a $/ton basis). If the distance-based transportation rate of shipping coal from a particular supply region increases, the transportation component of coal price should also increase; and vice-versa. Therefore, by estimating the incremental costs of capacity on particular rail routes, I can make a qualitative statement about the effect the investment will likely have on the cost and, thus, price of coal originating from a particular supply region. To adequately and quantitatively determine the precise effects, however, would require a complex pricing model that takes into account other transportation modes, substitute fuels for coal, and a number of other considerations. This level of detail is outside the scope of the present analysis.

VI. RESULTS AND DISCUSSION

The primary results of this study consist of the following:

1. Maps of freight rail traffic, both now and in the future, under the different scenarios for coal demand growth;
2. Estimates of infrastructure requirements and capital investments that might need to be made in the future to increase the capacity of the selected rail routes.
3. Identification of routes where increased investment might lead to higher rail transport costs for coal than those currently experienced.

The methods for arriving at these results have been described in previous sections. The results and my interpretation of them are discussed in this section.

Freight Rail Traffic Maps for Different Coal Demand Scenarios

To get a sense of where coal is currently transported, it is helpful to look at a map of freight rail traffic in 2004, the base case year of this study. The map shows that the most heavily trafficked rail routes are those transporting coal out of Wyoming's Powder River Basin (PRB) and delivering it to Texan and Midwestern power plants, barge docks on the Missouri and Mississippi rivers, and lake vessel docks on the Great Lakes. Other major coal routes are found in the East, where coal is shipped from Appalachian mines to cities in the South and East and to export terminals on the Atlantic coast.

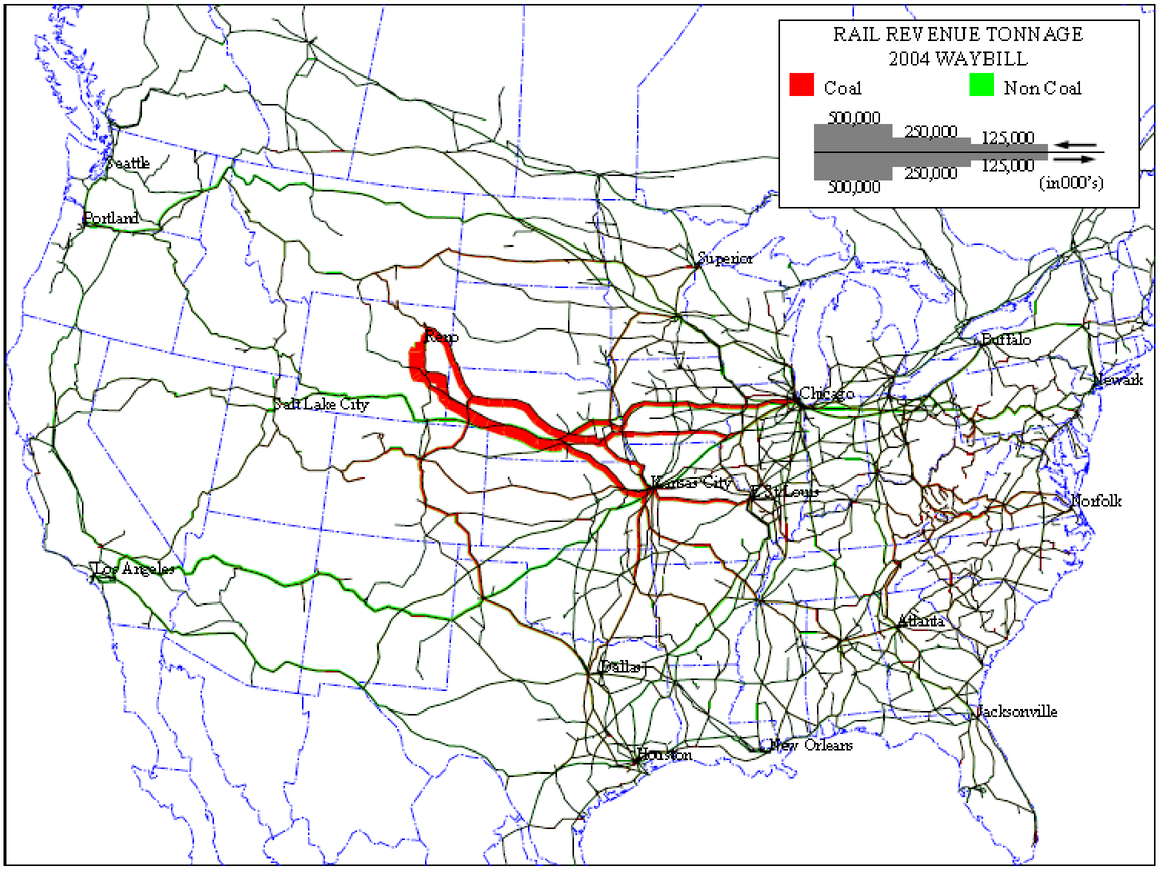


Figure 41: Freight rail traffic in annual tonnage flows on the U.S. rail network in 2004

As discussed previously, in my modeling of future freight rail traffic, I have assumed that coal continues to be transported along these same routes. It is also assumed that coal destined for H2 production is routed in the same way as coal for power plants, since any future coal-to-H2 production is assumed to occur at the same locations that coal power plants currently exist. Moreover, I have not assumed any new train routing schemes nor the presence of new rail routes in territories where routes do not currently exist. These key assumptions contribute to my finding that with increasing amounts of coal demand and, thus, coal transport, today's most heavily trafficked coal corridors will continue to be the busiest in the future as well. The quantities of coal to be transported will be much larger than current levels. For example, by my projections BNSF's and UP's rail routes transporting Western coal (primarily from the PRB) eastward across the Midwest will need to be able, in some scenarios, to handle an additional 100 – 250 million tons of coal shipments per year by the year 2050. These incremental demands are in some cases equal to, or even greater than, the quantities of coal that some of these routes are currently carrying. While the Eastern routes coming out of Appalachia are not expected to face as much additional coal traffic in absolute terms as their counterparts in the Midwest, in relative terms the growth rates could be just as large on some routes. For example, the heavily trafficked routes of NS and CSX, which transport coal out of Appalachia and then head across West Virginia and Virginia to the coastal cities of Norfolk and Newport News, could see more than a doubling of coal traffic by 2050; though this only equates to an additional 20 – 30 million tons of coal per year. Maps of projected freight rail traffic under the various scenarios are shown below. (Larger versions are reproduced in the appendix. For the numerical data underlying these maps, the reader may contact the authors. Though, certain confidentiality agreements partially restrict the dissemination of this data.)

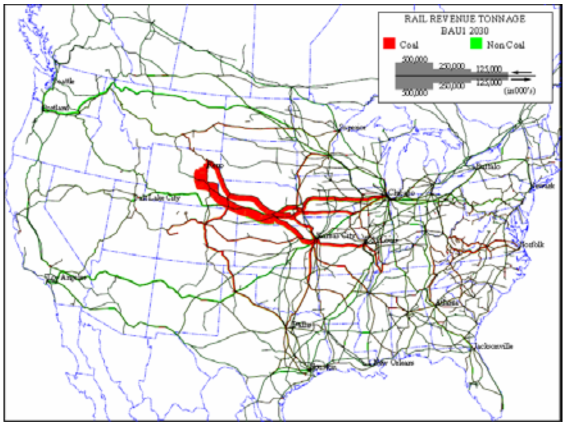


Figure 42: Projected annual tonnage flows in 2030, Scenario BAU1

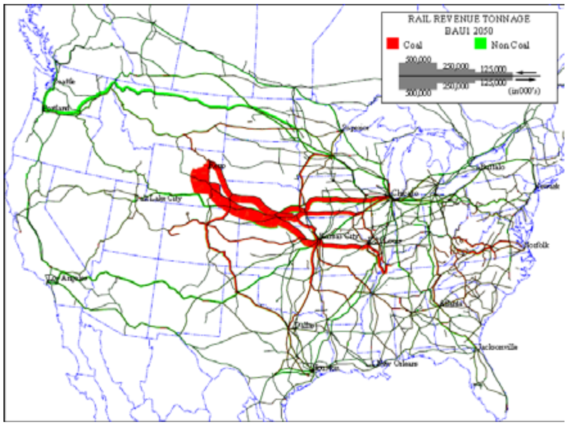


Figure 43: Projected annual tonnage flows in 2050, Scenario BAU1

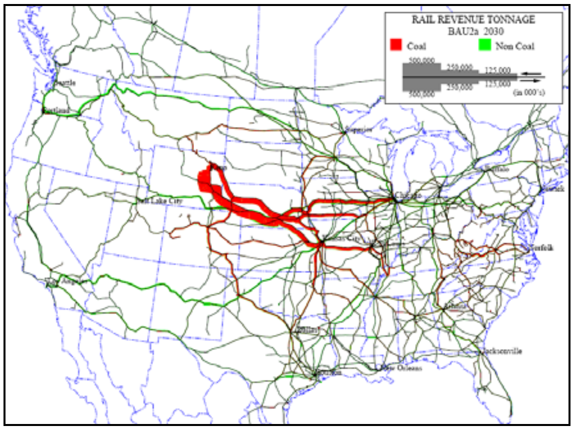


Figure 44: Projected annual tonnage flows in 2030, Scenario BAU2a

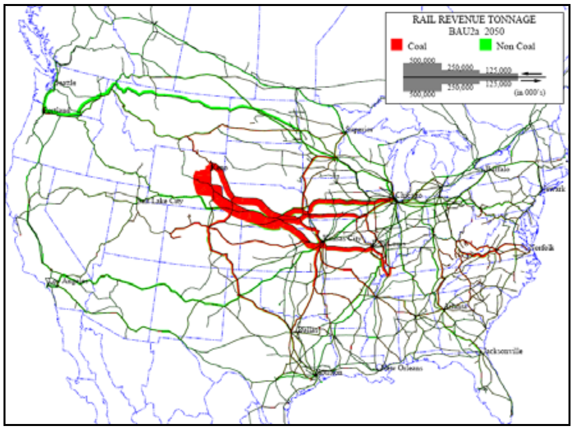


Figure 45: Projected annual tonnage flows in 2050, Scenario BAU2a

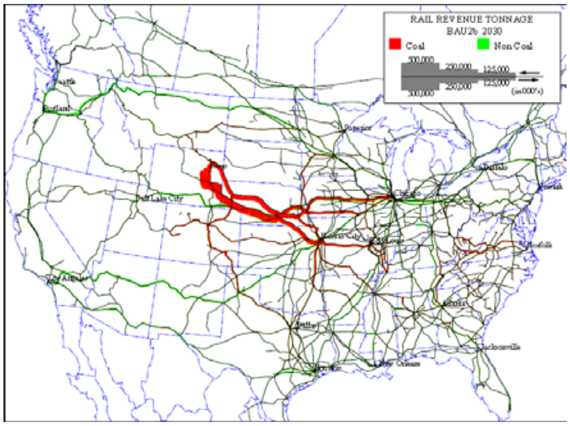


Figure 46: Projected annual tonnage flows in 2030, Scenario BAU2b

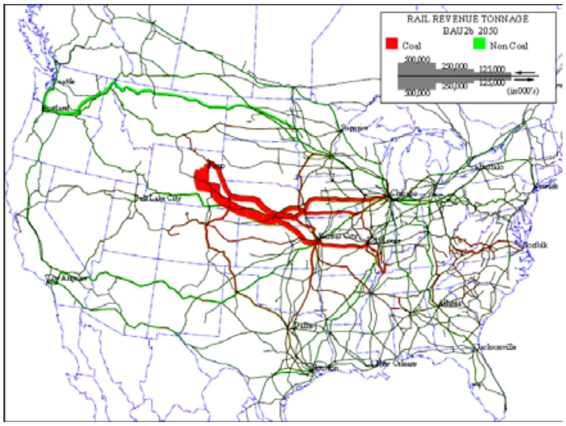


Figure 47: Projected annual tonnage flows in 2050, Scenario BAU2b

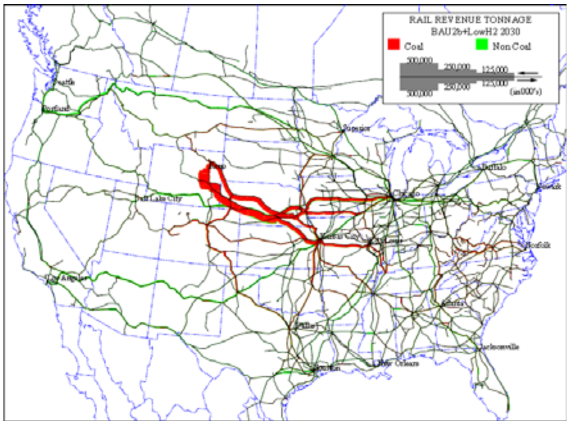


Figure 48: Projected annual tonnage flows in 2030, Scenario BAU2+LowH2

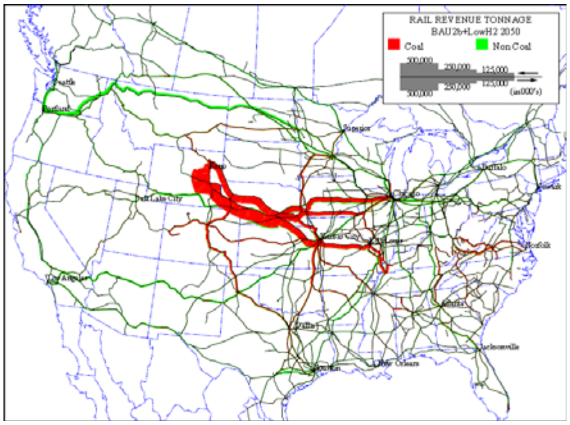


Figure 49: Projected annual tonnage flows in 2050, Scenario BAU2+LowH2

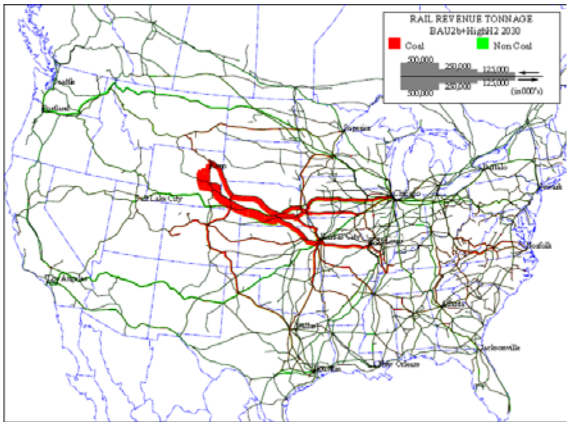


Figure 50: Projected annual tonnage flows in 2030, Scenario BAU2+HighH2

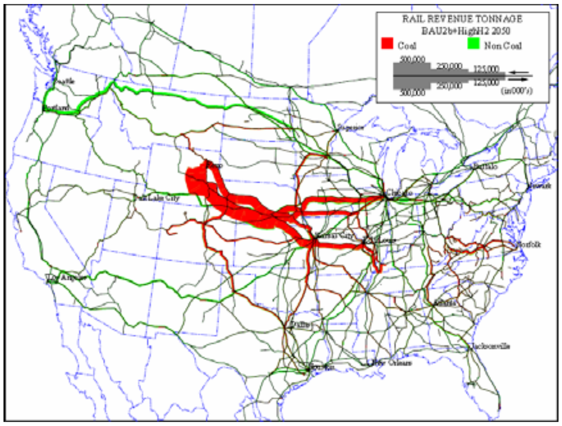


Figure 51: Projected annual tonnage flows in 2050, Scenario BAU2+HighH2

By my estimation, over 800 million tons of coal was transported over U.S. rail lines in 2004. The 42 selected rail routes in this study originated about 700 million tons (~85%) of this coal. Under each of the five scenarios of coal demand growth, the incremental quantities of coal to be transported by these routes in the future are enormous (see table below).

Scenario	Quantity of Coal Transported (million tons)		
	2004	2030	2050
BAU1	700	967	1182
BAU2a	700	929	1124
BAU2b	700	780	948
BAU2+LowH2	700	807	1158
BAU2+HighH2	700	946	1370

Table 16: Quantity of coal transported by 42 selected rail routes under the different scenarios

The quantity of coal transported via the 42 selected rail routes in the BAU2a scenario is *not* significantly less than that in the BAU1 scenario, even though the BAU2a scenario is one in which all new coal plant builds are more efficient IGCC plants, rather than conventional PC, as is the case in scenario BAU1.

Scenario BAU2b, on the other hand, does contribute to fairly significant reductions in coal transport since old PC plants are assumed to be repowered/retrofitted to new IGCC plants. Also, remember that the BAU2+LowH2 and BAU2+HighH2 scenarios extensions of BAU2b, save for the fact that additional coal is used to produce hydrogen for fuel cell vehicles. But since my modeling does not assume major coal demand for hydrogen until later in the forecast period, the total quantity of coal transported in the two hydrogen scenarios does not become significantly greater than the no-hydrogen scenarios until later in the time period, if at all. For instance, note that the quantity of coal transported via the 42 selected rail routes in the BAU2+LowH2 scenario is roughly the same as the BAU1 and BAU2a scenarios. This is due to the fact that old PC plants are assumed to be repowered in BAU2+LowH2. If this future were realized, then half of the 2050 light-duty vehicle fleet could be fueled with coal-derived hydrogen, though no more coal would need to be transported via rail than in a more business-as-usual scenario in which old PC power plants are not repowered to IGCC and no hydrogen is produced from coal.

In summary, I identified 42 key rail corridors which currently account for about 80% of all coal transport by rail. Depending on the particular scenario, future coal transport along these corridors is expected to increase 35 – 95% by 2050 compared to the present coal tonnage carried.

Total Incremental Investments on All Routes

Estimates of infrastructure requirements and capital investments to increase the capacity of the selected rail routes, and comparison with historical spending.

The total incremental costs for capacity and rolling stock have been estimated for each of the 42 selected routes. Given that these selected routes account for about 80 – 85% of all coal transportation in the U.S., these costs are close to reflecting the total costs that might be required in the future to increase the capacity of the entire U.S. network of coal-carrying rail lines.

The following table summarizes, for each scenario of coal demand growth, the total incremental costs on the 42 selected routes for (1) capacity only, i.e. signal upgrades and new mainline trackage, and (2) rolling stock.[23] These costs reflect the addition of several thousand additional miles of mainline trackage and CTC/PTC signaling, as well as several thousand new locomotives and tens of thousands of new coal-rail cars.

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[23] In addition to estimating the incremental capacity costs for each of the 42 selected coal routes, I have also estimated the total costs of new rolling stock for all routes on a discounted present value basis. Note that this calculation is not an attempt to fully model the costs of railroad operation, but rather to include another one of the more important cost components in my calculations. Other important cost components that I have not included in my modeling are maintenance, fuel, and labor, among others. One would expect that the addition of new rolling stock (rail cars and locomotives) to the previously estimated incremental capacity costs would cause the figures to increase. If increased quantities of coal are to be transported along a particular route, then new rail cars (rapid discharge hoppers and rotary gondolas) and locomotives will be required for the additional number of trains that are run. Yet, this need not always be the case. Some of the 42 selected routes in this study are projected to experience a decrease in coal transportation demand between 2004 and 2050. This causes the incremental amount of rolling stock, and the costs associated with it, to be negative, since reduced coal traffic on one route means that rail cars and locomotives can be freed up and moved to other routes where they are more needed. In my modeling, I assume that the incremental costs of new rolling stock are borne fully by the railroad companies. This is merely a simplifying assumption that does not always hold true in reality. In fact, it is quite common for non-railroad companies to purchase rail cars, which the railroads then haul for them. For example, in the case of coal transportation, a mining company or electric utility might purchase a set of coal rail cars that the operating railroad would then use to haul coal on unit trains back and forth between mine and plant. Hence, by assuming that railroads bear all the costs of new rolling stock, it is quite possible that I have overestimated the incremental rolling stock costs.

Scenario	Incremental Capacity Costs[24] (discounted billion $)[25, 26]		Incremental Rolling Stock Costs[27] (discounted billion $)		Capital Costs for Coal Power and Coal-to-Hydrogen Plants (discounted billion $)
	CTC	PTC	CTC	PTC	
BAU1	2.25 – 5.34	1.58 – 3.72	2.72 – 4.74	2.76 – 5.05	54
BAU2a	1.88 – 4.45	1.28 – 3.02	2.37 – 4.21	2.40 – 4.43	59
BAU2b	0.64 – 1.48	0.53 – 1.24	1.05 – 2.05	0.98 – 2.02	140
BAU2b+LowH2	1.00 – 2.30	0.76 – 1.73	1.44 – 2.61	1.40 – 2.63	147
BAU2b+HighH2	2.28 – 5.33	1.61 – 3.73	2.84 – 4.93	2.88 – 5.23	166

Table 17: Incremental costs of increasing capacity of all 42 selected rail routes up (2005$)

The incremental costs of rail infrastructure and equipment may appear at first glance to be quite small, but the reader should remember that these costs have been discounted back to 2005 dollars, and since some the costs are assumed to be incurred several decades into the future, the discounted present value ends up being smaller than one might anticipate. Although I did not explicitly estimate the non-discounted costs in my modeling, from inspection of my cost calculation methodology it appears that $1 in discounted terms is equivalent to something like $1.5 – $4.5 in non-discounted terms. Therefore, costs in non-discounted dollars would be quite a bit greater than those shown in the table above, on the order of tens of billions of dollars total over the 2005-2050 timeframe. By comparison, Class I railroads have been spending about $5 – $8 billion annually over the past several years to maintain and improve all of their infrastructure and equipment across the U.S. (Hamberger, 2006). This figure includes all commodities

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[24] "Incremental Capacity Costs" refer to the capital costs associated with upgrading signal systems and adding new mainline trackage from 2004 to 2050.

[25] The discount rate is assumed to be in the range of 7 – 12% and is varied during Monte Carlo simulation.

[26] A range is given for each cost estimate to reflect the multiple costing methodologies and variable input assumptions used in this study.

[27] Incremental Rolling Stock Costs" refer to the capital costs associated with investing in new locomotives and coal rail cars from 2004 to 2050.

and routes, not just coal and the 42 selected routes being studied in this analysis. (Note that if these historical annual investments were assumed to be made in every future year, then the total investment costs over the study period would be $235-375 billion in non-discounted terms, or $50-125 billion in discounted terms, assuming discount rates in the 7-12% range.) More representative estimates of capital spending are those that railroads have made in the recent past to increase the carrying capacity of their coal transportation networks. To this end, over the past decade both BNSF and UP have spent more than $2 billion, investments that are quite similar in magnitude to the cost estimates of this study, as shown above, for future decades. If these trends were to continue and if NS and CSX were assumed to spend a similar amount on their coal infrastructure and equipment every decade, then I figure that approximately $10 billion (in non-discounted dollars) might need to be invested every decade, or about $45 billion over 45 years, to increase the carrying capacity of the coal transportation networks of BNSF, UP, NS, and CSX. Depending on the scenario, the sum of incremental capacity and rolling stock costs that I estimate are on the order of tens of billions of dollars (in non-discounted terms).

In sum my incremental cost estimates appear to be in line with historical trends for capital spending by the railroads on their coal transportation businesses.

Identification of routes where increased investment might lead to higher rail transport costs for coal than those currently experienced

One of the key questions of this study is whether or not the railroads will be able to handle these increased levels of coal transportation in the future and what the impact will be on the costs and delivered prices of coal as a result of the capacity investments that might need to be made.

To estimate whether coal transport costs are likely to rise on a particular route, I use a simplified approach, described in section V. In particular, I estimate whether the ***incremental capacity cost*** is greater than the ***historical capacity cost***, thus potentially leading to an increase in the rail transportation rate of coal along the route. By estimating the incremental costs of capacity on particular rail routes, I can make a qualitative statement about the effect the investment will likely have on the cost and, thus, price of coal originating from a particular supply region.

The reader should note that the approach used in this analysis does not allow me to say exactly how much a competitively determined rail rate and, thus, the delivered price of coal might increase due to incremental costs of capacity enhancement and infrastructure investment. Coal costs and prices are functions of a number of factors, and a quantitative estimate of the new cost/price of coal after a capacity-enhancing capital investment has been made can only be reliably estimated by employing a detailed coal pricing model that incorporates feedback effects and considers other modes of coal transportation, substitute coals from different locations, and other substitute fuels. This level of detail is outside the scope of the present analysis. What I have tried to do here is use quantitative estimates to provide a qualitative conclusion regarding the impact of incremental rail capacity investments on the cost/price of coal originating from a particular supply region.

My estimates of the total and levelized costs for each of the 42 selected rail routes under the various scenarios are shown in tables in the appendix. Note that, as discussed previously, two different costing methods are used to span the possibilities of when capital investments might be made throughout the long time periods and, thus, bracket the likely incremental costs incurred.[28]

Summary of Results for All Routes

Comparing incremental capacity costs to historical capacity costs, my analysis suggests that several of the 42 selected routes could potentially see an increase in rail transportation costs due to the higher coal transportation demands placed on them in the future and the incremental capacity-enhancing capital investments that would have to be made to keep pace with demand. The following table indicates whether or not rail transportation costs are expected to increase on each of the given routes due to growth in coal transportation demand along them for the two different signaling cases and under each of the various coal demand growth scenarios. Calculations and analyses for each route have been carried out by exactly the same methodology that is described in the sidebar below for Route #2.

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[28] The cost estimates generated by each methodology are represented by probability distributions, which have been developed from Monte Carlo simulations that take into account a multitude of combinations of input assumptions. These probability distributions take the form of P10, P50, and P90 estimates. The P10 estimate says that there is a 10% probability that the cost will be below the estimated value. Similarly, the P50 and P90 estimates say that the probabilities are 50% and 90%, respectively, that the cost will be below the estimated value. The combination of the two costing methodologies and the probability distributions allows me to develop a fairly large range of estimates in which the actual incremental costs might fall into. In reporting my results, I use a combination of these approaches to develop a slightly narrower range. The range of cost estimates that I report on the following pages are the P50 estimates from the two different costing methodologies.

Is route expected to see an increase in rail coal transportation costs in the future?
(Y = Yes, N = No, ?? = Inconclusive)

Route	Scenario									
	BAU1		BAU2a		BAU2b		BAU2b+LowH2		BAU2b+HighH2	
	CTC	*PTC*	*CTC*	*PTC*	*CTC*	*PTC*	*CTC*	*PTC*	*CTC*	*PTC*
1	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
2	**Y**	**Y**	**Y**	**Y**	**Y**	**??**	**Y**	**??**	**Y**	**Y**
3	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
4	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
5	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
6	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
7	**??**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
8	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
9	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
10	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
11	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
12	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
13	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
14	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
15	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
16	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
17	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
18	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
19	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
20	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
21	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
22	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
23	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
24	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
25	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
26	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
27	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
28	**N**	**Y**	**N**	**Y**	**N**	**Y**	**N**	**Y**	**N**	**Y**
29	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
30	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
31	**??**	**N**	**??**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
32	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
33	**N**	**Y**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
34	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
35	**Y**	**??**	**Y**	**??**	**N**	**N**	**N**	**N**	**Y**	**N**
36	**Y**	**Y**	**Y**	**Y**	**??**	**N**	**??**	**N**	**Y**	**??**
37	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
38	**??**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
39	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
40	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
41	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
42	**??**	**??**	**??**	**??**	**??**	**??**	**??**	**??**	**??**	**??**

Table 18: Indication of rail rate changes for all routes under various scenarios and multiple capacity enhancement strategies

From the table it is clear that the vast majority of routes will not experience an increase in rail transportation costs due to the incremental costs of enhancing capacity. On only 9 of the 42 routes does there even appear to be a slight possibility that rail costs might increase, and in some of these instances my findings are inconclusive. Routes where there appears to be a stronger chance of the cost of coal transportation increasing are Routes #2, 28, 35, 36, and 42, which are labeled on the following map.

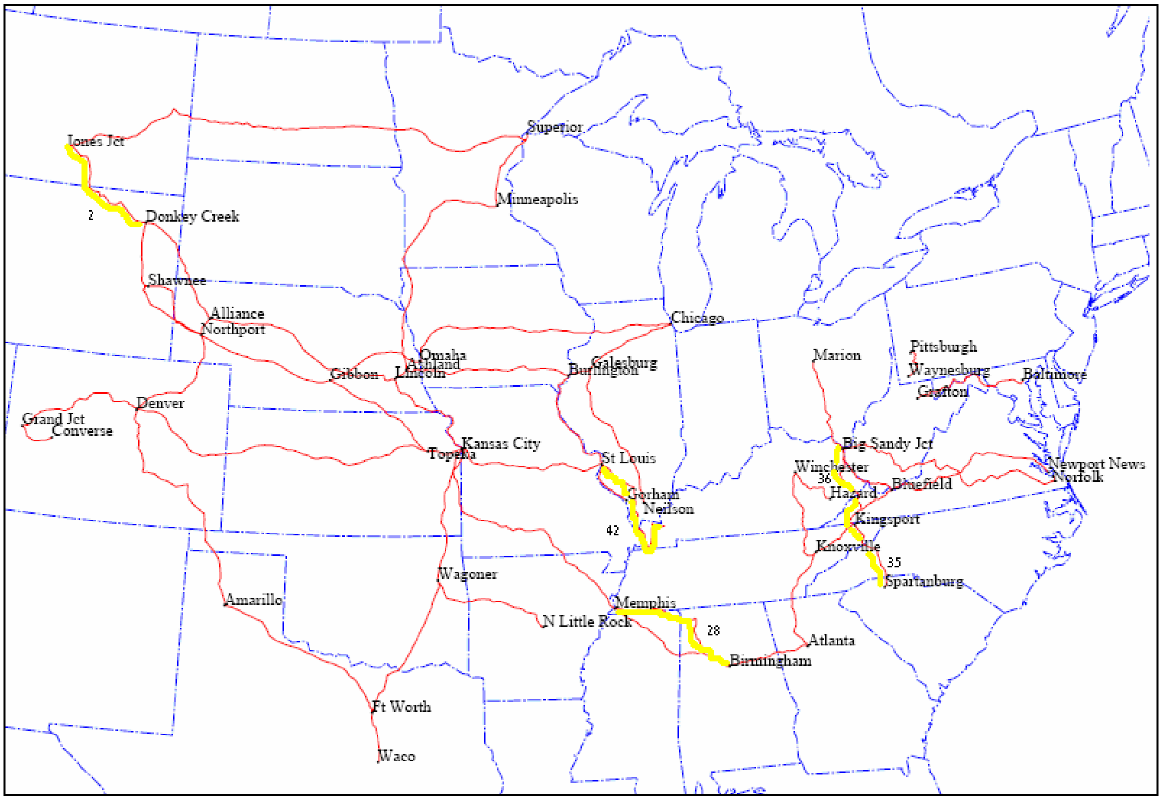

Figure 52: Routes where rail rates for coal transportation could potentially increase

Route #2 seems to be the most obvious example of a route whose rail rate might face upward pressure in the future. However, this is, more or less, an isolated occurrence for coal being transported out of the PRB in this direction. Most of the coal transported via Route #2 makes its way northwest to Montana, and then back east across North

Dakota and Minnesota to the docks on Lake Superior, where the coal is then transported via lake vessel or river barge to power plants all along the inland waterway system. But the rail rates along the eastern Montana-North Dakota-Minnesota corridor (Route #3) of BNSF are not expected to increase. The transportation of a shipment of coal via Route #2 is but one leg of a potentially long journey, and in terms of distance it is actually one of the shorter legs. Therefore, while it is possible that the delivered price of coal transported via this pathway could increase due to the higher rail rate necessitated by the incremental capacity upgrades along Route #2, it is not likely that it will increase markedly.

Outside of a handful of isolated cases, it does not seem likely that the incremental costs of adding new coal-carrying capacity will markedly increase coal transportation rates or the delivered prices of coal throughout the country. In fact, the railroad companies operating the most heavily-trafficked coal-carrying routes—e.g., those traversing the Midwest and Virginia—do not appear as though they will have to increase their rail rates in order to compensate for the incremental costs of adding capacity on these routes. This even includes the Joint Line (Route #1), which is co-owned by BNSF and UP, and is one of the primary routes responsible for transporting coal out of the PRB. Although traffic along the route is expected to reach levels higher than any other during the forecast timeframe, it appears that the huge investments made in the line, including the addition of fourth and fifth mainline trackage in some places, will not lead to higher rail transportation rates of PRB coal.

These findings should come as good news to the many electric utilities that own the scores of coal power plants whose coal is transported along the 42 selected rail routes for at least some distance on its way from mine to plant. My results, which are derived from a first-order attempt to look at the impact of increased coal transportation, indicate that the price of coal, delivered by railroads, across the country is not expected to increase even under aggressive scenarios of coal demand growth.[29]

My analysis does **not** *seem to indicate that future investments in coal transportation infrastructure and equipment will, in general, be prohibitively expensive or cause the delivered price of coal to skyrocket. While investments on certain routes may lead to an increase in rail transportation costs, this does not seem to be the case for the rail-coal transportation network as a whole.*

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[29] Of course, the results are entirely dependent on certain key assumptions that underlie my modeling and analysis methodology. Perhaps most important is the assumption that in the future coal will be transported from the same origins to the same destinations that it is today; though, I attempt to account for the changing mix of coal demanded by consumers (i.e., an increasing amount of coal coming from Western mines in the future). I have also assumed that gasification, either for electricity or hydrogen production, of Western sub-bituminous coal will be technologically feasible and that any new coal power or coal-to-hydrogen plants will be built in the same places that they exist today.

Both assumptions seem reasonable based on recent technological developments and considering the history of siting new coal power plants. But the latter assumption may not be true in all cases, as some future power plants will likely be constructed on greenfield sites. I have also assumed that coal will continue to be transported along the same major coal-carrying rail routes and corridors in the future. In other words, if coal is currently transported from origin A to destination B via route X, then it is assumed that any coal transported between locations A and B in the future will continue to be transported via route X, albeit perhaps in different quantities.

All of these key assumptions have led to the results that I have obtained. Perhaps, different mixes of coal demand, routing schemes, and power plant siting assumptions would lead to different findings. But based on my "static snapshot" modeling of coal traffic on the rail network in future years, these are not things that can be easily modified in my methodology. Therefore, the reader should acknowledge and consider these assumptions before drawing his or her own conclusions regarding the results.

Methodological Example: Route #2

The task I face is one of looking for routes where the incremental capacity cost is greater than the historical capacity cost, thus potentially leading to an increase in the rail transportation rate of coal along the route. One example of such a route is Route #2, BNSF's line leaving the Powder River Basin at Donkey Creek Junction, WY, and heading northwest to Jones Junction, MT. The results for this route and my interpretation of them will serve as an illustration of my analysis methodology.

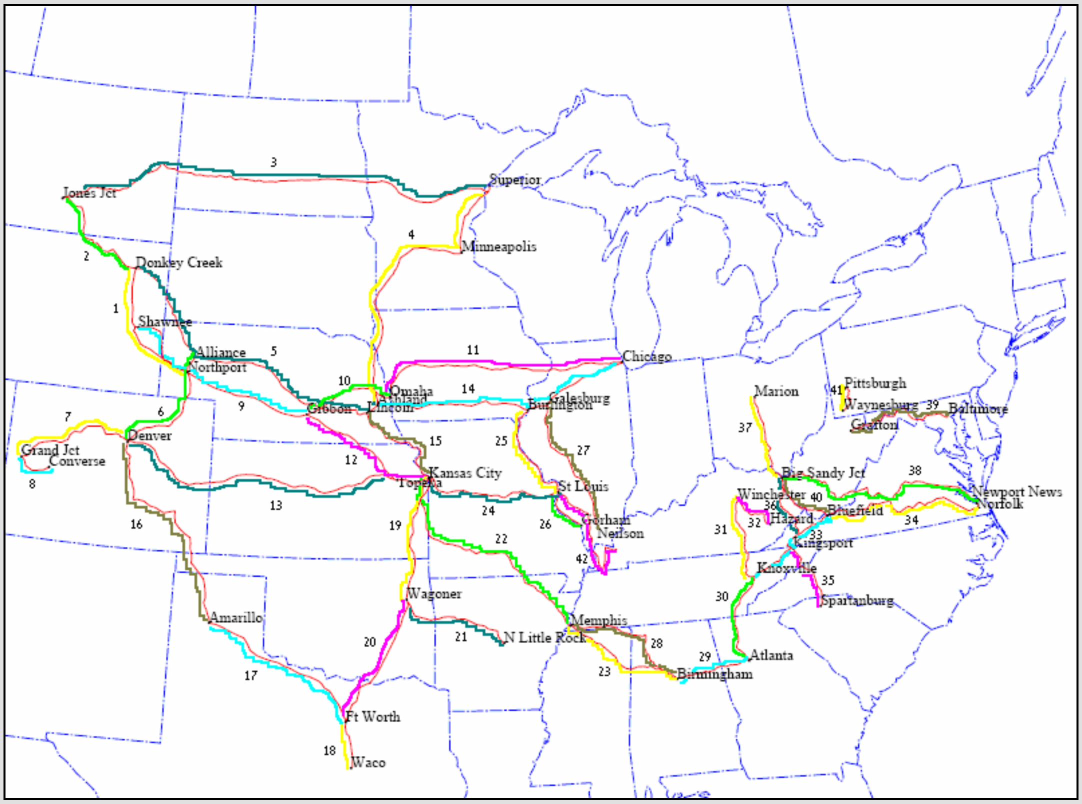

Figure 53: Major coal-carrying rail corridors subdivided into individual routes

At present, this 240-mile route is completely single tracked with high-density trackage, and CTC is fully installed along the route. Therefore, the only potential capacity-enhancing strategies that can be made along this route are to add new mainline trackage, upgrade the signaling system to PTC, and/or increase the capacity of the coal-carrying rail cars. (Of course, an upgrade to PTC along this route would probably not occur in isolation, but would rather be accompanied by similar upgrades throughout BNSF's rail network.) The following table shows the incremental cost estimates for increasing the capacity of this route up to the levels required in 2050 under each of the different scenarios of coal demand growth. Rolling stock capital costs are not included in the table, but they are similar in magnitude to capital costs for capacity enhancements.

Scenario	Discounted Present Value Cost (million $)		Levelized Cost ($/ton-mile)	
	CTC	PTC	CTC	PTC
BAU1	126 – 286	64 – 152	0.00336 – 0.01674	0.00180 – 0.00850
BAU2a	107 – 252	48 – 113	0.00329 – 0.01615	0.00148 – 0.00689
BAU2b	33 – 76	9 – 19	0.00148 – 0.00683	0.00038 – 0.00169
BAU2b+LowH2	55 – 127	21 – 47	0.00158 – 0.00735	0.00062 – 0.00287
BAU2b+HighH2	124 – 284	63 – 147	0.00252 – 0.01241	0.00133 – 0.00623

Table 19: Incremental capacity costs of increasing capacity of Route #2 to required 2050 levels
(all costs are expressed in 2005$)

What is not entirely clear from the table is that essentially four different strategies for enhancing capacity are employed and the resulting costs estimated. One is a case where CTC signal upgrades are put in place first, if there is any portion of the track that is not already CTC-signaled; after that, new mainline track is added to bring the route capacity up to the necessary level. The second case is one where the current signaling system is first upgraded to PTC; and after that, new mainline track is added to bring the route capacity up to the necessary level. The logic behind each of these strategies is the fact that signal system upgrades are generally a less expensive option for increasing capacity than the addition of new mainline tracks. Therefore, a competitive railroad wanting to increase the capacity of one of its routes would probably prefer to upgrade signals before laying new trackage. A fourth capacity enhancement measure—the utilization of higher capacity rail cars—though not immediately evident, is also wrapped up in the cost estimates. Higher capacity rail cars are able to carry more coal per carload. Thus, the total number of carloads and, ultimately, the number of trains needed to transport coal along a particular route are reduced. However, higher capacity rail cars require high-density, heavy-haul trackage to accommodate the increased weight of the cars, and high-density trackage is more expensive than conventional medium-density trackage. Several of the 42 selected routes already have high-density trackage, but some do not. Since I cannot predict whether or not high-density or medium-density trackage will be installed on a given route in the future, I set the choice of installing high-density or medium-density trackage on a route to be an input parameter in my model that is varied during Monte Carlo simulation. Therefore, the ranges of cost estimates that are reported above inherently take all four capacity enhancement strategies into account.

Route #2 is used to transport coal out of the PRB mining region. Based on the discussion in a previous section of this report, the total transportation rate for coal originating from the PRB is, on average, $0.01108/ton-mile. Applying the rule-of-thumb that one-third (1/3) of the total transportation rate is attributable to the historical capacity cost, I figure that the fixed capital (i.e., capacity) cost component of the PRB rail rate is approximately $0.00369/ton-mile. If it is assumed that rail rates are reflective of the costs of rail transportation, then I can compare the historical rate/cost to the estimated incremental capacity costs for increasing the capacity of this route up to the higher levels required in the various scenarios. It appears that in the CTC case the historical capacity cost of PRB coal falls within the range of incremental capacity costs that I estimate for each scenario. In fact, it seems that the incremental capacity cost could very likely be higher than the historical capacity cost. This might, in turn, cause the rail rate to increase (assuming that it is competitively determined), which would then probably increase the delivered price of coal being transported out of the PRB via Route #2. That being said, PRB coal is quite often transported very long distances and along several different route segments before reaching its final destination. Whether or not the delivered price of coal is pressured to increase would ultimately depend on the incremental capacity costs of each of the other routes that the same shipments of coal were transported along. If no other routes were expected to see an increase in rail rates and if Route #2 was, for instance, inconsequential in the overall coal shipment, then perhaps the delivered price of the coal leaving the PRB on these lines might not ultimately rise. To determine ultimate impact incremental capacity costs have on rail rates, the entire logistics chain of a given coal shipment must be considered. This can only be done to a limited extent by my analysis methodology.

Now, consider another capacity-enhancing strategy, PTC signal upgrades. By my estimates, it appears that installing PTC instead of CTC along Route #2 could save BNSF a fairly significant amount of money under all scenarios of coal demand growth. Even after accounting for the costs associated with PTC, the capacity benefits and the resultant savings generated from a reduced need to build new mainline trackage lead to lower costs in the PTC case under all scenarios. Moreover, it does not appear as conclusive that the rail rate would increase due to the incremental capacity costs in the PTC case. While the historical capacity cost of $0.00369/ton-mile falls within the range of incremental capacity cost estimates for three of the five coal demand growth scenarios (BAU1, BAU2a, BAU2+HighH2), it is not clear that the incremental cost would be greater than the historical cost, thereby causing the rail rate to increase. Moreover, the lower coal demands of the BAU2b and BAU2+LowH2 scenarios, resulting from the building of and repowering to less coal-intensive IGCC power plants, appear to reduce the incremental capacity costs for Route #2 to levels low enough that there is no risk of the rail rate increasing. In sum, opting for PTC signal upgrades rather than CTC upgrades could be an effective means of enhancing the coal-carrying capacity of Route #2 without contributing to an increase in the rail transportation rate of the coal being shipped along this route. Installing CTC instead of PTC, on the other hand, seems like it would cause the rail rate to increase.

Comparison to Costs of Coal Power and Coal-to-Hydrogen Plants

Also shown in the previous cost summary table are the capital costs that have been estimated for the new coal power and coal-to-hydrogen plants that are projected to be built under each of the various scenarios and that directly contribute to the growth in coal demand. Plant costs are based on assumptions from the EIA's NEMS model documentation (EIA, 2006o) and personal communication with Simbeck (2006). The table below documents these assumptions for each type of plant. For simplicity, the plant capacity required for coal-to-hydrogen production is modeled as an enlargement of the IGCC capacity required for coal-to-electricity production. This is a generalized approximation, of course. While IGCC and coal-to-hydrogen gasification plants share many similarities, they are different in several key ways. However, I have simply modeled the costs of IGCC and coal-to-hydrogen plants as being roughly the same. Moreover, I have assumed that the capital cost of repowering an old PC plant to a new IGCC plant is approximately 80% of the capital cost of a new IGCC plant built on a greenfield site. The 20% cost savings incurred can be attributed to some of the old PC plant equipment that can be recycled and incorporated into the new IGCC plant.

Year	Capital cost of pulverized coal plant ($/kW)	Capital cost of IGCC coal plant ($/kW)	Capital cost of repowering PC plant to IGCC ($/kW)	Capital cost of coal-to-H2 plant ($/kW$_{th}$)
2005	1249	1443	1154	722
2010	1233	1415	1132	708
2015	1217	1386	1109	693
2020	1199	1340	1072	670
2025	1184	1265	1012	633
2030	1171	1190	952	595
2035	1171	1190	952	595
2040	1171	1190	952	595
2045	1171	1190	952	595
2050	1171	1190	952	595

Table 20: Assumptions for coal power and coal-to-hydrogen plant capital costs

The differences in costs between the various scenarios are particularly noteworthy. For instance, the total incremental capacity costs are lower in the BAU2a scenario than they are in the BAU1 scenario: a $0.37 – $0.89 billion difference in the CTC case and a $0.30 – $0.70 billion difference in the PTC case. If incremental rolling stock costs are also included, then the comparable differences are $0.72 – $1.42 billion in the CTC case and $0.66 – $1.32 billion in the PTC case. These differences in incremental rail infrastructure and equipment costs can be compared to the corresponding differences in plant costs. Plant capital costs in the BAU2a scenario are roughly $5 billion greater than costs in the BAU1 scenario. In other words, if the only coal power plants that the U.S. were to build from now to 2050 were IGCC, the capital costs of doing so would be on the order of $5 billion greater than if the only plants to be built were PC. That being said, the reduction in coal demand would mean that some $0.37 – $1.32 billion less would need to be spent on the rail infrastructure network. So in terms of capital costs, an IGCC future would cost more than a PC future, which is probably no surprise. But the total cost to the railroads would be reduced by the savings incurred via reduced rail infrastructure and equipment investment. This is likely a result that few have considered in doing their analyses of the future costs of coal power plants. Of course, these comparisons fail to take into account the variable costs of rail transportation and electricity generation, which is an important cost component in both areas. In fact, the variable costs of rail-coal transportation tend to be a larger component of the total cost than the capital costs, whereas just the opposite is generally true for coal power plants. Therefore, I might speculate that the total cost to the economy of the IGCC future (BAU2a) considering both the increased cost of IGCC power plants and the cost savings achieved from reduced coal transportation, would be even smaller than I estimate here. In the extreme case, it is possible that the increased cost of building a fleet of IGCC plants vs. PC plants could be more than made up for by the reduced need to invest in rail-coal transportation infrastructure and equipment. Based on all of my assumptions, it is difficult to make this claim for certain. Though, it is definitely worth noting that the cost increases and cost savings associated with an IGCC future, although they accrue to different parties, are roughly on the same order of magnitude as each other. As for the other scenarios (BAU2b, BAU2+LowH2, and BAU2+HighH2), the total capital costs of plants greatly overshadows the costs of rail infrastructure and equipment investments. This is due to the fact that all old PC plants are assumed to be repowered to IGCC, which is quite an expensive endeavor.

VII. CONCLUSIONS & FUTURE WORK

This project is the first attempt in several decades to look at the costs of increasing the coal-carrying capacity of the nation's rail network. Because of the scope of the project, the long timeframes considered, and temporal and financial constraints, I decided to take a fairly high-level approach to analyzing the problem. In this light, I believe that my methods, assumptions, and results are transparent, and should be easily replicable by me, or anyone else, in the future.

Key Findings of This Study

- I have developed a range of scenarios for future coal use in the United States for power generation and hydrogen production. Over the next few decades, major increases in U.S. coal demand are likely, resulting in a significant increase in coal transportation, particularly by rail.
- Future U.S. coal consumption and transportation demands can be moderately reduced if all new coal power plant builds from today onwards are integrated gasification combined cycle (IGCC) plants instead of modern pulverized coal (PC) plants.
- Much greater reductions in coal demand can be achieved if, in addition to building only new IGCC coal plants, all currently operating conventional PC plants are gradually retrofitted/repowered to IGCC over time.
- If a hydrogen economy ever comes to fruition in the U.S. and if all hydrogen is produced via coal gasification, then, depending on the particular scenario, the demand for coal consumption and transportation in 2050 could increase by 0 – 50% compared to a case with no hydrogen.
- If we retrofit/repower old PC plants with IGCC, while simultaneously implementing hydrogen vehicles that achieve a 50% share of the entire light-duty vehicle and bus market by 2050, the overall coal demand in 2050 is comparable to a case with no hydrogen and all PC plants.
- The capital costs of implementing an IGCC future will be higher than the costs of a PC future. But since coal transportation demands will be lower in an IGCC future, a share of the higher power plant capital costs will be offset by the reduced capital investments that will need to be made by the railroads.
- I identified 42 key rail corridors which currently account for about 80% of all coal transport by rail. Depending on the particular scenario, future coal transport along

these corridors is expected to increase 35 – 95% by 2050 compared to the present coal tonnage carried.

- The increased demand for rail transportation of coal might require capital investments by the railroads on the order of \$1.5 – \$11.0 billion (in discounted 2005\$) from 2004 to 2050, depending on the particular scenario and how the accounting is done. This includes investments in new mainline trackage, upgraded signaling systems, and new rolling stock (locomotives and coal-rail cars).
- While these costs are significant, it does not seem likely that delivered prices of coal throughout the country will increase as a result of adding new rail capacity for the purpose of transporting coal.
- The railroad companies operating the most heavily-trafficked coal-carrying routes—e.g., those traversing the Midwest and Virginia—do not appear as though they will be forced to increase their rail rates in order to compensate for the incremental costs of adding capacity on these routes. This includes the Joint Line, co-owned by BNSF and UP, that is one of the primary routes responsible for transporting coal out of the Powder River Basin (PRB) in Wyoming. Although traffic along the route is expected to reach levels higher than any other during the forecast timeframe, it appears that the huge investments made to increase the capacity of the line, including the addition of fourth and fifth mainline track in some places, will not lead to significantly higher rail transportation rates of PRB coal. And if rail transportation rates for shipping coal do not increase, then the delivered prices of coal should not increase either.

Future Work

Future iterations of my modeling approach might include some important modifications. For example, instead of just estimating the incremental costs of capacity and rolling stock, it might also be insightful to consider fuel, labor, maintenance, and other variable costs that significantly contribute to the total cost of rail transportation. This would allow one to make a more decisive conclusion regarding the effects that capacity-enhancing infrastructure investments and equipment might have on rail rates for coal. Another modification might be to alter the important assumption that in the future coal will be transported from the same origins to the same destinations, and along the same routes, that it is today—i.e., coal plants will be sited in the same places where they are now, and the same rail routes will be used to transport coal from mines to plants.

Perhaps, one could vary this assumption by considering new coal plant sites, alternative train routing schemes, or even the presence of new routes. In addition, one of the fundamental assumptions of this study is that gasification, either for electricity or hydrogen production, of Western sub-bituminous coal will be technologically feasible in the future. This assumption could be altered by assuming, in the coal demand projection phase of the project, that Western coal will not be amenable to coal gasification and, thus, Eastern coal becomes more attractive and experiences higher demand growth rates than Western coal. The modification of these important assumptions could very well alter the results I have obtained.

The methodology I have developed could also be used to look at commodities other than coal. For example, one might be interested in rail transportation of ethanol, which has recently been getting a significant amount of attention due to its attractiveness as an alternative vehicle fuel. Of course, my analysis, and any future analysis that is based on it, only begins to fill in the knowledge gap regarding the adequacy of the nation's railroads to meet increasing demands for coal and non-coal commodities. If one were truly interested in enhancing the capacity of a particular rail route, a detailed engineering-economic study would need to be carried out, considering route-specific characteristics and constraints to adding capacity. If it were found that competitively determined rail rates along the route might increase as a result of the investments, then a detailed coal pricing model would probably need to be employed to get a feel for how the higher rail rates might affect the delivered prices of coal for any shipments that use the route. This level of detail is outside the scope of the present analysis, but future studies should consider going into such detail, if circumstances warrant it.

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IX. APPENDICES

A. *Freight rail projection maps*

A.1 Modeled annual tonnage flows on the rail network in 2004
A.2 Projected annual tonnage flows on the rail network in 2030, Scenario BAU1
A.3 Projected annual tonnage flows on the rail network in 2050, Scenario BAU1
A.4 Projected annual tonnage flows on the rail network in 2030, Scenario BAU2a
A.5 Projected annual tonnage flows on the rail network in 2050, Scenario BAU2a
A.6 Projected annual tonnage flows on the rail network in 2030, Scenario BAU2b
A.7 Projected annual tonnage flows on the rail network in 2050, Scenario BAU2b
A.8 Projected annual tonnage flows on the rail network in 2030, Scenario BAU2b+LowH2
A.9 Projected annual tonnage flows on the rail network in 2050, Scenario BAU2b+LowH2
A.10 Projected annual tonnage flows on the rail network in 2030, Scenario BAU2b+HighH2
A.11 Projected annual tonnage flows on the rail network in 2050, Scenario BAU2b+HighH2

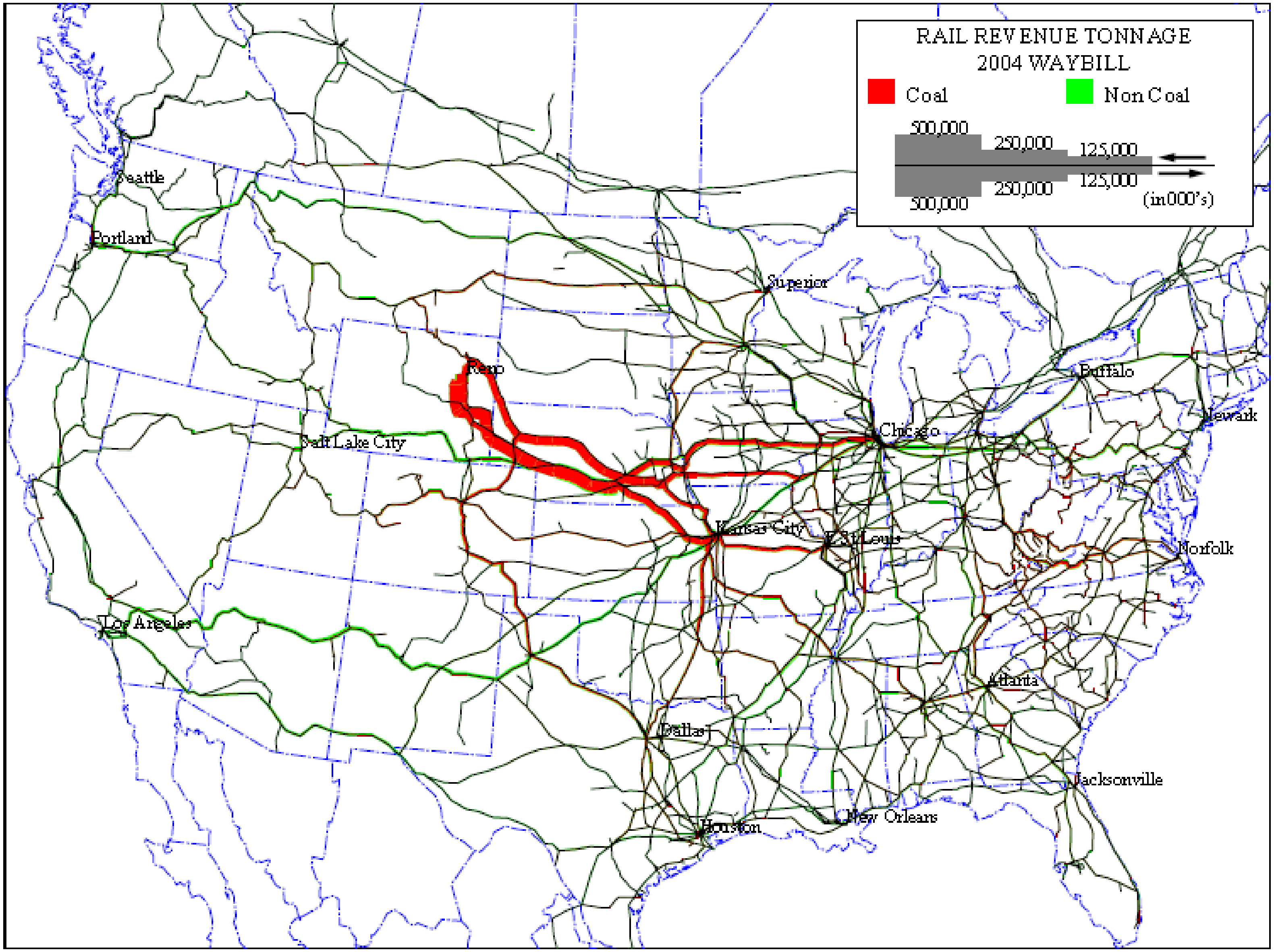
B. *Information and assumptions collected on each major coal carrying rail route*

B.1 Map of major coal carrying rail routes analyzed in this study
B.2 Routing information for each major coal carrying rail route
B.3 Route specific information for each major coal carrying rail route

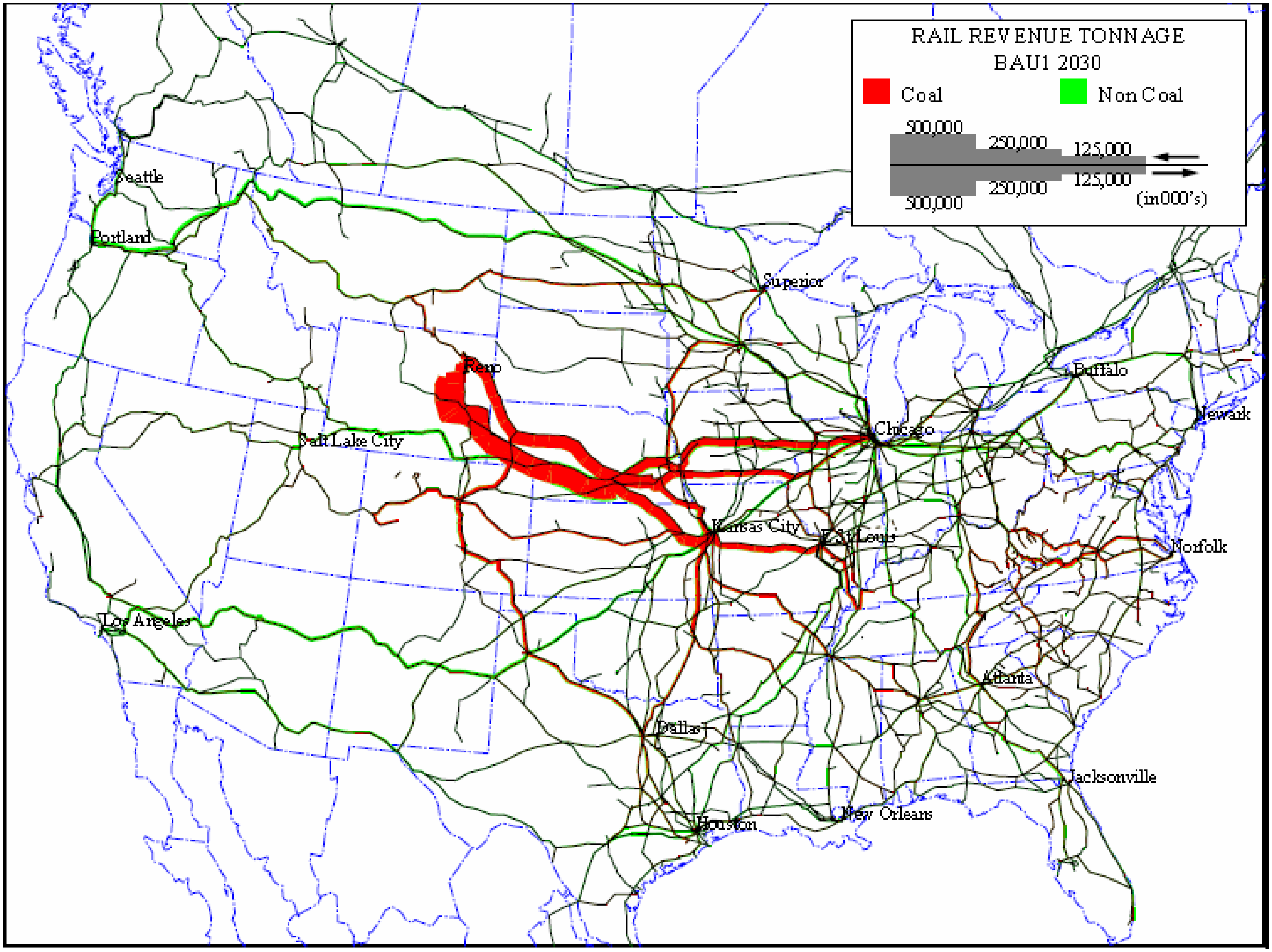
C. *Incremental cost estimates*

C.1 Levelized incremental capacity costs for each route, all scenarios, CTC case
C.2 Discounted present values of incremental capacity costs for each route, all scenarios, CTC case
C.3 Levelized incremental capacity costs for each route, all scenarios, PTC case
C.4 Discounted present values of incremental capacity costs for each route, all scenarios, PTC case

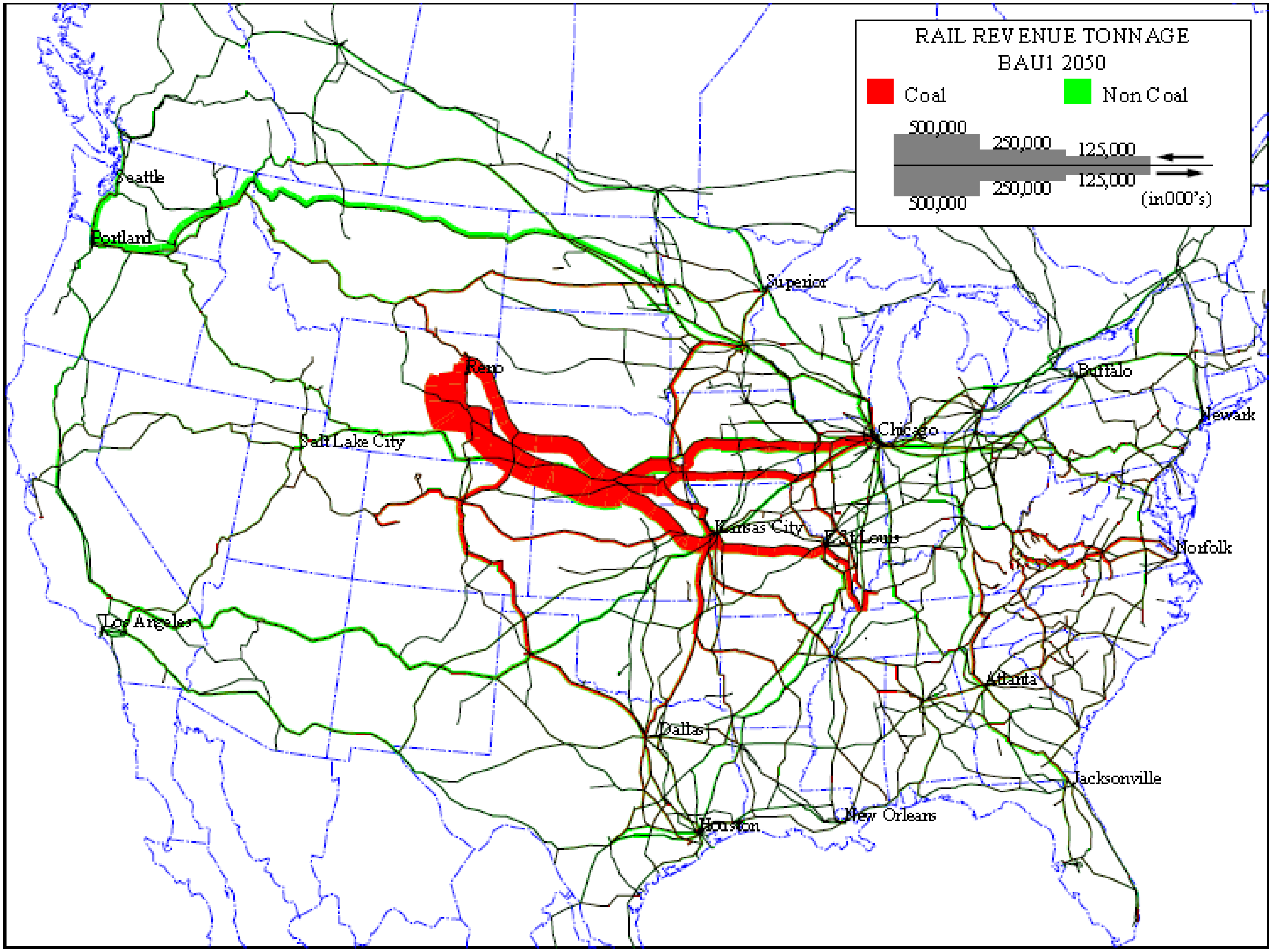
D. *Corollary on Coal-to-Liquid Synfuels Production*



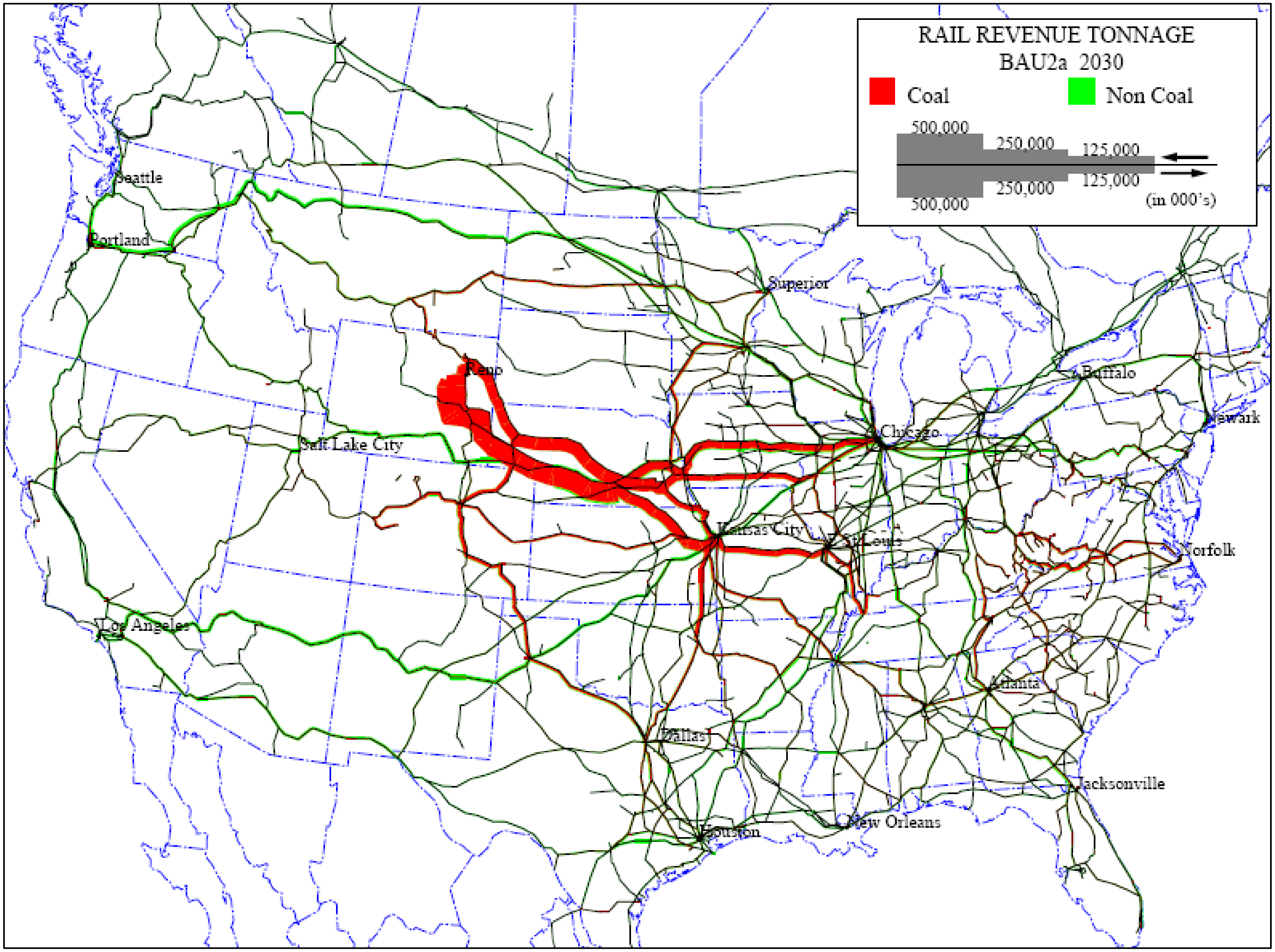
A.1 Modeled annual tonnage flows on the rail network in 2004



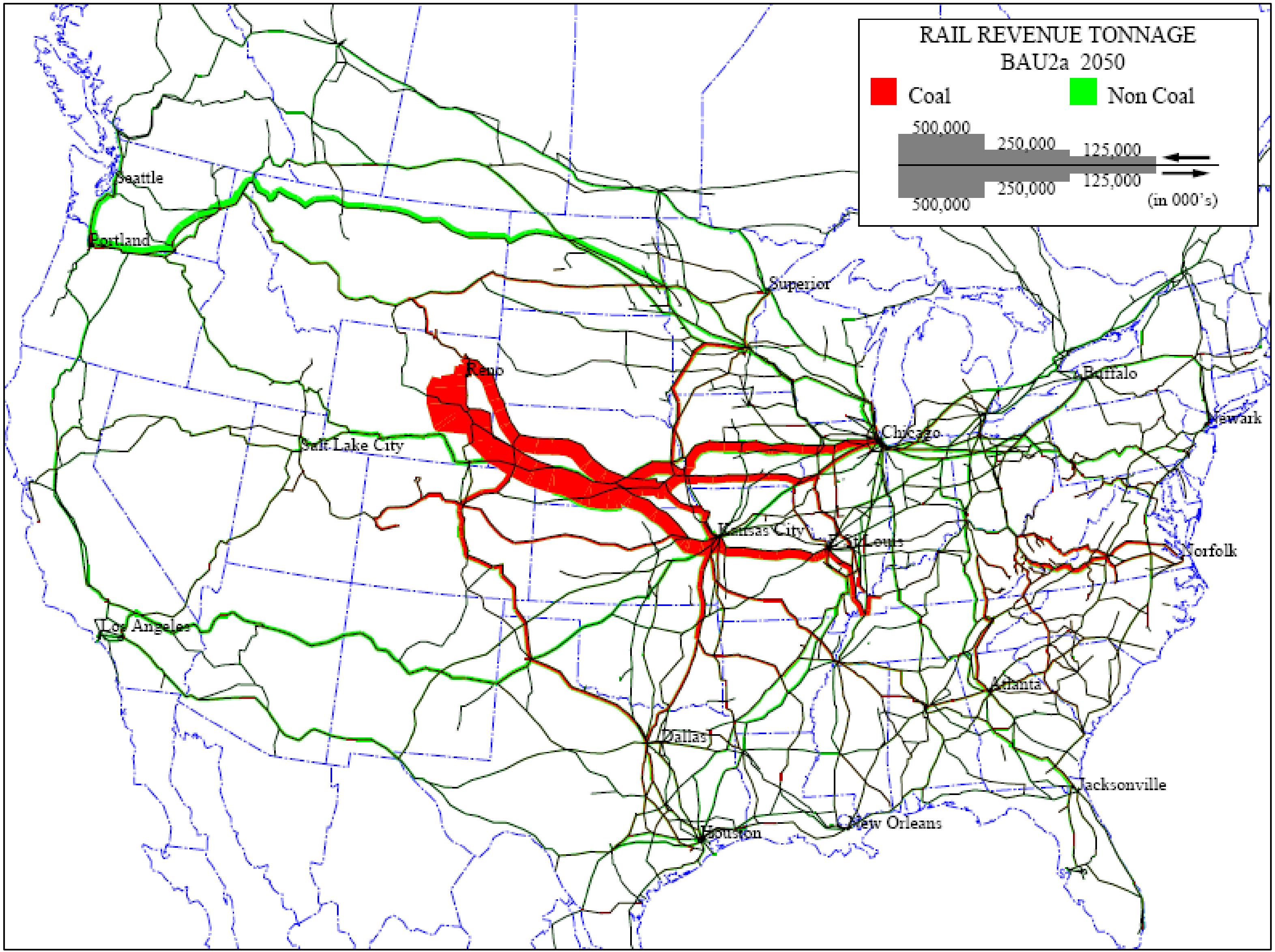
A.2 Projected annual tonnage flows on the rail network in 2030, Scenario BAU1



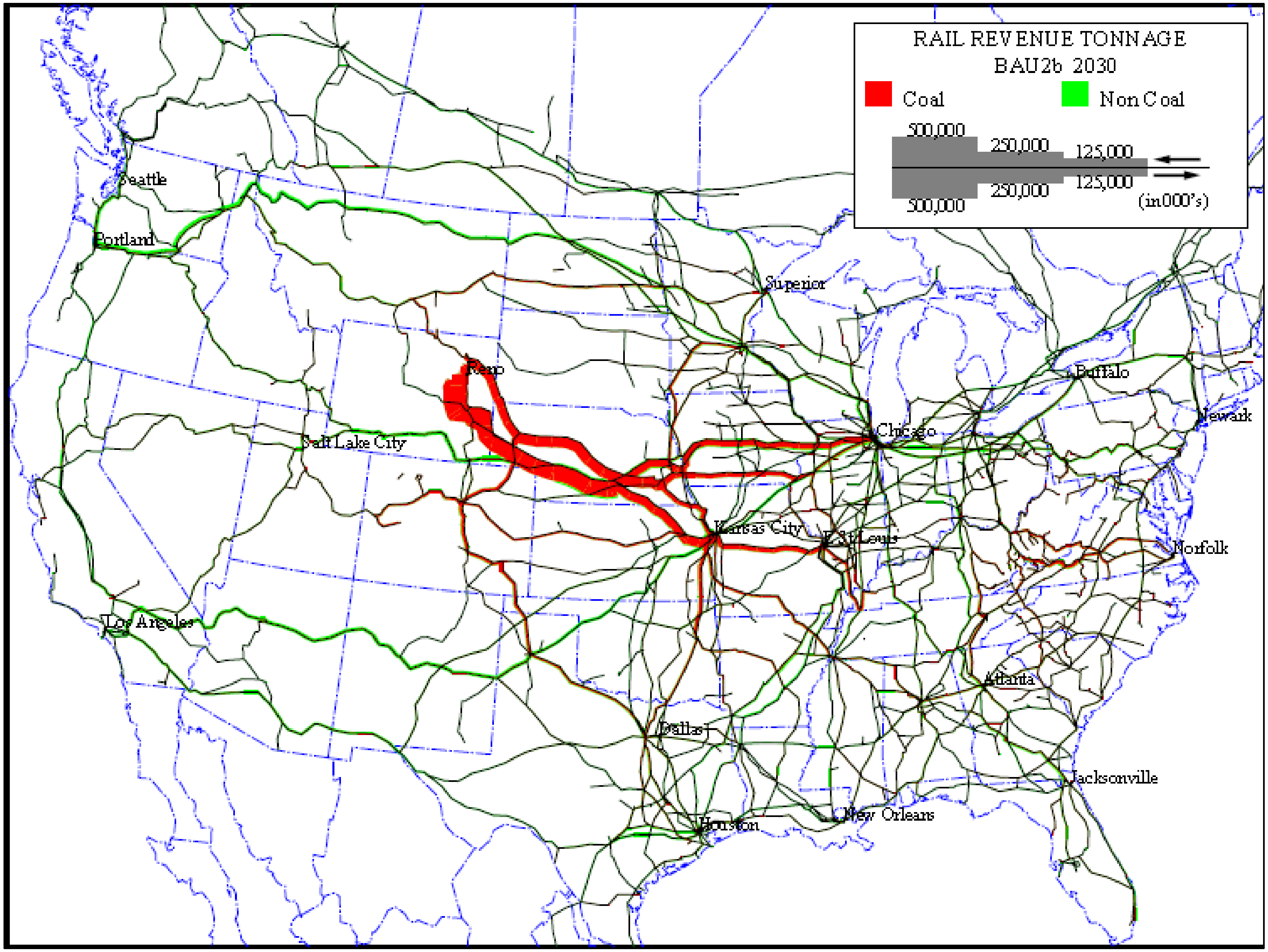
A.3 Projected annual tonnage flows on the rail network in 2050, Scenario BAU1



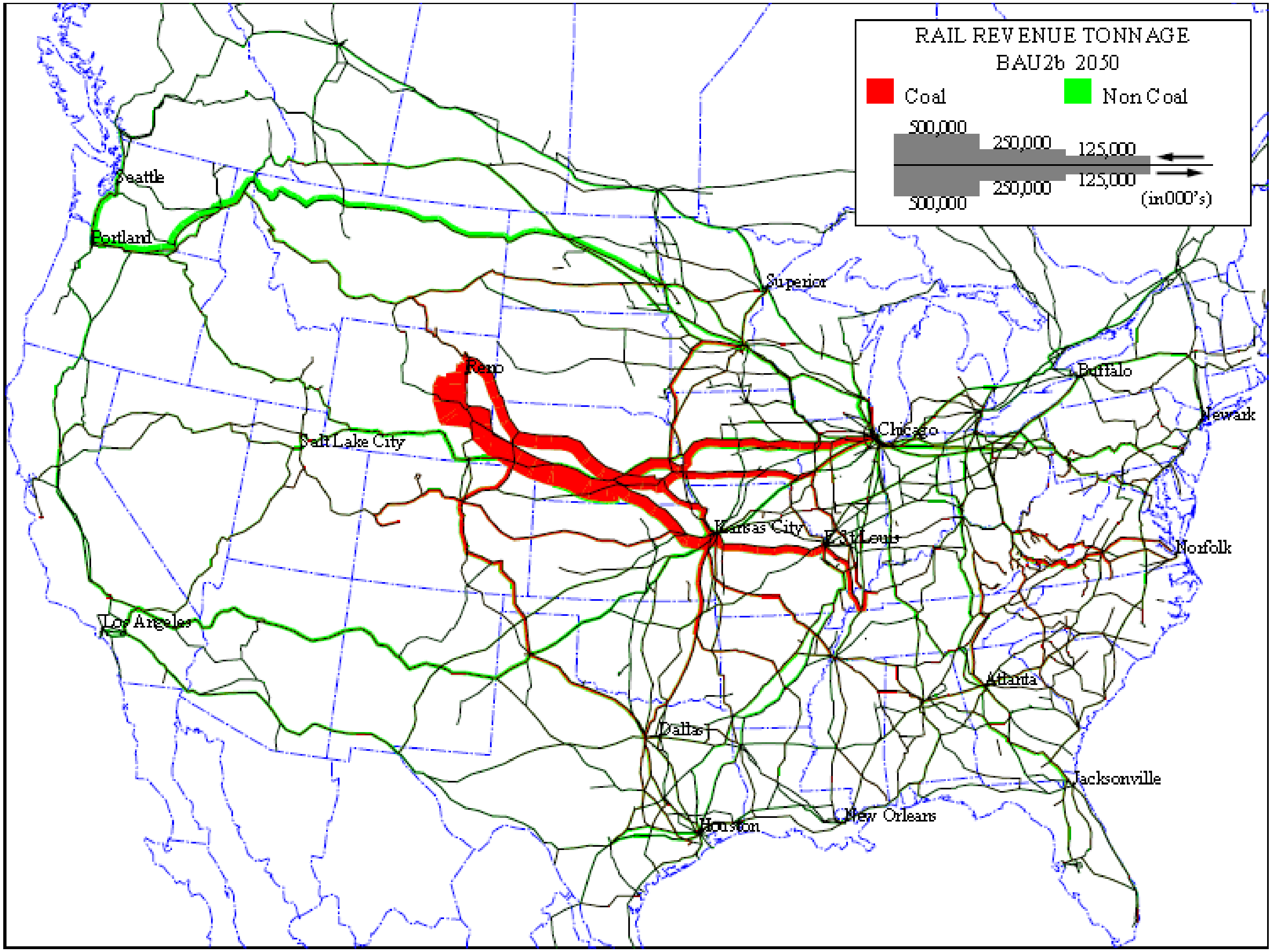
A.4 Projected annual tonnage flows on the rail network in 2030, Scenario BAU2a



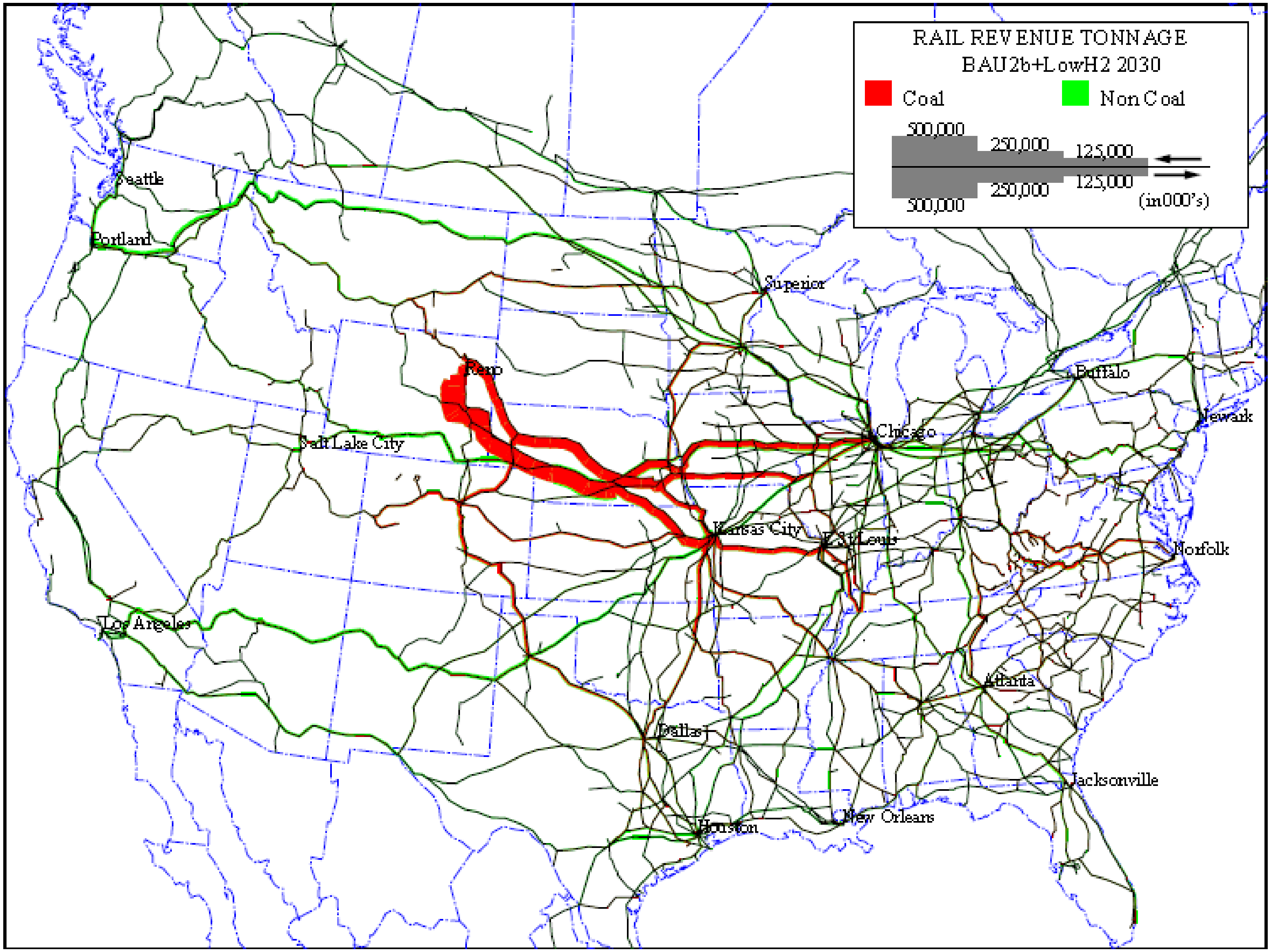
A.5 Projected annual tonnage flows on the rail network in 2050, Scenario BAU2a



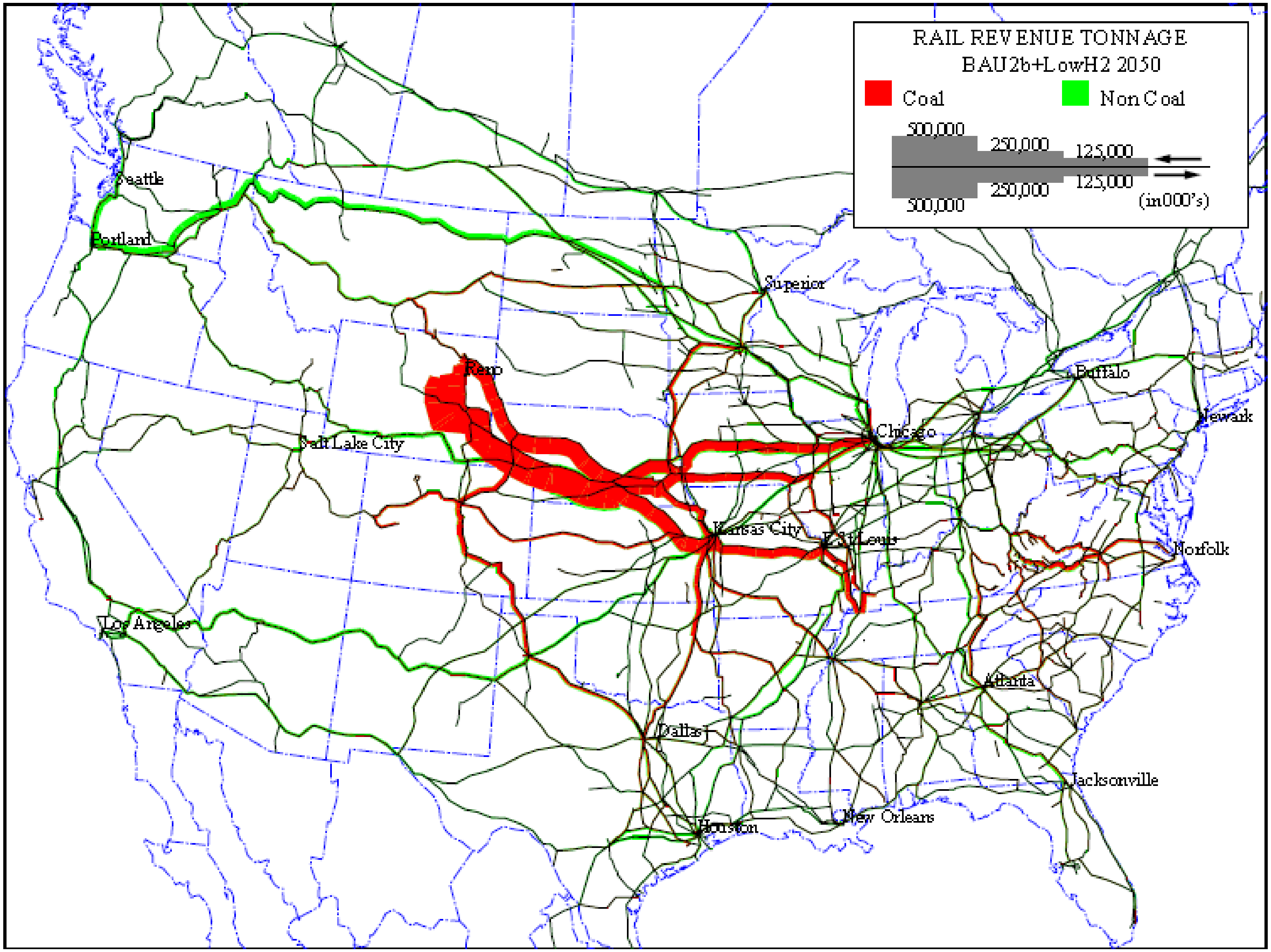
A.6 Projected annual tonnage flows on the rail network in 2030, Scenario BAU2b



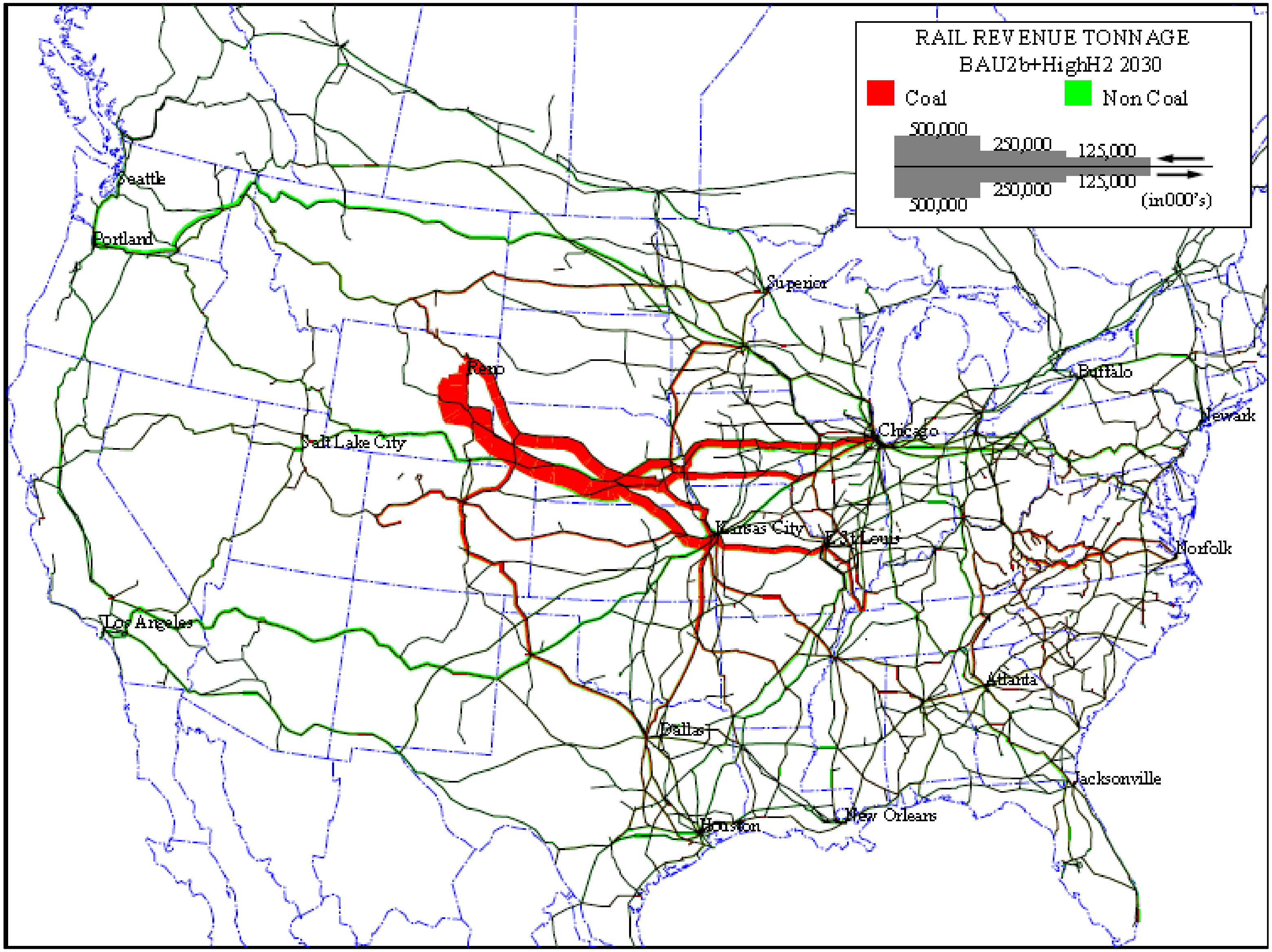
A.7 Projected annual tonnage flows on the rail network in 2050, Scenario BAU2b



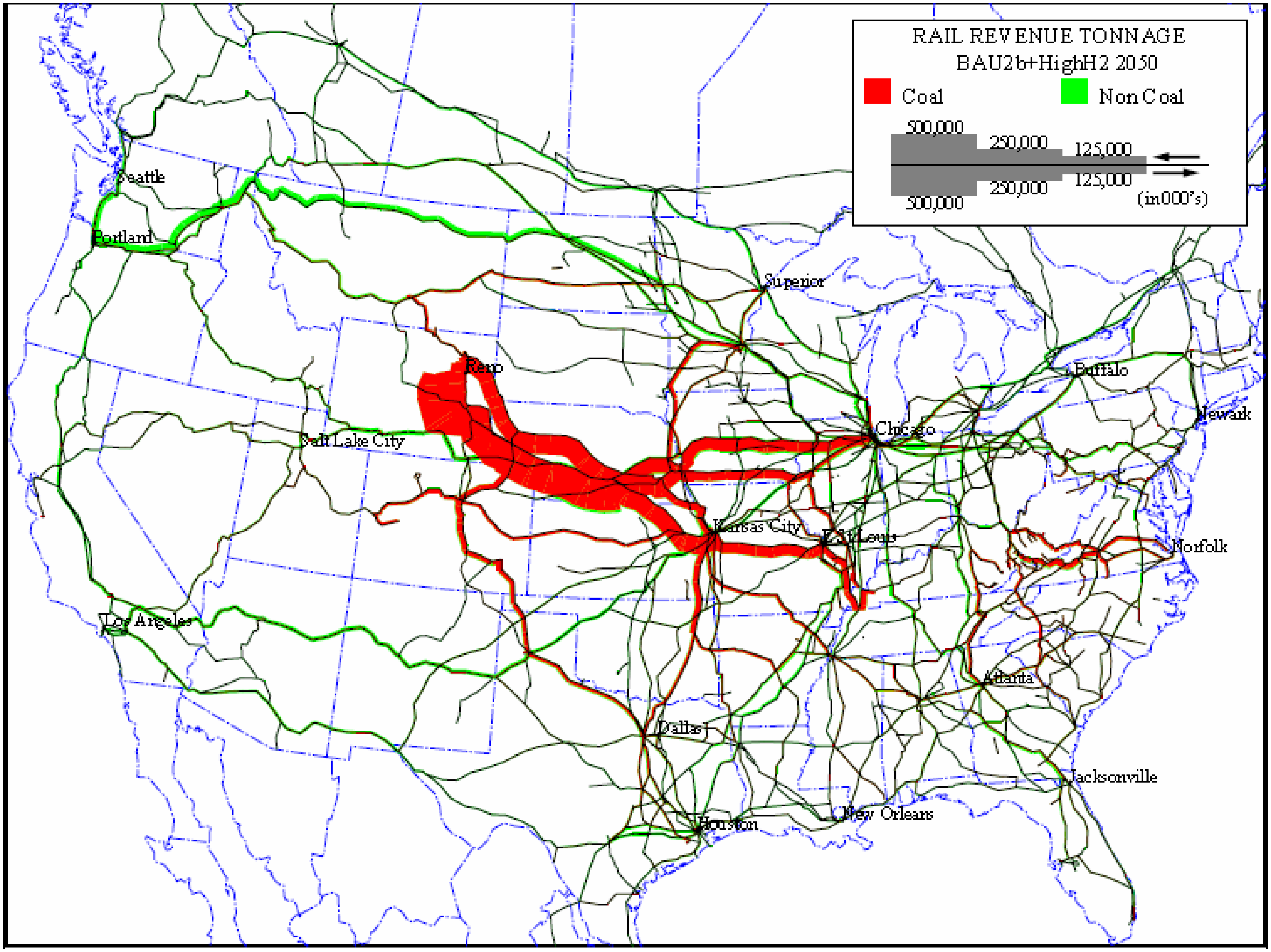
A.8 Projected annual tonnage flows on the rail network in 2030, Scenario BAU2b+LowH2



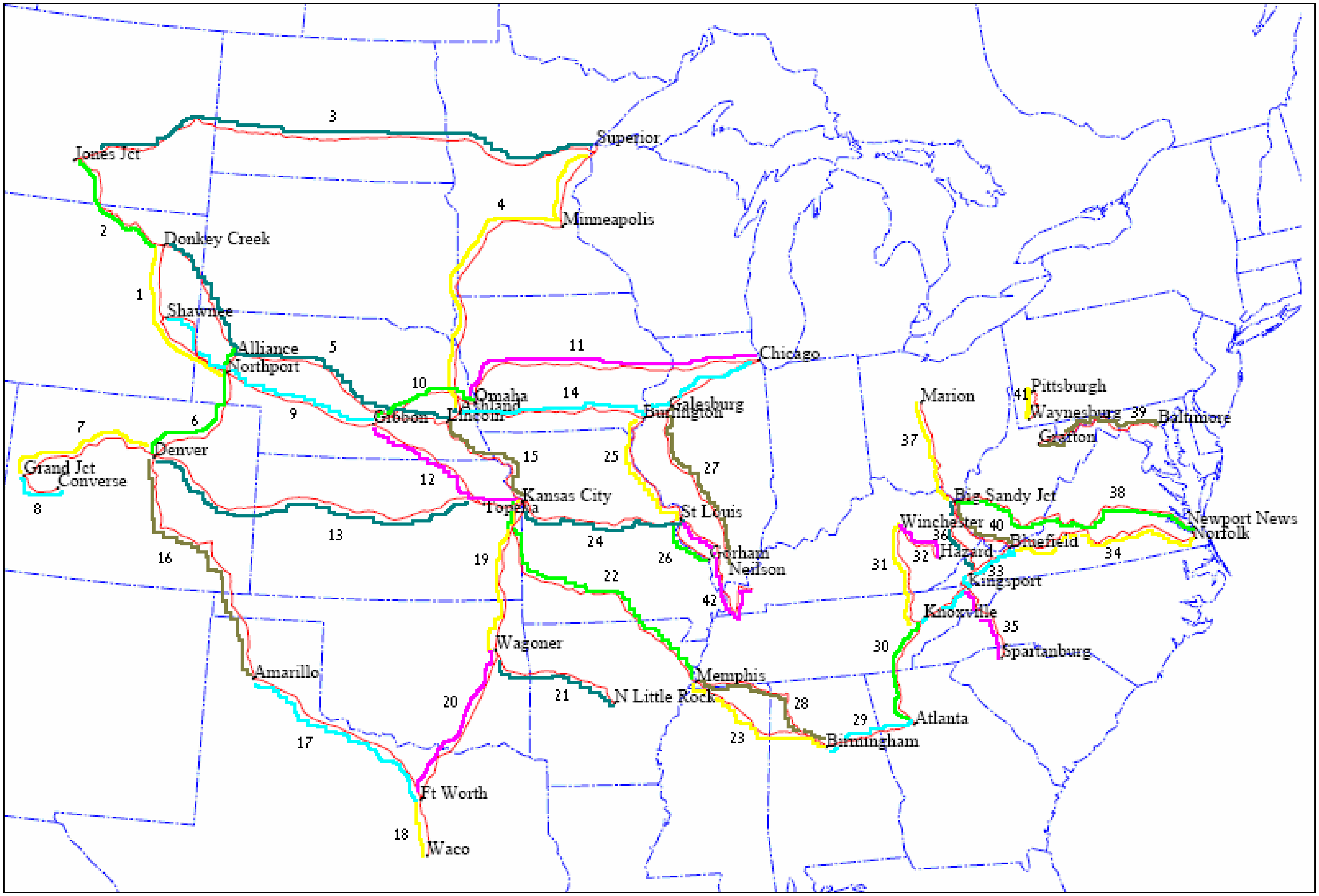
A.9 Projected annual tonnage flows on the rail network in 2050, Scenario BAU2b+LowH2



A.10 Projected annual tonnage flows on the rail network in 2030, Scenario BAU2b+HighH2



A.11 Projected annual tonnage flows on the rail network in 2050, Scenario BAU2b+HighH2



B.1 Map of major coal carrying rail routes analyzed in this study

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B.2 Routing information for each major coal carrying rail route

UCD-ID	Railroad	Start	End	Route
1	BNSF/UP	Northport, NE	Donkey Creek Junction, WY	Northport, NE => Guernsey, WY => Wendover, WY => Bridger Jct, WY => Shawnee Jct, WY => Bill, WY => Reno, WY => Donkey Creek Jct, WY
2	BNSF	Donkey Creek Junction, WY	Jones Junction, MT	Donkey Creek Junction, WY => Gillette, WY => Jones Junction, MT
3	BNSF	Jones Junction, MT	Superior, WI	Jones Jct, MT => Glendive, MT => Mandan, ND => Staples, MN => Superior, WI
4	BNSF	Ashland, NE	Superior, WI	Ashland, NE => Fremont, NE => Sioux City, IA => Willmar, MN => Minneapolis, MN => Hinckley, MN => Superior, WI
5	BNSF	Donkey Creek Junction, WY	Ashland, NE	Donkey Creek Jct, WY => Edgemont, SD => Alliance, NE => Ravenna, NE => Lincoln, NE => Ashland, NE
6	BNSF	Alliance, NE	Denver, CO	Alliance, NE => Northport, NE => Sterling, CO => Denver, CO
7	UP	Denver, CO	Grand Junction, CO	Denver, CO => Bond, CO => Grand Junction, CO
8	UP	Grand Junction, CO	Converse, CO	Grand Junction, CO => Delta, CO => Converse, CO
9	UP	Shawnee Junction, WY	Gibbon, NE	Shawnee Junction, WY => South Morrill, NE => O'Fallons, NE => Gibbon, NE
10	UP	Gibbon, NE	Omaha, NE	Gibbon, NE => Grand Island, NE => Columbus, NE => Fremont, NE => Omaha, NE
11	UP	Omaha, NE	Chicago, IL	Omaha, NE => Council Bluffs, IA => Missouri Valley, IA => Grand Junction, IA => Marshalltown, IA => Clinton, IA => Nelson, IL => De Kalb, IL => Chicago, IL
12	UP	Gibbon, NE	Kansas City, MO	Gibbon, NE => Hastings, NE => Marysville, KS => Topeka, KS => Kansas City, MO
13	UP	Denver, CO	Topeka, KS	Denver, CO => Sharon Springs, KS => Oakley, KS => Salina, KS => Topeka, KS
14	BNSF	Ashland, NE	Chicago, IL	Ashland, NE => Oreapolis, NE => Pacific Junction, IA => Creston, IA => Burlington, IA => Galesburg, IL => Mendota, IL => Montgomery, IL => Chicago, IL
15	BNSF	Lincoln, NE	Kansas City, MO	Lincoln, NE => Napier, MO => Kansas City, MO
16	BNSF/UP	Denver, CO	Amarillo, TX	Denver, CO => Pueblo, CO => Las Animas Junction, CO => Boise City, OK => Stratford, TX => Amarillo, TX

17	BNSF	Amarillo, TX	Fort Worth, TX	Amarillo, TX => Wichita Falls, TX => Fort Worth, TX
18	UP	Fort Worth, TX	Waco, TX	Fort Worth, TX => Waco, TX
19	UP	Kansas City, MO	Wagoner, OK	Kansas City, MO => Paola, KS => Chetopa, KS => Wagoner, OK
20	UP	Wagoner, OK	Fort Worth, TX	Wagoner, OK => McAlester, TX => Fort Worth, TX
21	UP	Wagoner, OK	North Little Rock, AR	Wagoner, OK => Van Buren, AR => North Little Rock, AR
22	BNSF	Kansas City, MO	Memphis, TN	Kansas City, MO => Paola, KS => Henson, KS => Fontana, KS => Edward, MO => Springfield, MO => Thayer, MO => Hoxie, AR => Memphis, TN
23	BNSF	Memphis, TN	Birmingham, AL	Memphis, TN => Amory, MS => Birmingham, AL
24	UP	Kansas City, MO	St. Louis, MO	Kansas City, MO => Pleasant Hill, MO => Jefferson, City, MO => St. Louis, MO
25	BNSF	Burlington, IA	St. Louis, MO	Burlington, IA => Ft. Madison, IA => Mark, MO => Hannibal, MO => Machens, MO => St. Louis, MO
26	UP	East St. Louis, IL	Gorham, IL	East St. Louis, IL => Fults, IL => Gorham, IL
27	BNSF	Galesburg, IL	Neilson, IL	Galesburg, IL => Bushnell, IL => Beardstown, IL => Girard, IL => Centralia, IL => Neilson, IL
28	NS	Memphis, TN	Birmingham, AL	Memphis, TN => Middleton, TN => Burnsville, MS => Norala Jct, AL => Russellville, AL => Jasper, AL => Birmingham, AL
29	NS	Birmingham, AL	Atlanta, GA	Birmingham, AL => Anniston, AL => Tallapoosa, GA => Atlanta, GA
30	CSX	Atlanta, GA	Knoxville, TN	Atlanta, GA => Chatsworth, GA => Etowah, TN => Vonore, TN => Knoxville, TN
31	CSX	Knoxville, TN	Winchester, KY	Knoxville, TN => La Follette, TN => Hyde, TN => Corbin, KY => Winchester, KY
32	CSX	Winchester, KY	Hazard, KY	Winchester, KY => Irvine, KY => Jackson, KY => Hazard, KY
33	NS	Knoxville, TN	Bluefield, VA	Knoxville, TN => Morristown, TN => Bulls Gap, TN => Church Hill, TN => Dungannon, VA => Cedar Bluff, VA => Bluefield, VA
34	NS	Bluefield, VA	Norfolk, VA	Bluefield, VA => Belspring, VA => Shawsville, VA => Roanoke, VA => Lynchburg, VA => Brookneal, VA => Burkeville, VA => Jack, VA => Suffolk, VA => Norfolk, VA
35	CSX	Kingsport, TN	Spartanburg, SC	Kingsport, TN => Johnson City, TN => Erwin, TN => Green Mountain, NC => Bostic, NC => Chesnee, SC => Spartanburg, SC
36	CSX	Kingsport, TN	Big Sandy Junction, KY	Kingsport, TN => Dungannon, VA => St. Paul, VA => Haysi, VA => Elkhorn City, KY => Beaver Junction, KY => Paintsville, KY => Louisa, KY => Big Sandy Junction, KY

37	NS	Big Sandy Junction, KY	Marion, OH	Big Sandy Junction, KY => Ashland, KY => Limeville, KY => Minford, OH => Vauces, OH => Hopetown, OH => Ashville, OH => Columbus, OH => Marion, OH
38	CSX	Big Sandy Junction, KY	Newport News, VA	Big Sandy Junction, KY => Barboursville, WV => Charleston, WV => Montgomery, WV => Meadow Creek, WV => Hinton, WV => Covington, VA => Clifton Forge, VA => Buchanan, VA => Lynchburg, VA => Gladstone, VA => Richmond, VA => Williamsburg, VA => Newport News, VA
39	CSX	Grafton, WV	Baltimore, MD	Grafton, WV => Cumberland, MD => Harpers Ferry, WV => Weverton, MD => Point of Rocks, MD => Woodbine, MD => Baltimore, MD
40	NS	Big Sandy Junction, KY	Bluefield, VA	Big Sandy Junction, KY => Fort Gay, WV => Iaeger, WV => Kimball, WV => Bluefield, VA
41	NS/CSX	Waynesburg, PA	Pittsburgh, PA	Waynesburg, PA => Pittsburgh, PA
42	CN	St. Louis, MO	Calvert City, KY	St. Louis, MO => Belleville, IL => Du Quoin, IL => Carbondale, IL => Fulton, KY => Chiles, KY => Paducah, KY => Calvert City

B.3 Route specific information for each major coal carrying rail route

UCD-ID	Avg Timetable Speed (mph)	Avg Number of Mainline Tracks	Track Type/Quality	Proportion of CTC	Proportion of Flat Terrain	Proportion of Rolling-Hilly Terrain	Proportion of Mountainous Terrain
1	38.0	1.84	MD	0.972	0.50	0.25	0.25
2	38.0	1.00	HD	1.000	0.00	0.50	0.50
3	38.0	1.08	MD	0.154	0.60	0.40	0.00
4	38.0	1.00	MD	0.172	0.60	0.30	0.10
5	38.0	1.73	HD	0.991	0.25	0.40	0.35
6	38.0	1.04	HD	0.870	0.25	0.75	0.00
7	38.0	1.01	MD	1.000	0.00	0.00	1.00
8	38.0	1.00	LD	0.000	0.00	0.00	1.00
9	38.0	2.37	MD	0.988	0.75	0.20	0.05
10	38.0	2.00	MD	0.373	1.00	0.00	0.00
11	38.0	2.04	MD	0.612	0.60	0.40	0.00
12	38.0	1.81	MD	1.000	0.50	0.50	0.00
13	38.0	1.01	HD	0.062	0.60	0.40	0.00
14	38.0	1.96	MD	0.578	0.40	0.60	0.00
15	38.0	1.22	MD	0.998	0.90	0.10	0.00
16	38.0	1.23	MD	0.239	0.25	0.50	0.25
17	38.0	1.06	MD	0.405	0.00	1.00	0.00
18	38.0	1.02	MD	1.000	1.00	0.00	0.00
19	38.0	1.00	HD	0.013	0.70	0.30	0.00
20	38.0	1.07	MD	1.000	1.00	0.00	0.00
21	38.0	1.00	MD	0.103	0.60	0.40	0.00
22	38.0	1.12	MD	0.986	0.25	0.75	0.00
23	38.0	1.00	MD	1.000	0.80	0.20	0.00

24	38.0	1.47	MD	1.000	0.80	0.20	0.00
25	38.0	1.00	HD	0.440	0.90	0.10	0.00
26	38.0	1.85	MD	1.000	0.90	0.10	0.00
27	38.0	1.01	MD	0.126	0.20	0.80	0.00
28	30.0	1.00	MD	1.000	0.50	0.50	0.00
29	30.0	1.00	MD	1.000	0.20	0.70	0.10
30	30.0	1.03	HD	1.000	0.50	0.50	0.00
31	30.0	1.40	HD	1.000	0.30	0.50	0.20
32	30.0	1.18	MD	1.000	0.50	0.50	0.00
33	30.0	1.25	HD	1.000	0.25	0.50	0.25
34	30.0	1.60	MD	1.000	0.40	0.40	0.20
35	30.0	1.00	HD	1.000	0.20	0.30	0.50
36	30.0	1.16	HD	1.000	0.00	0.75	0.25
37	30.0	2.00	MD	1.000	0.40	0.40	0.20
38	30.0	1.47	MD	1.000	0.30	0.10	0.60
39	30.0	1.75	MD	1.000	0.40	0.20	0.40
40	30.0	2.00	MD	1.000	0.00	0.00	1.00
41	30.0	1.10	HD	1.000	0.00	1.00	0.00
42	30.0	1.00	MD	1.000	0.80	0.20	0.00

C.1 Levelized incremental capacity costs for each route, all scenarios, CTC case

Levelized Total Capital Costs (2005$/ton-mile) -- w/ CTC signaling

	BAU1		BAU2a		BAU2b		BAU2b+LowH2		BAU2b+HighH2	
	C.M. #1	C.M. #2	C.M. #1	C.M. #2	C.M. #1	C.M. #2	C.M. #1	C.M. #2	C.M. #1	C.M. #2
Route 1										
P10	0.00133	0.00029	0.00128	0.00028	0.00078	0.00017	0.00071	0.00015	0.00101	0.00022
P50	0.00209	0.00041	0.00209	0.00041	0.00154	0.00032	0.00131	0.00027	0.00157	0.00031
P90	0.00417	0.00087	0.00413	0.00086	0.00318	0.00067	0.00257	0.00055	0.00316	0.00066
Route 2										
P10	0.00813	0.00174	0.00736	0.00159	0.00124	0.00030	0.00238	0.00052	0.00605	0.00130
P50	0.01674	0.00336	0.01615	0.00329	0.00683	0.00148	0.00735	0.00158	0.01241	0.00252
P90	0.04195	0.00885	0.04113	0.00866	0.02875	0.00614	0.02387	0.00515	0.03150	0.00670
Route 3										
P10	0.00000	0.00000	0.00000	0.00000	---	---	0.00003	0.00001	0.00002	0.00000
P50	0.00000	0.00000	0.00000	0.00000	---	---	0.00004	0.00001	0.00005	0.00001
P90	0.00034	0.00007	0.00038	0.00008	---	---	0.00005	0.00001	0.00014	0.00003
Route 4										
P10	0.00003	0.00001	0.00002	0.00000	0.00001	0.00000	0.00002	0.00000	0.00003	0.00001
P50	0.00012	0.00003	0.00011	0.00002	0.00004	0.00001	0.00005	0.00001	0.00010	0.00002
P90	0.00023	0.00005	0.00020	0.00004	0.00016	0.00003	0.00013	0.00003	0.00033	0.00007
Route 5										
P10	0.00128	0.00028	0.00117	0.00025	0.00021	0.00005	0.00031	0.00007	0.00093	0.00020
P50	0.00254	0.00050	0.00241	0.00049	0.00072	0.00016	0.00089	0.00020	0.00183	0.00037
P90	0.00527	0.00110	0.00507	0.00107	0.00277	0.00060	0.00250	0.00055	0.00381	0.00081
Route 6										
P10	0.00213	0.00046	0.00178	0.00039	0.00034	0.00007	0.00044	0.00010	0.00154	0.00034
P50	0.00356	0.00075	0.00319	0.00067	0.00063	0.00014	0.00090	0.00021	0.00258	0.00055
P90	0.00595	0.00125	0.00551	0.00117	0.00208	0.00045	0.00220	0.00049	0.00431	0.00092
Route 7										
P10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00035	0.00008
P50	0.00458	0.00095	0.00152	0.00040	0.00000	0.00000	0.00101	0.00024	0.00354	0.00082
P90	0.03854	0.00822	0.03668	0.00776	0.01550	0.00337	0.01554	0.00347	0.02749	0.00589
Route 8										
P10	0.00017	0.00004	0.00014	0.00003	0.00001	0.00000	0.00003	0.00001	0.00012	0.00003
P50	0.00032	0.00007	0.00031	0.00007	0.00018	0.00004	0.00016	0.00003	0.00024	0.00005
P90	0.00052	0.00011	0.00053	0.00011	0.00046	0.00010	0.00034	0.00007	0.00039	0.00008
Route 9										
P10	0.00014	0.00003	0.00008	0.00002	0.00004	0.00001	0.00006	0.00001	0.00011	0.00002
P50	0.00056	0.00012	0.00051	0.00011	0.00013	0.00003	0.00017	0.00004	0.00042	0.00009
P90	0.00117	0.00025	0.00113	0.00024	0.00075	0.00016	0.00063	0.00014	0.00087	0.00019
Route 10										
P10	0.00000	0.00000	0.00000	0.00000	0.00001	0.00000	0.00001	0.00000	0.00001	0.00000

P50	0.00005	0.00001	0.00003	0.00001	0.00001	0.00000	0.00003	0.00001	0.00008	0.00002
P90	0.00016	0.00004	0.00015	0.00003	0.00010	0.00002	0.00012	0.00003	0.00015	0.00004
Route 11										
P10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00005	0.00001
P50	0.00009	0.00002	0.00008	0.00002	0.00002	0.00000	0.00008	0.00002	0.00013	0.00003
P90	0.00060	0.00013	0.00048	0.00010	0.00019	0.00004	0.00022	0.00005	0.00044	0.00010
Route 12										
P10	0.00015	0.00003	0.00011	0.00003	0.00006	0.00001	0.00011	0.00002	0.00015	0.00004
P50	0.00090	0.00019	0.00080	0.00017	0.00022	0.00005	0.00028	0.00007	0.00068	0.00015
P90	0.00193	0.00041	0.00186	0.00040	0.00127	0.00027	0.00107	0.00023	0.00145	0.00031
Route 13										
P10	0.00031	0.00007	0.00031	0.00007	0.00027	0.00006	0.00021	0.00005	0.00027	0.00006
P50	0.00041	0.00009	0.00041	0.00009	0.00037	0.00008	0.00029	0.00006	0.00042	0.00009
P90	0.00053	0.00011	0.00054	0.00011	0.00050	0.00010	0.00038	0.00008	0.00065	0.00014
Route 14										
P10	0.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00001	0.00000	0.00001	0.00000
P50	0.00001	0.00000	0.00001	0.00000	0.00001	0.00000	0.00001	0.00000	0.00010	0.00002
P90	0.00028	0.00006	0.00025	0.00006	0.00012	0.00003	0.00022	0.00005	0.00031	0.00007
Route 15										
P10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00002
P50	0.00021	0.00005	0.00016	0.00004	0.00000	0.00000	0.00018	0.00004	0.00032	0.00008
P90	0.00256	0.00054	0.00239	0.00050	0.00079	0.00017	0.00090	0.00019	0.00179	0.00038
Route 16										
P10	0.00001	0.00000	0.00001	0.00000	0.00002	0.00000	0.00002	0.00000	0.00001	0.00000
P50	0.00002	0.00000	0.00002	0.00000	0.00002	0.00001	0.00002	0.00001	0.00003	0.00001
P90	0.00016	0.00003	0.00015	0.00003	0.00004	0.00001	0.00005	0.00001	0.00011	0.00002
Route 17										
P10	0.00000	0.00000	0.00000	0.00000	0.00001	0.00000	0.00001	0.00000	0.00001	0.00000
P50	0.00001	0.00000	0.00001	0.00000	0.00001	0.00000	0.00001	0.00000	0.00001	0.00000
P90	0.00003	0.00001	0.00002	0.00000	0.00002	0.00000	0.00002	0.00000	0.00002	0.00001
Route 18										
P10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00012	0.00003
P50	0.00023	0.00006	0.00019	0.00005	0.00008	0.00002	0.00033	0.00007	0.00067	0.00016
P90	0.00497	0.00104	0.00475	0.00100	0.00216	0.00047	0.00182	0.00040	0.00330	0.00070
Route 19										
P10	0.00006	0.00001	0.00005	0.00001	0.00001	0.00000	0.00001	0.00000	0.00004	0.00001
P50	0.00009	0.00002	0.00009	0.00002	0.00002	0.00000	0.00003	0.00001	0.00006	0.00001
P90	0.00014	0.00003	0.00014	0.00003	0.00009	0.00002	0.00007	0.00001	0.00010	0.00002
Route 20										
P10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00009	0.00002
P50	0.00024	0.00006	0.00018	0.00004	0.00000	0.00000	0.00027	0.00006	0.00051	0.00012
P90	0.00468	0.00098	0.00442	0.00093	0.00199	0.00043	0.00182	0.00040	0.00323	0.00069
Route 21										
P10	0.00001	0.00000	0.00001	0.00000	0.00002	0.00000	0.00002	0.00001	0.00002	0.00000

P50	0.00014	0.00003	0.00011	0.00002	0.00003	0.00001	0.00004	0.00001	0.00010	0.00002
P90	0.00035	0.00007	0.00034	0.00007	0.00022	0.00005	0.00017	0.00004	0.00025	0.00005
Route 22										
P10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
P50	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
P90	0.00131	0.00029	0.00060	0.00015	0.00016	0.00004	0.00050	0.00012	0.00093	0.00021
Route 23										
P10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
P50	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00047	0.00011
P90	0.00596	0.00130	0.00474	0.00102	0.00078	0.00018	0.00131	0.00031	0.00400	0.00087
Route 24										
P10	0.00077	0.00016	0.00061	0.00013	0.00018	0.00004	0.00022	0.00005	0.00060	0.00013
P50	0.00166	0.00036	0.00158	0.00034	0.00096	0.00021	0.00092	0.00020	0.00131	0.00028
P90	0.00277	0.00057	0.00273	0.00057	0.00225	0.00047	0.00186	0.00039	0.00217	0.00045
Route 25										
P10	0.00003	0.00001	0.00003	0.00001	0.00008	0.00002	0.00005	0.00001	0.00003	0.00001
P50	0.00004	0.00001	0.00004	0.00001	0.00011	0.00002	0.00007	0.00002	0.00005	0.00001
P90	0.00014	0.00003	0.00008	0.00002	0.00015	0.00004	0.00010	0.00002	0.00008	0.00002
Route 26										
P10	0.00012	0.00003	0.00009	0.00002	0.00000	0.00000	0.00012	0.00003	0.00028	0.00006
P50	0.00041	0.00010	0.00038	0.00009	0.00032	0.00007	0.00038	0.00009	0.00061	0.00015
P90	0.00250	0.00053	0.00234	0.00050	0.00129	0.00029	0.00123	0.00027	0.00188	0.00041
Route 27										
P10	0.00002	0.00000	0.00002	0.00000	0.00003	0.00001	0.00003	0.00001	0.00002	0.00000
P50	0.00007	0.00001	0.00005	0.00001	0.00004	0.00001	0.00004	0.00001	0.00005	0.00001
P90	0.00019	0.00004	0.00018	0.00004	0.00010	0.00002	0.00010	0.00002	0.00022	0.00005
Route 28										
P10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
P50	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
P90	0.00002	0.00000	0.00000	0.00000	0.00009	0.00002	0.00027	0.00006	0.00020	0.00005
Route 29										
P10	---	---	---	---	---	---	---	---	---	---
P50	---	---	---	---	---	---	---	---	---	---
P90	---	---	---	---	---	---	---	---	---	---
Route 30										
P10	0.00329	0.00071	0.00286	0.00062	0.00087	0.00019	0.00097	0.00021	0.00220	0.00047
P50	0.00552	0.00118	0.00514	0.00110	0.00196	0.00043	0.00183	0.00041	0.00363	0.00078
P90	0.00927	0.00193	0.00898	0.00186	0.00398	0.00087	0.00329	0.00072	0.00601	0.00127
Route 31										
P10	0.00557	0.00119	0.00512	0.00109	0.00157	0.00035	0.00160	0.00035	0.00354	0.00076
P50	0.01114	0.00228	0.01047	0.00217	0.00404	0.00088	0.00340	0.00073	0.00696	0.00144
P90	0.02122	0.00435	0.02077	0.00426	0.00905	0.00195	0.00687	0.00152	0.01311	0.00275
Route 32										
P10	0.00034	0.00007	0.00000	0.00000	0.00000	0.00000	0.00022	0.00005	0.00095	0.00021

P50	0.00737	0.00160	0.00309	0.00073	0.00000	0.00000	0.00144	0.00032	0.00453	0.00103
P90	0.02300	0.00483	0.02163	0.00451	0.00384	0.00089	0.00616	0.00139	0.01482	0.00317
Route 33										
P10	0.00000	0.00000	---	---	---	---	---	---	0.00000	0.00000
P50	0.00000	0.00000	---	---	---	---	---	---	0.00136	0.00030
P90	0.00000	0.00000	---	---	---	---	---	---	0.00444	0.00103
Route 34										
P10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00016	0.00004
P50	0.00043	0.00010	0.00029	0.00006	0.00000	0.00000	0.00038	0.00008	0.00077	0.00018
P90	0.00626	0.00133	0.00544	0.00113	0.00135	0.00032	0.00168	0.00041	0.00432	0.00093
Route 35										
P10	0.01002	0.00215	0.00890	0.00190	0.00125	0.00028	0.00198	0.00045	0.00709	0.00152
P50	0.02457	0.00526	0.02138	0.00444	0.00513	0.00119	0.00672	0.00151	0.01731	0.00374
P90	0.04974	0.01051	0.04844	0.01021	0.02594	0.00556	0.02249	0.00493	0.03531	0.00749
Route 36										
P10	0.01112	0.00244	0.01040	0.00228	0.00398	0.00088	0.00445	0.00097	0.00808	0.00176
P50	0.02192	0.00494	0.02044	0.00449	0.00985	0.00211	0.00916	0.00196	0.01620	0.00355
P90	0.04067	0.00859	0.03958	0.00839	0.02549	0.00553	0.02081	0.00454	0.02919	0.00624
Route 37										
P10	---	---	---	---	---	---	---	---	---	---
P50	---	---	---	---	---	---	---	---	---	---
P90	---	---	---	---	---	---	---	---	---	---
Route 38										
P10	0.00074	0.00018	0.00048	0.00011	0.00000	0.00000	0.00058	0.00013	0.00097	0.00023
P50	0.00903	0.00193	0.00773	0.00165	0.00115	0.00027	0.00268	0.00062	0.00631	0.00137
P90	0.03595	0.00755	0.03456	0.00730	0.01747	0.00383	0.01593	0.00347	0.02542	0.00543
Route 39										
P10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
P50	0.00063	0.00014	0.00056	0.00012	0.00043	0.00010	0.00101	0.00022	0.00147	0.00036
P90	0.01176	0.00245	0.01000	0.00214	0.00617	0.00142	0.00459	0.00106	0.00749	0.00162
Route 40										
P10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00021	0.00005
P50	0.00075	0.00017	0.00062	0.00014	0.00004	0.00001	0.00079	0.00017	0.00129	0.00030
P90	0.00833	0.00189	0.00603	0.00139	0.00502	0.00115	0.00459	0.00108	0.00614	0.00142
Route 41										
P10	---	---	---	---	---	---	---	---	---	---
P50	---	---	---	---	---	---	---	---	---	---
P90	---	---	---	---	---	---	---	---	---	---
Route 42										
P10	0.00455	0.00097	0.00456	0.00097	0.00413	0.00087	0.00351	0.00075	0.00376	0.00080
P50	0.00620	0.00129	0.00626	0.00131	0.00597	0.00126	0.00495	0.00105	0.00511	0.00107
P90	0.00857	0.00176	0.00871	0.00179	0.00874	0.00180	0.00715	0.00148	0.00705	0.00146
Average										

P10	0.00208	0.00044	0.00192	0.00041	0.00060	0.00013	0.00071	0.00016	0.00162	0.00035
P50	0.00381	0.00081	0.00356	0.00076	0.00147	0.00033	0.00153	0.00034	0.00285	0.00061
P90	0.00716	0.00150	0.00681	0.00144	0.00390	0.00083	0.00323	0.00070	0.00496	0.00107

C.2 Discounted present values of incremental capacity costs for each route, all scenarios, CTC case

Total Discounted Present Value of Coal-Related Costs (2005$) -- w/ CTC signaling

	BAU1		BAU2a		BAU2b		BAU2b+LowH2		BAU2b+HighH2	
	C.M. #1	C.M. #2	C.M. #1	C.M. #2	C.M. #1	C.M. #2	C.M. #1	C.M. #2	C.M. #1	C.M. #2
Route 1										
P10	312,014,551	123,129,663	274,648,689	108,874,683	113,316,675	46,771,339	157,366,837	63,116,342	305,214,930	119,625,289
P50	446,512,516	207,923,628	407,202,109	189,718,253	221,308,237	94,455,759	284,644,364	123,016,668	442,220,573	209,646,098
P90	939,475,952	416,200,630	850,231,999	374,543,067	461,936,977	198,105,020	569,495,645	251,283,549	924,186,933	415,429,188
Route 2										
P10	148,724,426	60,488,376	121,011,579	49,610,224	14,882,665	7,016,695	40,637,748	17,526,632	144,207,559	58,733,792
P50	285,916,137	125,750,027	252,132,589	106,952,683	75,967,245	33,195,549	127,304,931	55,206,627	283,594,065	123,655,852
P90	757,588,555	320,349,303	669,327,484	285,026,692	319,635,517	137,942,491	420,138,333	178,256,926	748,138,283	319,515,397
Route 3										
P10	0	0	0	0	0	0	242,969	99,907	577,578	258,927
P50	0	0	0	0	0	0	402,233	184,619	1,384,435	635,311
P90	4,314,168	1,798,685	3,026,079	1,226,650	0	0	652,870	331,193	3,982,876	1,711,952
Route 4										
P10	2,377,970	974,299	1,231,634	544,853	567,477	239,228	968,890	407,755	2,757,441	1,170,773
P50	8,334,142	3,390,313	7,002,387	2,878,668	2,048,015	918,863	3,431,245	1,500,196	8,727,794	3,780,625
P90	15,066,544	6,662,952	12,779,877	5,557,883	6,771,940	2,933,010	8,861,395	4,028,432	30,154,522	13,776,050
Route 5										
P10	461,688,317	188,328,905	372,608,783	154,446,677	42,292,805	19,040,172	110,427,320	47,950,751	446,710,453	181,036,545
P50	843,235,780	375,598,606	729,830,766	313,988,863	150,722,571	68,388,382	302,890,738	132,363,714	832,450,662	368,599,674
P90	1,839,875,228	791,715,459	1,593,541,060	685,418,000	569,433,650	245,633,947	858,063,978	370,258,343	1,804,350,045	787,707,597
Route 6										
P10	113,854,925	46,809,488	85,781,365	35,487,503	9,380,641	3,980,695	20,704,512	8,843,644	109,977,390	44,498,199
P50	186,008,223	77,892,190	148,388,531	62,317,254	19,721,897	9,331,804	46,111,939	20,949,367	178,550,642	75,292,864
P90	311,620,285	134,682,335	261,374,406	112,594,866	64,062,959	28,545,410	114,498,513	52,325,890	303,347,534	132,695,823
Route 7										
P10	0	0	0	0	0	0	0	0	10,281,689	4,456,711
P50	98,296,953	40,697,372	35,280,580	17,643,951	0	0	21,796,626	10,042,279	112,864,754	50,830,346

P90	851,566,550	360,751,733	713,544,128	306,374,347	191,195,672	82,634,150	340,208,852	145,449,252	836,320,271	359,910,044
Route 8										
P10	1,278,355	523,708	967,961	402,588	63,654	27,496	178,440	79,665	1,219,068	503,371
P50	2,446,926	1,017,491	2,143,793	885,422	831,675	345,467	1,197,195	506,612	2,398,632	999,560
P90	3,922,057	1,696,023	3,577,441	1,545,354	2,150,145	914,047	2,524,837	1,096,203	3,877,377	1,694,409
Route 9										
P10	70,153,742	30,041,795	33,634,792	15,431,227	11,203,386	4,788,867	27,381,272	11,660,824	67,763,438	30,218,227
P50	269,913,662	112,406,611	220,971,079	91,088,241	41,679,357	20,630,317	86,183,220	41,805,221	264,700,102	110,342,730
P90	558,801,301	242,320,235	490,454,801	212,911,880	218,306,763	97,131,763	292,672,731	130,166,437	548,744,299	240,506,778
Route 10										
P10	373,209	158,922	343,680	144,889	285,888	117,355	397,118	167,344	1,639,110	713,318
P50	4,598,549	2,047,833	2,821,345	1,207,359	668,189	334,724	2,537,985	1,157,147	8,773,273	3,811,563
P90	15,286,240	7,298,121	12,077,532	5,695,683	5,325,917	2,316,497	10,863,077	5,121,427	19,745,772	9,606,254
Route 11										
P10	905,286	416,451	635,983	277,054	426,418	175,095	863,369	389,029	10,935,821	4,766,443
P50	17,984,127	7,668,021	13,203,994	5,841,458	2,365,618	1,172,337	14,171,184	6,275,298	32,999,473	15,209,778
P90	112,018,061	48,725,461	82,116,974	36,094,001	22,852,196	10,763,775	43,372,681	20,779,273	111,645,085	49,509,370
Route 12										
P10	28,750,473	12,883,486	18,783,312	7,982,962	7,088,980	3,058,222	18,487,864	7,915,007	37,398,803	16,100,674
P50	172,283,849	71,144,894	140,587,907	57,486,624	28,514,980	13,459,122	56,825,635	26,546,509	168,435,150	69,903,098
P90	367,701,046	156,094,975	324,172,872	137,897,974	148,443,223	64,627,278	194,341,650	85,718,263	360,714,226	156,388,801
Route 13										
P10	19,761,078	7,975,927	18,130,014	7,303,054	11,026,627	4,448,867	12,964,845	5,212,866	21,737,102	8,719,720
P50	25,303,568	10,628,034	23,240,261	9,776,183	14,765,364	6,248,776	17,036,295	7,253,002	33,079,441	14,000,751
P90	31,427,438	13,920,958	29,025,145	12,825,645	19,597,858	8,541,906	22,165,248	9,873,928	52,503,632	24,513,897
Route 14										
P10	695,045	288,256	0	0	0	0	699,820	289,880	1,081,403	466,972
P50	2,107,782	1,103,347	1,900,629	994,423	741,051	314,965	2,187,042	1,156,896	15,976,306	6,943,510
P90	36,467,684	17,379,726	28,279,234	13,339,852	8,788,836	3,933,342	28,263,304	13,415,041	54,274,804	25,815,207
Route 15										

P10	0	0	0	0	0	0	0	0	4,438,313	1,940,737
P50	8,631,325	4,323,123	5,400,011	2,570,852	0	0	5,849,154	2,593,321	17,496,749	8,481,309
P90	90,062,461	38,206,409	74,392,808	31,392,884	15,106,756	6,398,085	30,660,800	13,425,904	87,747,219	38,114,359
Route 16										
P10	314,651	130,073	287,376	118,984	261,262	107,839	596,737	245,696	787,477	325,888
P50	987,593	493,092	785,037	408,543	444,032	207,341	1,046,444	487,162	2,075,791	1,013,325
P90	7,343,670	3,122,135	5,908,118	2,500,580	811,156	412,907	2,015,858	964,253	7,131,076	3,077,196
Route 17										
P10	70,030	28,886	61,980	25,572	56,939	23,339	146,723	60,263	214,406	92,781
P50	123,617	58,415	106,337	49,667	92,498	42,691	238,681	110,078	428,484	197,877
P90	690,624	299,071	394,441	171,642	154,234	78,565	398,422	202,878	904,182	444,844
Route 18										
P10	0	0	0	0	0	0	0	0	645,835	283,969
P50	979,894	512,543	664,165	310,875	141,822	65,075	1,177,224	515,709	4,158,121	1,953,080
P90	19,326,666	8,202,854	15,778,045	6,630,781	3,481,500	1,488,407	6,813,970	3,001,442	19,219,736	8,235,864
Route 19										
P10	2,091,963	848,411	1,554,721	630,104	141,068	59,379	354,721	150,347	2,015,166	815,317
P50	3,186,417	1,358,645	2,584,111	1,107,300	388,673	182,202	967,526	433,926	3,129,134	1,342,888
P90	4,820,449	2,077,421	4,140,942	1,769,354	1,534,013	651,692	2,244,321	964,163	4,749,224	2,073,902
Route 20										
P10	0	0	0	0	0	0	0	0	2,161,493	928,827
P50	5,079,281	2,572,357	3,040,231	1,418,031	0	0	4,443,001	1,950,958	14,009,841	7,043,659
P90	83,980,010	35,987,670	69,732,132	29,630,867	17,958,509	7,856,150	32,471,754	13,998,158	83,380,144	35,605,922
Route 21										
P10	174,646	75,698	149,953	63,157	137,482	56,593	312,929	129,393	404,800	172,374
P50	2,119,911	868,222	1,376,250	587,901	288,755	140,789	687,241	336,458	2,044,206	869,025
P90	5,275,453	2,245,667	4,569,125	1,935,713	1,718,651	745,130	2,501,076	1,075,538	5,157,160	2,222,325
Route 22										
P10	0	0	0	0	0	0	0	0	0	0

P50	0	0	0	0	0	0	0	0	0	0
P90	34,743,724	14,571,693	15,397,172	6,936,365	1,978,895	873,683	12,345,142	5,838,572	36,398,161	17,107,217
Route 23										
P10	0	0	0	0	0	0	0	0	0	0
P50	0	0	0	0	0	0	0	0	4,739,331	2,108,254
P90	45,137,808	18,928,998	30,409,578	12,734,755	2,594,118	1,168,094	9,696,068	4,645,381	43,700,488	18,608,779
Route 24										
P10	104,103,656	43,071,644	77,060,512	31,963,980	15,580,670	6,657,016	27,363,695	11,915,965	101,737,027	42,185,012
P50	230,240,015	95,854,053	203,360,119	83,893,513	89,395,677	37,841,601	120,931,906	51,212,845	227,777,482	95,397,162
P90	370,532,979	163,758,977	337,728,916	149,863,009	208,285,646	93,047,395	244,171,635	109,131,679	368,907,820	163,462,905
Route 25										
P10	180,563	74,325	165,212	68,128	157,683	64,771	294,132	120,819	325,301	133,879
P50	339,702	161,400	280,107	130,672	253,135	115,453	472,182	215,359	559,913	260,982
P90	1,066,195	464,924	519,234	258,719	410,469	212,908	765,663	397,146	1,018,096	502,438
Route 26										
P10	903,407	390,719	647,475	290,293	0	0	915,129	393,169	2,760,228	1,182,221
P50	3,759,900	1,851,320	3,046,093	1,459,953	1,539,085	673,011	2,999,576	1,389,045	7,163,698	3,385,550
P90	20,572,972	8,752,090	17,503,240	7,352,961	6,628,052	2,880,781	9,809,754	4,391,518	20,697,446	9,001,930
Route 27										
P10	570,944	240,252	530,375	219,881	469,943	193,696	689,842	283,777	810,411	338,133
P50	2,132,451	931,240	1,515,192	753,203	870,072	407,164	1,311,983	621,300	2,291,976	1,064,093
P90	5,936,601	2,583,247	5,157,124	2,242,333	2,020,348	893,198	2,895,679	1,283,199	8,824,091	3,774,056
Route 28										
P10	0	0	0	0	0	0	0	0	0	0
P50	0	0	0	0	0	0	0	0	0	0
P90	3,729	1,668	178	81	2,237	1,019	57,060	25,605	80,564	36,298
Route 29										
P10	0	0	0	0	0	0	0	0	0	0
P50	0	0	0	0	0	0	0	0	0	0

P90	0	0	0	0	0	0	5,209	2,355	6,481	2,940
Route 30										
P10	34,759,253	14,225,436	25,782,825	10,521,060	3,333,327	1,407,360	8,981,345	3,793,296	34,620,056	14,134,859
P50	57,592,021	24,416,139	45,452,220	19,132,573	7,781,193	3,486,766	18,073,624	8,027,691	56,942,052	24,209,198
P90	94,876,336	40,615,180	77,522,654	33,300,650	16,099,260	7,167,089	32,720,828	14,866,306	93,162,914	40,300,136
Route 31										
P10	49,391,865	20,418,190	37,567,367	15,568,792	4,151,349	1,786,332	12,662,114	5,359,541	48,724,647	20,139,044
P50	94,606,160	39,861,485	75,148,357	31,417,538	11,066,228	4,766,592	27,442,899	11,896,697	92,755,577	39,249,149
P90	181,138,577	77,800,458	146,988,887	62,825,633	24,773,015	11,067,155	57,528,568	25,764,497	176,229,361	76,962,497
Route 32										
P10	1,522,397	662,789	0	0	0	0	938,125	417,091	6,212,569	2,693,470
P50	36,246,069	15,197,213	13,801,979	6,298,169	0	0	6,424,056	2,912,999	33,922,507	14,479,210
P90	111,093,145	48,224,686	88,694,239	38,803,610	7,890,728	3,843,548	29,133,749	12,702,849	107,417,618	47,308,255
Route 33										
P10	0	0	0	0	0	0	0	0	3,537	1,620
P50	0	0	0	0	0	0	0	0	3,629,373	1,634,385
P90	0	0	0	0	0	0	1,577,469	711,543	12,375,533	5,796,227
Route 34										
P10	0	0	0	0	0	0	0	0	6,911,850	3,034,454
P50	14,248,449	6,709,609	8,140,611	3,888,098	0	0	10,683,021	4,665,494	35,080,069	16,290,775
P90	203,403,791	86,431,778	152,284,696	64,865,738	23,167,357	11,045,179	57,265,967	27,062,782	198,448,134	87,524,582
Route 35										
P10	108,189,290	44,228,229	84,521,942	34,784,123	6,873,524	3,055,148	20,239,722	9,053,792	104,357,111	42,829,241
P50	264,403,182	106,778,396	197,897,757	83,982,986	30,199,308	13,899,180	69,955,511	31,103,189	254,710,619	103,171,340
P90	527,670,563	225,582,109	454,073,131	194,230,101	148,625,230	64,310,889	234,220,837	100,378,239	518,257,088	223,760,876
Route 36										
P10	167,355,755	67,766,207	139,774,100	56,523,090	32,643,971	13,760,859	61,966,444	25,318,064	163,528,408	65,501,238
P50	338,886,044	132,359,473	271,551,581	111,908,090	80,616,487	34,242,876	127,122,079	54,810,459	322,343,113	128,931,546
P90	591,465,793	254,621,320	517,026,130	221,059,587	213,084,635	90,299,546	294,976,277	127,564,615	581,185,603	253,252,248

Route 37										
P10	0	0	0	0	0	0	0	0	0	0
P50	0	0	0	0	0	0	0	0	0	0
P90	0	0	0	0	0	0	0	0	0	0
Route 38										
P10	41,891,855	19,762,171	22,720,145	10,516,584	0	0	27,669,170	11,902,114	73,445,461	34,516,090
P50	467,478,005	195,067,701	355,544,259	147,025,339	32,301,617	14,878,108	137,150,357	62,969,513	450,721,415	189,348,043
P90	1,857,633,831	802,366,977	1,591,625,446	690,133,586	501,098,684	216,801,397	799,470,103	355,390,865	1,821,968,269	789,390,346
Route 39										
P10	0	0	0	0	0	0	0	0	0	0
P50	2,785,344	1,311,678	2,008,164	898,069	507,893	246,773	4,113,637	1,792,899	12,028,611	5,633,695
P90	54,565,032	23,674,306	38,826,071	16,291,733	7,202,660	3,281,502	20,377,771	9,535,294	57,683,135	26,200,248
Route 40										
P10	0	0	0	0	0	0	0	0	3,080,163	1,397,611
P50	7,559,681	3,445,126	5,024,333	2,173,534	113,942	50,069	7,069,691	3,116,492	20,048,396	9,441,508
P90	88,917,278	38,306,656	53,687,025	25,288,877	19,455,229	9,352,889	45,549,290	21,828,035	98,712,568	47,192,779
Route 41										
P10	0	0	0	0	0	0	0	0	0	0
P50	0	0	0	0	0	0	0	0	0	0
P90	0	0	0	0	0	0	0	0	0	0
Route 42										
P10	406,344,559	162,508,083	380,484,818	153,661,238	274,936,651	112,720,344	304,252,546	123,968,547	403,251,991	162,120,981
P50	544,054,277	232,132,629	515,108,478	219,683,439	396,247,339	167,743,455	428,054,036	183,395,064	541,109,777	230,843,754
P90	743,445,917	327,296,924	709,756,810	311,698,407	567,315,429	249,303,495	608,501,266	267,818,851	737,843,510	327,087,452
Sum										
P10	3,093,868,493	1,277,027,430	2,514,484,329	1,038,421,378	736,050,072	303,580,381	1,206,741,325	494,860,145	3,150,671,227	1,289,446,628
P50	5,342,142,877	2,246,827,763	4,451,591,261	1,882,826,740	1,484,677,458	637,771,144	2,301,653,413	1,003,777,966	5,329,118,032	2,276,918,169

P90	8,643,889,070	3,765,165,420	7,484,989,456	3,247,839,916	3,182,675,721	1,385,900,100	4,396,380,630	1,961,280,438	8,597,611,049	3,815,582,284
Average										
P10	73,663,536	30,405,415	59,868,674	24,724,319	17,525,002	7,228,104	28,731,936	11,782,384	75,015,982	30,701,110
P50	127,193,878	53,495,899	105,990,268	44,829,208	35,349,463	15,185,027	54,801,272	23,899,475	126,883,763	54,212,337
P90	205,806,883	89,646,796	178,214,035	77,329,522	75,777,993	32,997,621	104,675,729	46,697,153	204,705,025	90,847,197

C.3 Levelized incremental capacity costs for each route, all scenarios, PTC case

Levelized Total Capital Costs (2005$/ton-mile) -- w/ PTC signaling

	BAU1		BAU2a		BAU2b		BAU2b+LowH2		BAU2b+HighH2	
	C.M. #1	C.M. #2	C.M. #1	C.M. #2	C.M. #1	C.M. #2	C.M. #1	C.M. #2	C.M. #1	C.M. #2
Route 1										
P10	0.00110	0.00024	0.00104	0.00022	0.00042	0.00009	0.00044	0.00010	0.00084	0.00018
P50	0.00182	0.00038	0.00173	0.00036	0.00086	0.00019	0.00086	0.00019	0.00137	0.00029
P90	0.00348	0.00073	0.00338	0.00070	0.00207	0.00044	0.00185	0.00040	0.00263	0.00055
Route 2										
P10	0.00249	0.00056	0.00145	0.00034	0.00079	0.00016	0.00127	0.00026	0.00198	0.00047
P50	0.00850	0.00180	0.00689	0.00148	0.00169	0.00038	0.00287	0.00062	0.00623	0.00133
P90	0.02685	0.00575	0.02468	0.00527	0.00707	0.00158	0.00895	0.00194	0.02010	0.00429
Route 3										
P10	0.00136	0.00030	0.00214	0.00047	---	---	0.00140	0.00031	0.00060	0.00013
P50	0.00175	0.00037	0.00276	0.00058	---	---	0.00179	0.00037	0.00077	0.00016
P90	0.00224	0.00044	0.00352	0.00070	---	---	0.00228	0.00045	0.00098	0.00020
Route 4										
P10	0.00021	0.00005	0.00023	0.00005	0.00029	0.00006	0.00020	0.00004	0.00017	0.00004
P50	0.00028	0.00006	0.00030	0.00006	0.00038	0.00008	0.00025	0.00005	0.00022	0.00005
P90	0.00035	0.00007	0.00038	0.00008	0.00048	0.00010	0.00032	0.00006	0.00029	0.00006
Route 5										
P10	0.00081	0.00018	0.00059	0.00013	0.00039	0.00008	0.00035	0.00007	0.00058	0.00013
P50	0.00167	0.00035	0.00141	0.00030	0.00058	0.00012	0.00061	0.00013	0.00119	0.00025
P90	0.00391	0.00082	0.00356	0.00075	0.00098	0.00024	0.00114	0.00026	0.00281	0.00060
Route 6										
P10	0.00081	0.00018	0.00062	0.00013	0.00050	0.00010	0.00057	0.00012	0.00066	0.00015
P50	0.00209	0.00045	0.00155	0.00034	0.00072	0.00015	0.00076	0.00017	0.00150	0.00032
P90	0.00412	0.00086	0.00354	0.00074	0.00105	0.00024	0.00115	0.00028	0.00296	0.00063
Route 7										

P10	0.00040	0.00009	0.00044	0.00010	0.00064	0.00014	0.00039	0.00008	0.00034	0.00007
P50	0.00073	0.00015	0.00069	0.00014	0.00087	0.00018	0.00068	0.00014	0.00124	0.00028
P90	0.01828	0.00398	0.01430	0.00310	0.00217	0.00048	0.00376	0.00087	0.01305	0.00286
Route 8										
P10	0.00043	0.00009	0.00047	0.00010	0.00066	0.00015	0.00042	0.00009	0.00033	0.00007
P50	0.00054	0.00011	0.00059	0.00013	0.00084	0.00018	0.00054	0.00011	0.00041	0.00009
P90	0.00069	0.00014	0.00075	0.00015	0.00106	0.00021	0.00068	0.00014	0.00052	0.00010
Route 9										
P10	0.00016	0.00003	0.00016	0.00003	0.00015	0.00003	0.00015	0.00003	0.00015	0.00003
P50	0.00043	0.00009	0.00035	0.00008	0.00025	0.00005	0.00022	0.00005	0.00032	0.00007
P90	0.00100	0.00021	0.00094	0.00020	0.00054	0.00012	0.00048	0.00010	0.00074	0.00016
Route 10										
P10	0.00011	0.00002	0.00012	0.00003	0.00015	0.00003	0.00010	0.00002	0.00009	0.00002
P50	0.00017	0.00004	0.00018	0.00004	0.00021	0.00004	0.00015	0.00003	0.00015	0.00003
P90	0.00025	0.00005	0.00025	0.00005	0.00029	0.00006	0.00022	0.00005	0.00022	0.00005
Route 11										
P10	0.00012	0.00002	0.00012	0.00003	0.00015	0.00003	0.00010	0.00002	0.00010	0.00002
P50	0.00019	0.00004	0.00020	0.00004	0.00022	0.00005	0.00017	0.00004	0.00019	0.00004
P90	0.00031	0.00007	0.00031	0.00007	0.00033	0.00007	0.00028	0.00006	0.00029	0.00007
Route 12										
P10	0.00021	0.00004	0.00020	0.00004	0.00018	0.00004	0.00019	0.00004	0.00021	0.00004
P50	0.00056	0.00012	0.00043	0.00010	0.00030	0.00006	0.00029	0.00006	0.00042	0.00009
P90	0.00150	0.00032	0.00140	0.00030	0.00072	0.00015	0.00068	0.00015	0.00111	0.00024
Route 13										
P10	0.00035	0.00008	0.00038	0.00008	0.00050	0.00011	0.00034	0.00008	0.00028	0.00006
P50	0.00045	0.00009	0.00048	0.00010	0.00064	0.00013	0.00044	0.00009	0.00036	0.00008
P90	0.00056	0.00011	0.00061	0.00012	0.00081	0.00016	0.00055	0.00011	0.00048	0.00010
Route 14										
P10	0.00013	0.00003	0.00014	0.00003	0.00018	0.00004	0.00012	0.00003	0.00010	0.00002
P50	0.00019	0.00004	0.00020	0.00004	0.00025	0.00005	0.00017	0.00004	0.00017	0.00003

P90	0.00030	0.00006	0.00029	0.00006	0.00033	0.00007	0.00027	0.00006	0.00031	0.00007
Route 15										
P10	0.00027	0.00006	0.00029	0.00006	0.00043	0.00009	0.00025	0.00006	0.00023	0.00005
P50	0.00042	0.00009	0.00044	0.00009	0.00059	0.00012	0.00040	0.00008	0.00040	0.00009
P90	0.00151	0.00032	0.00122	0.00027	0.00083	0.00017	0.00064	0.00014	0.00107	0.00023
Route 16										
P10	0.00034	0.00007	0.00038	0.00008	0.00069	0.00015	0.00032	0.00007	0.00023	0.00005
P50	0.00044	0.00009	0.00050	0.00010	0.00089	0.00019	0.00042	0.00009	0.00030	0.00006
P90	0.00057	0.00011	0.00065	0.00013	0.00115	0.00023	0.00054	0.00011	0.00039	0.00008
Route 17										
P10	0.00027	0.00006	0.00031	0.00007	0.00058	0.00013	0.00025	0.00005	0.00018	0.00004
P50	0.00037	0.00008	0.00042	0.00009	0.00078	0.00016	0.00034	0.00007	0.00025	0.00005
P90	0.00050	0.00010	0.00056	0.00011	0.00104	0.00021	0.00045	0.00009	0.00033	0.00007
Route 18										
P10	0.00043	0.00009	0.00048	0.00010	0.00085	0.00019	0.00039	0.00009	0.00031	0.00007
P50	0.00063	0.00013	0.00069	0.00014	0.00116	0.00024	0.00061	0.00012	0.00060	0.00013
P90	0.00239	0.00053	0.00201	0.00045	0.00161	0.00033	0.00109	0.00025	0.00169	0.00038
Route 19										
P10	0.00026	0.00006	0.00028	0.00006	0.00043	0.00009	0.00024	0.00005	0.00018	0.00004
P50	0.00034	0.00007	0.00037	0.00008	0.00056	0.00012	0.00031	0.00006	0.00024	0.00005
P90	0.00044	0.00009	0.00049	0.00010	0.00073	0.00015	0.00041	0.00008	0.00031	0.00006
Route 20										
P10	0.00034	0.00007	0.00037	0.00008	0.00056	0.00012	0.00031	0.00007	0.00026	0.00006
P50	0.00051	0.00010	0.00054	0.00011	0.00075	0.00015	0.00047	0.00010	0.00051	0.00011
P90	0.00233	0.00050	0.00185	0.00040	0.00106	0.00022	0.00089	0.00020	0.00164	0.00036
Route 21										
P10	0.00043	0.00009	0.00048	0.00010	0.00073	0.00016	0.00042	0.00009	0.00032	0.00007
P50	0.00055	0.00012	0.00061	0.00013	0.00092	0.00019	0.00053	0.00011	0.00040	0.00008
P90	0.00070	0.00014	0.00077	0.00015	0.00116	0.00023	0.00066	0.00013	0.00050	0.00010
Route 22										

P10	0.00046	0.00010	0.00052	0.00011	0.00088	0.00019	0.00045	0.00010	0.00033	0.00007
P50	0.00061	0.00013	0.00069	0.00014	0.00115	0.00024	0.00060	0.00012	0.00045	0.00009
P90	0.00083	0.00017	0.00091	0.00018	0.00149	0.00030	0.00080	0.00016	0.00070	0.00015
Route 23										
P10	0.00059	0.00013	0.00066	0.00014	0.00111	0.00024	0.00055	0.00012	0.00042	0.00009
P50	0.00079	0.00016	0.00086	0.00018	0.00141	0.00030	0.00073	0.00015	0.00062	0.00013
P90	0.00127	0.00028	0.00126	0.00026	0.00181	0.00036	0.00123	0.00027	0.00138	0.00031
Route 24										
P10	0.00033	0.00007	0.00030	0.00006	0.00028	0.00006	0.00028	0.00006	0.00032	0.00007
P50	0.00124	0.00027	0.00113	0.00024	0.00046	0.00011	0.00049	0.00012	0.00097	0.00021
P90	0.00228	0.00048	0.00224	0.00047	0.00168	0.00035	0.00143	0.00031	0.00179	0.00038
Route 25										
P10	0.00074	0.00016	0.00087	0.00019	0.00205	0.00045	0.00072	0.00016	0.00047	0.00010
P50	0.00093	0.00020	0.00109	0.00023	0.00259	0.00055	0.00091	0.00019	0.00060	0.00013
P90	0.00117	0.00023	0.00138	0.00027	0.00326	0.00065	0.00114	0.00023	0.00075	0.00015
Route 26										
P10	0.00021	0.00004	0.00021	0.00004	0.00025	0.00005	0.00018	0.00004	0.00024	0.00005
P50	0.00044	0.00009	0.00043	0.00009	0.00043	0.00009	0.00043	0.00009	0.00050	0.00011
P90	0.00135	0.00029	0.00115	0.00025	0.00084	0.00019	0.00079	0.00019	0.00105	0.00024
Route 27										
P10	0.00024	0.00005	0.00026	0.00006	0.00033	0.00007	0.00023	0.00005	0.00019	0.00004
P50	0.00030	0.00006	0.00033	0.00007	0.00042	0.00009	0.00029	0.00006	0.00024	0.00005
P90	0.00038	0.00008	0.00041	0.00008	0.00053	0.00011	0.00036	0.00007	0.00030	0.00006
Route 28										
P10	0.01696	0.00368	0.02171	0.00472	0.14869	0.03231	0.01837	0.00399	0.00998	0.00215
P50	0.02213	0.00466	0.02833	0.00597	0.19399	0.04089	0.02395	0.00505	0.01293	0.00273
P90	0.02847	0.00569	0.03643	0.00729	0.24954	0.04992	0.03081	0.00616	0.01660	0.00333
Route 29										
P10	---	---	---	---	---	---	---	---	---	---
P50	---	---	---	---	---	---	---	---	---	---

P90	---	---	---	---	---	---	---	---	---	---
Route 30										
P10	0.00104	0.00023	0.00107	0.00023	0.00179	0.00037	0.00112	0.00023	0.00096	0.00021
P50	0.00301	0.00064	0.00252	0.00054	0.00228	0.00049	0.00149	0.00033	0.00205	0.00044
P90	0.00624	0.00132	0.00586	0.00124	0.00331	0.00072	0.00240	0.00054	0.00410	0.00089
Route 31										
P10	0.00180	0.00040	0.00158	0.00034	0.00282	0.00060	0.00155	0.00032	0.00158	0.00035
P50	0.00610	0.00128	0.00522	0.00110	0.00392	0.00084	0.00252	0.00054	0.00393	0.00084
P90	0.01382	0.00291	0.01271	0.00272	0.00622	0.00135	0.00447	0.00100	0.00876	0.00187
Route 32										
P10	0.00111	0.00023	0.00122	0.00026	0.00232	0.00050	0.00110	0.00023	0.00130	0.00027
P50	0.00221	0.00049	0.00202	0.00042	0.00308	0.00065	0.00202	0.00043	0.00236	0.00054
P90	0.01507	0.00321	0.01309	0.00278	0.00421	0.00085	0.00361	0.00084	0.00961	0.00210
Route 33										
P10	0.02919	0.00638	---	---	---	---	---	---	0.00213	0.00046
P50	0.03813	0.00804	---	---	---	---	---	---	0.00287	0.00060
P90	0.04912	0.00976	---	---	---	---	---	---	0.00417	0.00087
Route 34										
P10	0.00034	0.00007	0.00037	0.00008	0.00056	0.00012	0.00031	0.00007	0.00027	0.00006
P50	0.00055	0.00011	0.00057	0.00012	0.00077	0.00016	0.00051	0.00010	0.00061	0.00013
P90	0.00206	0.00045	0.00139	0.00033	0.00119	0.00026	0.00128	0.00029	0.00163	0.00038
Route 35										
P10	0.00364	0.00083	0.00221	0.00051	0.00133	0.00028	0.00180	0.00037	0.00284	0.00063
P50	0.01142	0.00243	0.00883	0.00189	0.00247	0.00054	0.00374	0.00080	0.00792	0.00172
P90	0.03335	0.00708	0.02976	0.00637	0.00609	0.00145	0.00775	0.00188	0.02319	0.00503
Route 36										
P10	0.00706	0.00151	0.00566	0.00122	0.00232	0.00049	0.00223	0.00048	0.00506	0.00110
P50	0.01401	0.00293	0.01244	0.00261	0.00436	0.00094	0.00467	0.00104	0.00998	0.00211
P90	0.03026	0.00640	0.02820	0.00599	0.01220	0.00256	0.01217	0.00260	0.02176	0.00463
Route 37										

P10	---	---	---	---	---	---	---	---	---	---
P50	---	---	---	---	---	---	---	---	---	---
P90	---	---	---	---	---	---	---	---	---	---
Route 38										
P10	0.00073	0.00015	0.00061	0.00013	0.00073	0.00016	0.00066	0.00014	0.00097	0.00021
P50	0.00356	0.00079	0.00236	0.00055	0.00117	0.00024	0.00159	0.00036	0.00321	0.00074
P90	0.02408	0.00516	0.02143	0.00464	0.00437	0.00102	0.00561	0.00131	0.01709	0.00366
Route 39										
P10	0.00095	0.00021	0.00113	0.00024	0.00324	0.00070	0.00090	0.00019	0.00061	0.00013
P50	0.00141	0.00029	0.00165	0.00034	0.00449	0.00094	0.00141	0.00028	0.00121	0.00026
P90	0.00307	0.00070	0.00319	0.00071	0.00699	0.00154	0.00387	0.00085	0.00342	0.00078
Route 40										
P10	0.00041	0.00009	0.00046	0.00010	0.00088	0.00019	0.00038	0.00008	0.00030	0.00006
P50	0.00069	0.00014	0.00074	0.00015	0.00124	0.00025	0.00063	0.00013	0.00089	0.00019
P90	0.00292	0.00068	0.00282	0.00063	0.00274	0.00062	0.00314	0.00069	0.00327	0.00079
Route 41										
P10	---	---	---	---	---	---	---	---	---	---
P50	---	---	---	---	---	---	---	---	---	---
P90	---	---	---	---	---	---	---	---	---	---
Route 42										
P10	0.00391	0.00084	0.00387	0.00083	0.00321	0.00069	0.00282	0.00061	0.00325	0.00070
P50	0.00547	0.00115	0.00548	0.00116	0.00507	0.00107	0.00427	0.00091	0.00451	0.00095
P90	0.00781	0.00160	0.00792	0.00162	0.00772	0.00159	0.00637	0.00132	0.00642	0.00133
Average										
P10	0.00265	0.00058	0.00180	0.00039	0.00521	0.00114	0.00134	0.00028	0.00134	0.00028
P50	0.00399	0.00084	0.00296	0.00062	0.00675	0.00142	0.00178	0.00038	0.00220	0.00046
P90	0.00623	0.00130	0.00518	0.00108	0.00875	0.00177	0.00261	0.00057	0.00374	0.00079

C.4 Discounted present values of incremental capacity costs for each route, all scenarios, PTC case

Total Discounted Present Value of Coal-Related Costs (2005$) -- w/ PTC signaling

	BAU1		BAU2a		BAU2b		BAU2b+LowH2		BAU2b+HighH2	
	C.M. #1	C.M. #2	C.M. #1	C.M. #2	C.M. #1	C.M. #2	C.M. #1	C.M. #2	C.M. #1	C.M. #2
Route 1										
P10	255,761,580	102,720,720	217,895,108	87,268,649	59,638,062	24,705,385	94,197,305	38,973,669	247,497,560	99,727,199
P50	407,678,859	177,712,804	354,233,520	155,593,528	127,206,956	55,393,070	191,387,110	82,722,333	398,533,200	175,191,879
P90	783,373,890	343,920,189	690,596,856	301,957,071	300,747,422	131,602,554	410,049,827	184,046,910	771,912,850	341,801,787
Route 2										
P10	46,141,232	19,295,344	25,385,325	11,293,171	8,434,310	3,434,917	20,122,981	8,265,588	50,092,256	21,304,415
P50	151,672,461	64,224,876	112,552,008	47,574,781	18,932,508	8,540,599	47,008,971	20,529,286	146,895,041	63,263,032
P90	486,131,553	208,577,825	398,724,585	170,674,050	81,197,966	35,897,157	156,204,569	68,358,210	475,472,741	208,541,537
Route 3										
P10	18,128,938	7,184,478	17,603,812	6,970,147	15,403,667	6,107,493	15,936,129	6,297,827	18,026,958	7,147,236
P50	22,142,290	9,319,004	21,479,684	9,044,162	18,792,775	7,903,020	19,441,265	8,170,071	22,073,622	9,291,880
P90	27,028,160	11,955,364	26,190,405	11,587,325	22,810,239	10,135,492	23,628,520	10,503,486	26,913,631	12,000,789
Route 4										
P10	15,571,237	6,178,174	15,181,919	6,015,244	13,563,367	5,350,638	13,959,311	5,516,880	15,711,311	6,224,238
P50	19,094,639	8,066,592	18,606,111	7,846,333	16,569,184	6,958,777	17,109,059	7,200,880	19,574,325	8,288,701
P90	23,432,420	10,441,162	22,767,776	10,130,857	20,101,573	8,961,705	20,818,692	9,316,271	25,360,631	11,390,901
Route 5										
P10	288,494,617	119,208,765	187,905,964	79,376,969	75,518,942	30,335,367	111,436,130	45,039,319	273,087,019	115,287,041
P50	576,204,712	246,597,446	445,525,596	189,762,239	114,576,318	50,225,881	192,790,236	85,061,240	555,147,257	239,835,714
P90	1,365,716,006	587,922,581	1,113,118,695	483,931,507	221,960,914	104,514,360	401,860,529	195,773,238	1,332,237,837	585,509,867
Route 6										
P10	42,073,669	18,230,624	28,774,524	12,151,211	14,959,879	5,986,439	26,083,042	10,340,227	45,775,611	19,429,246
P50	109,474,755	46,294,763	73,121,586	31,098,531	21,701,932	9,386,802	38,496,294	17,194,603	104,094,508	45,064,435
P90	213,820,392	93,586,836	165,744,650	72,692,607	34,260,362	16,491,047	65,222,073	31,958,858	207,758,091	92,025,615
Route 7										
P10	9,158,458	3,668,733	8,956,704	3,576,692	8,026,357	3,196,445	8,433,065	3,372,344	10,380,768	4,208,181
P50	15,231,335	6,472,085	12,902,858	5,664,625	10,196,524	4,328,320	13,561,400	5,829,080	37,713,115	17,036,786
P90	416,112,148	174,915,674	288,195,368	121,284,488	25,584,642	11,564,932	83,064,295	39,079,073	401,493,380	167,953,817

Route 8										
P10	3,417,677	1,352,158	3,381,073	1,339,039	3,234,268	1,285,526	3,276,252	1,300,139	3,434,671	1,359,704
P50	4,165,046	1,740,681	4,122,427	1,720,823	3,964,414	1,650,492	4,006,405	1,669,428	4,185,915	1,749,069
P90	4,995,649	2,232,502	4,936,706	2,206,378	4,727,934	2,106,380	4,785,421	2,135,296	5,029,313	2,247,198
Route 9										
P10	74,661,763	30,335,456	66,508,762	27,067,061	44,188,781	17,992,039	64,433,927	25,958,934	90,330,130	36,925,760
P50	209,071,222	88,474,994	155,765,963	68,624,411	72,095,149	31,038,681	101,992,079	45,280,545	205,157,385	89,450,788
P90	476,080,456	205,125,962	409,575,511	176,312,345	159,411,113	69,627,515	223,486,374	99,285,515	464,674,058	203,754,841
Route 10										
P10	10,173,696	4,142,862	9,730,018	3,965,746	8,222,017	3,313,093	8,828,987	3,612,298	10,769,423	4,436,831
P50	14,863,918	6,155,349	13,929,157	5,818,996	11,332,852	4,742,452	12,845,348	5,359,729	17,026,921	7,126,390
P90	21,550,118	9,524,446	19,772,919	8,746,772	15,440,088	6,733,690	18,939,180	8,386,330	25,684,701	11,812,017
Route 11										
P10	22,563,862	9,217,406	21,501,725	8,809,386	18,156,820	7,389,115	19,532,755	7,967,272	25,933,635	10,508,739
P50	35,437,320	14,929,660	32,938,273	13,829,686	25,603,323	10,652,863	31,155,890	13,159,333	44,814,648	19,073,997
P90	59,877,926	27,834,533	52,761,204	24,171,801	37,463,518	16,494,763	52,968,389	24,563,513	75,818,540	36,014,466
Route 12										
P10	36,933,194	15,018,000	33,046,972	13,256,781	20,576,334	8,366,363	33,246,643	13,335,106	47,758,579	19,331,220
P50	106,964,928	45,560,115	74,948,208	33,768,932	35,345,318	15,046,999	54,179,552	24,266,743	106,342,202	47,777,173
P90	282,877,319	120,655,510	241,751,633	103,564,013	85,169,638	37,590,893	128,379,728	56,593,359	277,191,128	119,868,612
Route 13										
P10	22,505,790	8,936,270	22,176,758	8,815,361	21,031,749	8,389,136	21,330,627	8,504,582	22,904,748	9,092,050
P50	27,400,298	11,437,051	27,012,275	11,290,531	25,653,247	10,687,986	26,005,821	10,854,088	28,420,113	11,966,608
P90	32,973,010	14,700,186	32,485,515	14,480,231	30,454,297	13,688,365	30,984,211	13,936,795	36,390,564	16,360,726
Route 14										
P10	17,292,708	7,002,046	16,628,806	6,638,922	14,112,222	5,646,687	15,002,754	6,008,020	17,876,972	7,256,431
P50	23,707,089	9,958,214	22,286,784	9,324,337	18,377,421	7,712,880	20,314,533	8,543,673	27,453,608	11,750,536
P90	36,548,356	16,494,162	32,078,818	14,103,584	24,165,618	10,613,035	31,915,595	14,216,794	52,710,588	24,382,930
Route 15										
P10	9,756,482	3,924,399	9,460,736	3,779,255	8,463,699	3,373,537	8,953,678	3,554,343	11,154,462	4,533,817
P50	14,622,136	6,270,079	13,632,405	5,790,398	10,988,941	4,615,134	13,216,878	5,632,629	19,509,757	8,266,900

P90	54,047,511	23,856,539	39,277,443	17,123,481	15,004,527	6,659,502	22,903,461	10,727,902	53,008,263	23,270,556
Route 16										
P10	15,987,219	6,373,199	15,620,993	6,221,051	14,118,126	5,611,720	14,480,218	5,755,527	16,011,183	6,379,899
P50	19,793,944	8,349,001	19,316,545	8,143,277	17,347,039	7,327,545	17,851,093	7,544,749	19,882,390	8,389,819
P90	24,683,696	10,935,631	24,058,009	10,640,343	21,437,627	9,479,891	22,124,880	9,815,642	24,796,269	11,008,735
Route 17										
P10	6,188,645	2,476,331	5,961,425	2,385,375	5,068,630	2,026,355	5,274,702	2,109,582	6,198,160	2,478,265
P50	7,981,718	3,343,358	7,678,456	3,217,589	6,491,757	2,724,680	6,783,631	2,846,164	8,002,296	3,365,175
P90	10,365,271	4,548,203	9,965,462	4,374,187	8,388,225	3,684,480	8,799,518	3,884,970	10,365,914	4,606,460
Route 18										
P10	1,729,053	691,068	1,670,211	663,766	1,425,289	567,380	1,506,536	602,292	1,803,568	725,963
P50	2,372,873	1,024,808	2,225,581	955,571	1,812,674	765,864	2,149,362	921,863	3,351,889	1,397,453
P90	9,780,141	4,128,329	7,049,984	2,967,241	2,511,104	1,134,931	4,218,078	2,014,550	10,047,482	4,377,557
Route 19										
P10	9,215,806	3,688,437	8,938,546	3,590,059	7,910,846	3,165,802	8,165,555	3,267,221	9,141,943	3,661,479
P50	11,604,710	4,867,267	11,258,999	4,728,855	9,878,620	4,158,491	10,236,349	4,308,883	11,543,435	4,846,160
P90	14,651,081	6,466,298	14,204,264	6,266,423	12,355,574	5,451,972	12,872,701	5,683,589	14,618,302	6,466,738
Route 20										
P10	6,339,143	2,531,935	6,122,778	2,429,558	5,238,066	2,078,956	5,571,871	2,216,828	6,637,818	2,672,294
P50	8,886,578	3,812,201	8,209,077	3,545,162	6,592,583	2,783,389	7,790,151	3,365,899	12,628,745	5,291,271
P90	42,888,835	18,179,685	29,821,842	12,591,148	9,163,420	4,072,987	16,085,129	7,688,973	42,808,455	18,417,873
Route 21										
P10	6,870,864	2,719,683	6,737,164	2,666,591	6,155,182	2,445,606	6,299,386	2,499,339	6,884,691	2,722,983
P50	8,375,935	3,499,694	8,208,618	3,428,840	7,534,700	3,137,801	7,698,119	3,210,610	8,388,655	3,504,831
P90	10,048,279	4,490,537	9,836,732	4,398,203	8,995,770	4,008,717	9,210,296	4,112,181	10,094,276	4,511,188
Route 22										
P10	12,525,815	4,985,573	12,274,639	4,886,089	11,321,222	4,515,938	11,567,876	4,606,911	12,749,010	5,065,795
P50	15,687,334	6,648,486	15,338,855	6,483,434	14,028,480	5,914,841	14,464,743	6,133,981	16,387,524	6,913,112
P90	20,344,649	9,025,049	19,496,793	8,613,352	17,545,036	7,752,157	18,666,962	8,320,879	25,181,395	11,152,075
Route 23										

P10	4,511,665	1,782,084	4,346,261	1,720,131	3,770,033	1,497,284	3,971,822	1,573,806	4,596,421	1,827,126
P50	5,708,566	2,428,118	5,418,872	2,279,854	4,643,898	1,935,918	5,019,198	2,134,958	6,360,088	2,796,614
P90	9,411,171	4,241,436	7,701,061	3,384,350	5,565,243	2,501,320	8,467,194	3,744,921	15,165,331	7,303,563
Route 24										
P10	45,634,826	19,696,364	36,480,037	15,163,825	24,347,353	9,782,200	34,492,293	13,850,987	53,469,144	22,501,722
P50	171,434,035	72,083,492	142,611,613	60,597,534	46,697,771	22,352,399	71,764,650	33,455,760	169,717,066	71,072,431
P90	308,521,729	135,375,700	276,672,712	122,019,108	156,723,374	67,140,306	190,463,596	83,497,770	305,924,050	135,609,423
Route 25										
P10	5,700,777	2,275,331	5,584,368	2,225,086	5,088,692	2,018,454	5,212,668	2,062,958	5,665,615	2,259,319
P50	6,948,401	2,894,487	6,798,492	2,832,299	6,192,296	2,577,031	6,340,944	2,641,365	6,903,410	2,878,672
P90	8,231,889	3,702,493	8,055,791	3,627,155	7,339,232	3,292,050	7,526,751	3,380,589	8,208,150	3,699,506
Route 26										
P10	1,710,925	694,346	1,593,080	633,687	1,273,838	509,003	1,462,601	592,378	2,512,976	1,029,795
P50	3,478,333	1,481,130	3,118,381	1,321,551	2,077,494	890,767	3,304,234	1,401,874	5,273,053	2,310,142
P90	11,200,371	4,806,067	8,717,777	3,782,620	4,484,109	2,155,194	6,813,779	3,287,191	11,762,837	5,366,170
Route 27										
P10	7,744,184	3,066,424	7,595,764	2,998,442	6,908,862	2,741,812	7,079,498	2,808,440	7,784,228	3,082,638
P50	9,468,719	3,957,628	9,273,264	3,880,913	8,463,108	3,527,125	8,670,611	3,621,049	9,528,279	3,986,536
P90	11,355,019	5,105,058	11,118,967	4,995,670	10,129,662	4,532,302	10,409,242	4,673,962	11,532,529	5,205,241
Route 28										
P10	4,102,252	1,646,025	4,095,632	1,643,283	4,069,823	1,632,696	4,075,760	1,635,183	4,139,584	1,656,514
P50	5,200,418	2,165,012	5,191,715	2,161,408	5,157,816	2,147,260	5,168,926	2,150,736	5,229,362	2,177,163
P90	6,354,132	2,831,922	6,341,153	2,827,321	6,299,400	2,809,684	6,308,496	2,814,297	6,391,036	2,853,775
Route 29										
P10	1,864,987	746,726	1,864,171	746,420	1,861,050	745,245	1,862,347	745,494	1,880,249	752,436
P50	2,351,107	992,221	2,350,084	991,804	2,346,169	990,206	2,347,008	990,605	2,367,147	997,713
P90	2,942,060	1,293,133	2,940,727	1,292,562	2,935,686	1,290,402	2,937,009	1,290,977	2,959,133	1,308,260
Route 30										
P10	10,714,044	4,514,329	9,183,496	3,719,512	6,785,251	2,660,913	10,034,923	3,967,240	14,596,949	6,018,153
P50	31,253,019	13,136,221	22,217,366	9,411,835	8,998,747	3,910,954	14,670,621	6,527,453	32,018,617	13,820,879
P90	64,654,088	28,176,912	51,510,787	22,371,440	13,327,088	6,269,469	24,319,314	11,630,521	65,016,166	28,955,248

Route 31										
P10	16,367,190	7,064,637	11,209,595	4,805,387	7,508,976	2,990,735	11,912,602	4,907,955	21,241,082	9,258,962
P50	52,613,848	22,108,017	37,486,422	15,816,236	10,425,172	4,520,910	19,726,043	8,852,791	53,087,140	22,908,987
P90	121,700,451	51,376,555	93,352,996	39,376,569	16,899,057	7,831,689	37,759,645	17,728,561	119,465,618	52,238,091
Route 32										
P10	5,405,171	2,188,295	5,071,859	2,060,872	4,647,954	1,849,297	5,107,267	2,067,818	8,768,737	3,570,397
P50	11,011,995	4,987,609	8,047,724	3,528,098	6,057,084	2,540,566	8,951,055	3,766,351	17,690,550	8,340,819
P90	73,752,493	31,546,123	54,146,453	23,322,941	7,840,630	3,489,181	17,398,119	8,468,793	70,893,365	30,986,985
Route 33										
P10	5,942,739	2,383,768	5,830,360	2,338,290	5,354,392	2,149,611	5,468,219	2,191,426	6,052,630	2,426,316
P50	7,487,434	3,129,258	7,344,469	3,071,319	6,770,504	2,825,922	6,922,105	2,887,799	7,852,257	3,290,042
P90	9,098,765	4,045,569	8,925,568	3,970,527	8,215,918	3,662,751	8,417,347	3,754,596	11,121,326	4,949,049
Route 34										
P10	11,275,060	4,507,621	10,860,776	4,319,484	9,352,876	3,727,372	9,915,143	3,973,358	12,261,302	4,911,660
P50	16,953,445	7,358,768	15,526,685	6,725,353	12,172,164	5,133,077	14,861,724	6,522,160	26,788,900	11,469,104
P90	67,791,556	29,588,787	43,119,348	19,537,981	19,036,735	8,322,780	39,647,125	18,292,522	79,612,027	37,899,186
Route 35										
P10	39,890,320	17,166,125	21,559,196	9,262,601	7,500,618	3,061,336	16,775,640	6,876,239	41,693,068	17,719,101
P50	121,919,645	51,104,617	83,258,827	34,718,201	13,914,885	6,215,177	35,834,889	15,664,644	117,403,454	50,112,616
P90	355,191,210	153,205,611	282,287,191	121,227,173	37,643,060	18,499,809	87,167,935	42,517,697	346,100,243	152,377,101
Route 36										
P10	103,715,482	42,429,749	74,472,558	30,963,868	18,129,359	7,423,455	29,387,763	12,668,398	100,276,724	41,037,458
P50	200,617,389	84,670,641	157,702,743	68,032,929	34,170,701	15,273,655	65,486,260	29,007,002	194,090,417	83,739,556
P90	438,233,523	189,552,365	366,290,286	157,817,795	96,548,426	42,223,509	168,439,065	74,692,474	431,077,912	187,230,142
Route 37										
P10	1,971,668	787,996	1,926,394	769,926	1,743,596	696,510	1,779,990	710,662	1,959,383	783,057
P50	2,481,553	1,035,457	2,424,058	1,011,622	2,192,891	915,409	2,238,746	934,569	2,460,745	1,030,551
P90	3,018,710	1,332,326	2,950,173	1,301,482	2,670,920	1,177,412	2,726,210	1,203,381	3,001,254	1,323,298
Route 38										
P10	36,065,578	14,715,601	27,748,425	11,392,598	20,779,961	8,326,931	31,195,647	12,866,881	66,034,346	28,102,069

P50	193,363,382	84,006,033	114,875,146	53,176,528	30,941,038	13,485,220	79,672,761	36,028,335	238,412,574	109,572,144
P90	1,252,175,699	540,656,521	1,002,601,991	424,645,723	130,950,650	62,631,551	298,972,535	139,838,737	1,216,368,080	527,675,112
Route 39										
P10	4,626,569	1,857,963	4,475,056	1,786,573	3,869,332	1,547,605	4,086,613	1,631,015	4,759,918	1,912,499
P50	6,505,478	2,830,325	6,177,572	2,661,787	5,165,721	2,191,589	5,932,211	2,592,925	9,123,181	3,835,960
P90	15,193,209	6,974,636	12,395,689	5,610,644	8,257,929	3,673,710	16,750,699	7,700,793	26,802,874	12,515,733
Route 40										
P10	4,277,695	1,711,550	4,123,740	1,642,017	3,530,460	1,411,118	3,732,352	1,495,364	4,564,037	1,830,967
P50	6,765,603	2,975,650	6,025,264	2,640,078	4,692,777	2,004,463	5,881,541	2,613,733	12,646,182	5,350,664
P90	30,516,440	14,574,540	24,215,658	11,015,690	10,920,865	4,939,093	29,317,930	13,571,594	52,866,095	25,470,289
Route 41										
P10	1,675,725	672,486	1,628,168	653,434	1,433,436	576,848	1,475,043	593,997	1,658,342	664,834
P50	2,109,922	880,721	2,049,433	855,927	1,806,756	755,124	1,860,762	777,782	2,088,394	872,017
P90	2,554,843	1,136,088	2,478,989	1,103,120	2,186,470	968,547	2,254,114	999,641	2,536,946	1,128,002
Route 42										
P10	352,512,212	141,856,076	326,326,740	130,996,860	213,956,377	86,553,025	246,309,654	98,377,358	350,226,666	140,048,581
P50	484,963,811	203,730,593	456,266,889	191,123,178	335,692,790	140,495,091	369,888,552	154,565,358	481,911,147	202,860,806
P90	675,974,632	296,089,746	643,086,443	279,812,975	500,843,314	216,730,589	542,866,413	236,151,091	672,549,030	296,211,688
Sum										
P10	2,099,871,321	868,800,959	1,660,692,380	695,530,694	849,359,397	338,001,543	1,153,597,376	460,959,727	2,182,869,119	896,564,409
P50	3,724,673,044	1,576,406,949	3,021,826,955	1,283,720,782	1,238,387,194	531,912,706	1,731,601,181	763,880,379	3,731,873,337	1,609,157,400
P90	6,440,593,359	2,793,118,289	5,411,689,958	2,352,422,487	1,990,797,662	903,123,489	2,905,191,198	1,341,025,085	6,368,987,835	2,853,639,407
Average										
P10	49,996,936	20,685,737	39,540,295	16,560,255	20,222,843	8,047,656	27,466,604	10,975,232	51,973,074	21,346,772
P50	88,682,692	37,533,499	71,948,261	30,564,781	29,485,409	12,664,588	41,228,600	18,187,628	88,854,127	38,313,271
P90	153,347,461	66,502,816	128,849,761	56,010,059	47,399,944	21,502,940	69,171,219	31,929,169	151,642,567	67,943,795

Appendix D: Corollary on Coal-to-Liquid Synfuels Production

The focus of the analysis has thus far been centered on the production of both electricity and hydrogen from coal. However, an (arguably) more near-term option for using coal in the transportation sector is to make synthetic fuels ("synfuels"), such as diesel, from it. Synfuels certainly have been receiving a great deal of attention lately due to concerns over high oil prices and energy security. Although I did not model different scenarios of coal-to-liquid synfuels growth in the U.S., I can use the scenarios for electricity/hydrogen that I did model and make some rough inferences about coal synfuels futures. This is possible because in my modeling framework the specific use of coal is of secondary importance to the aggregate amount of coal being used in a given year. While it is certainly true that different coal types (in terms of heating values, moisture/ash/sulfur contents, etc.) lend themselves better to some situations and technologies than others, one of the fundamental assumptions of my analysis is that the required technologies will exist when and where they are needed in order to produce the desired products from whatever types of coal are used as a feedstock. Therefore, I can take my scenarios for electricity/hydrogen demand and assume that instead of using a certain amount of coal to produce electricity and/or hydrogen, the coal is instead used to make liquid synfuels. By this logic, all that ultimately matters is the total amount of coal that is demanded and distributed around the country, not the specific desired end-uses of the coal.

It is possible to use the previously described electricity/hydrogen scenarios (BAU1, BAU2a, BAU2b, BAU2+LowH2, BAU2+HighH2) to construct some rough scenarios representing coal synfuels growth. It should be remembered that although the

Reference Case scenario of the EIA's Annual Energy Outlook 2006 (AEO2006) was not explicitly modeled, it was in fact used to develop the scenarios that I did model. The graph below shows how these scenarios compare to each other on an annual basis. (Note that BAU1 is represented by "EIA w/ Coal-to-Liquids (High)" in the graph. This notation will be discussed more fully later on.)

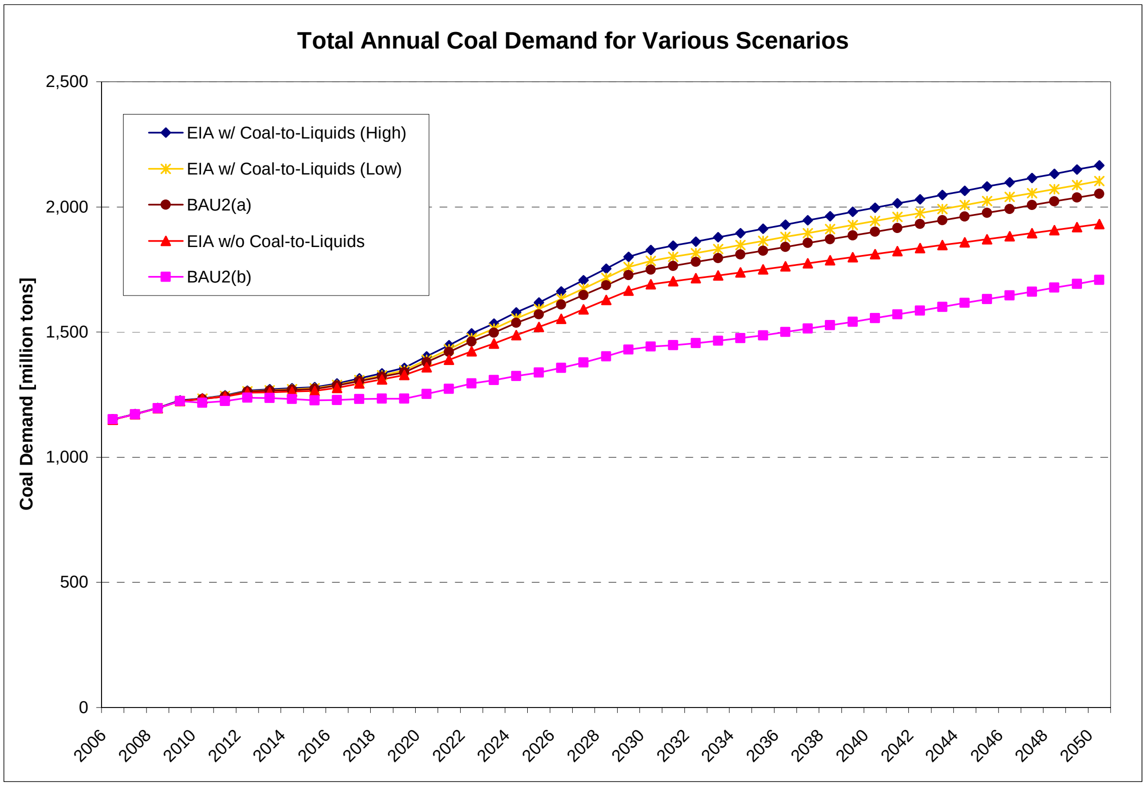

Figure A.D-1: Total annual coal demand for various scenarios

Three scenarios in the graph above refer to the EIA's Reference Case scenario—"EIA w/ Coal-to-Liquids (High)", "EIA w/ Coal-to-Liquids (Low)" and "EIA w/o Coal-to-Liquids". "EIA w/ Coal-to-Liquids (High)" is really just the previously described BAU1 scenario, and "EIA w/ Coal-to-Liquids (Low)" is the same as the EIA's Reference Case scenario. "EIA w/o Coal-to-Liquids" is fairly similar to the BAUa scenario.

The EIA's Reference Case assumes a certain amount of coal synfuels growth between now and 2030. I simply extrapolate the 2006-2030 growth trend in coal used for synfuels to project Reference Case coal synfuels demand out to 2050. Then, I subtract the amount of coal demand for synfuels from the EIA's Reference Case forecast of total annual coal demand. This yields two different scenarios: "EIA w/ Coal-to-Liquids (Low)" which assumes that new PC and IGCC coal electric capacity is built and that coal synfuels production capacity expands, and "EIA w/o Coal-to-Liquids" which assumes that new PC and IGCC coal electric capacity is built but that no expansion in coal synfuels production capacity takes place. Since there is no initial coal synfuels production in the EIA's Reference Case, the "EIA w/o Coal-to-Liquids" scenario is simply the EIA's Reference Case scenario but without any coal being used for synfuels production. From the graph above, the total amount of coal demand in each year of the "EIA w/o Coal-to-Liquids" scenario falls somewhere between the BAU2a and BAU2b scenarios, though it is quite a bit closer to the BAU2a scenario.

After developing a scenario with no coal-to-liquid synfuels production included, it is then useful to develop a contrasting scenario in which coal demand for synfuels does grow. I have used the BAU1 scenario to represent this latter case. The coal demand in BAU1 is higher than that in the EIA Reference Case (or in my new parlance, "EIA w/ Coal-to-Liquids (Low)") because it assumes that 100%, instead of 45%, of new coal power plant capacity will be PC. Also, since it is based on the EIA Reference Case, BAU1 also assumes that a certain amount of coal is used to produce synfuels. I can modify BAU1 for my purposes, however, by assuming that, like the EIA Reference Case, only 45% of coal electric capacity is met by PC, with the other 55% being met by IGCC.

When this assumption is made, a certain amount of coal gets “freed up” in a sense due to the greater efficiencies of IGCC. I then assume that this freed-up coal is used to produce synfuels. This yields a scenario, which I call “EIA w/ Coal-to-Liquids (High)”, in which coal synfuels production is even higher than in the EIA Reference Case scenario, i.e. “EIA w/ Coal-to-Liquids (Low)”.

Based on the assumptions and modifications mentioned above, I can focus my analysis on two scenarios of interest—“EIA w/ Coal-to-Liquids (High)” and “EIA w/o Coal-to-Liquids”—both of which have already been modeled to some degree in my other analyses of coal demand growth. The levels of coal demand in 2030 under these two different scenarios are, respectively, 1828 and 1691 million tons per year (mtpy). In 2050 the levels are 2166 and 1932 mtpy. The differences between the two scenarios are, of course, the amounts of coal being used for coal-to-liquid synfuels production in the “EIA w/ Coal-to-Liquids (High)” scenario. Thus, under the “EIA w/ Coal-to-Liquids (High)” scenario in 2030, some 137 mtpy of coal are used for making liquid synfuels, while in 2050 this figure is up to 234 mtpy. The corresponding values for the “EIA w/o Coal-to-Liquids” scenario are, of course, both zero. Based on projected levels of coal synfuels production and corresponding coal demand for synfuels as given in the EIA AEO2006 (EIA, 2006b; EIA, 2006n), this translates into roughly 1.11 million barrels per day (mbpd) of petroleum supply in 2030 and 1.89 mbpd in 2050 under the “EIA w/ Coal-to-Liquids (High)” scenario. These supplies of coal synfuels represent approximately 5.6% and 8.5% of total petroleum supplies to the transportation sector in 2030 and 2050, respectively, based on total projected transportation petroleum supplies of 19.81 and 22.12 mbpd (EIA, 2006b; EIA, 2006n). (Projections come from EIA’s Reference Case scenario and my extrapolations out to 2050.) I can then use the "EIA w/ Coal-to-Liquids (High)" scenario and compare it to the "EIA w/o Coal-to-Liquids" scenario to analyze the impact that increased coal demand for synfuels production might have on the rail transportation network if coal synfuels account for 5.6% and 8.5% of all petroleum supplied to the transportation sector in 2030 and 2050, respectively. I do not model these two scenarios explicitly, but rather they can be represented by the modeling that I have already described for the BAU1 scenario (i.e., "EIA w/ Coal-to-Liquids (High)") and a combination of the BAU2a and BAU2b scenarios (i.e., "EIA w/o Coal-to-Liquids"). The following table summarizes the coal-to-liquid synfuels scenarios.

	EIA w/o Coal-to-Liquids		**EIA w/ Coal-to-Liquids (High)**	
Year	***2030***	***2050***	***2030***	***2050***
Total Annual Coal Demand (mtpy)	1691	1932	1828	2166
Coal Demand for Synfuels (mtpy)	0	0	137	234
Petroleum from Coal Synfuels (mbpd)	0	0	1.11	1.89
Synfuels' Share of Transportation Sector Petroleum Supply (%)	0	0	5.6	8.5

Table A.D-1: Summary of coal-to-liquid synfuels scenarios