An Intermodal Network Model of Coal Distribution in the United States and Its Economic Implications for the Inland Waterway System

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Kentucky Transportation Center
176 Oliver H. Raymond Building
Lexington, KY 40506-0281
(859) 257-4513

www.ktc.uky.edu

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Research Report
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An Intermodal Network Model of Coal Distribution in the United States and Its Economic Implications for the Inland Waterway System

Authors:

Benjamin Blandford, PhD
Senior Research Scientist

Ted Grossardt, PhD
Program Manager

Michael Shouse, PhD
Research Associate

and

John Ripy, BS
Research Associate

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky

In Cooperation with
Multimodal Transportation and Infrastructure Consortium
P.O. Box 5425 Huntington, WV 25703-0425 • Phone: (304) 696-2313 • Fax: (304) 696-6088

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16. Abstract
This paper describes a GIS-based intermodal network model for the shipment of coal in the United States. The purpose of this research was to investigate the role played by railways, waterways, and highways in the movement of coal from its source area to point of use, and to highlight the implications these movements have for the U.S. economy. The project team modeled coal movements across the U.S. intermodal transportation network using the Energy Information Administration's 2010 data, which provided detailed origin, destination, primary mode, and volume information for coal shipments. The model identifies the optimum routes for coal shipments based on a rate structure that accounts for the relative costs of shipping by each of the modes. The model, as well as available statistics, reveals the dominance of coal mined from the Powder River Basin. Compared to other sources— principally, the Appalachian Basin — coal from Mountain West is significantly less expensive, thus giving it a significant comparative advantage. Both Texas and Illinois, the two largest coal consumers by state, obtain virtually all of their coal from the West or from within state. Appalachian Basin coal serves domestic and export markets primarily in the East and Southeastern U.S. Only the Ohio River provides significant movement of Central Appalachian Basin coal to the west and south. Although this modeling relies on 2010 data, a look at more recent trends in coal prices and mining indicate that the Powder River Basin continues to dominate, while production and industry employment have steadily declined in the Appalachian Basin. The shift away from coal and toward natural gas as a primary energy source argues for the region's coal extraction industries remaining in a depressed state, which could produce negative economic consequences for transportation industries. Carrier and port facilities will need to adopt a more diversified shipping portfolio to accommodate for these losses. It is possible that the loss of coal will open up opportunities for other commodity shipments on the inland waterways. This modeling demonstrates the potential for such integrated models to accommodate energy-related or similar data, and serves as a tool for freight planners in identifying energy transportation corridors of significance. It could potentially be used to analyze the movement of other commodities, which could let industry stakeholders identify new markets to tap into. Further, the model and analysis can help inform MAP-21 related efforts to develop a National Freight Network and National Freight Strategic Plan.

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Introduction

Despite various government agencies gathering and compiling significant data, the full multimodal paths of energy movement in the U.S. are not well understood. One reason for this is that transportation analysis is frequently mode-specific. The U.S. Army Corps of Engineers (USACE) holds extremely detailed, though confidential, data on cargo volumes and movements along the inland river system. Once cargo leaves the river, the USACE has limited knowledge of its movements. Likewise, data on rail movements remain proprietary because the infrastructure and the rolling stock are both privately owned. And the pattern of truck freight movement is also proprietary because of the multitude of carriers and business confidentiality requirements. States tend to focus attention on the movements within or close to their systems, which provides limited geographic understanding of end-to-end movements that are national or even international in scope. Consequently, transportation agencies lack comprehensive knowledge of the spatial pattern movements of particular commodities as they move through the freight network. This is problematic in that it prevents analysis of volume-to-capacity ratios on different modes, thus determining what industries most frequently take advantage of particular modes, and what economic consequences modal shifts or the declining performance of a specific industry have on particular modes and their associated networks of shippers and carriers.

The objective of this research is to develop new knowledge of a lynchpin in the energy transportation system — coal movements — and evaluate how the three surface-based modes of railway, waterway, and highway integrate and complement one another during the shipment of commodities. Along with helping states respond to MAP-21 requirements that call for giving elevated consideration to investments in “identification of routes providing access to energy exploration, development, installation, or production locations,” (1) this work explains many of the recent economic trends observed in the coal industry. Additionally, this research can bolster efforts to develop a National Freight Network and National Freight Strategic Plan as prescribed by MAP-21. As market conditions and the sources used to shift power change, this research will be useful in anticipating the transformations that will occur on the highway network as it articulates with water and rail, thus furthering state DOT's knowledge and ability to meet the energy corridor requirements.

The United States is home to the world's largest estimated coal reserves. In 2012, the U.S. produced just over one billion tons of coal (2). This coal was produced by nearly 90,000 employees working in 1,200 coal mines located throughout the U.S. (2). The National Mining Association placed the total value of coal production in the U.S. at nearly $45 billion for 2011 (3). Approximately 90 percent of all domestic production goes toward U.S.-based generation of electricity. Though coal's overall share of the total electricity generation on the grid has declined some in recent years, it still remains at nearly 40 percent of total generation, down from closer to 50 percent in 2007 (4). This decline can be attributed to a surge in natural gas production (driven by its lower prices), the increased market penetration of renewable energy sources, increased production costs for the mining of coal in some regions, and the introduction of new environmental regulations that make coal a less attractive option (5).

Nonetheless, coal remains the largest source for energy generation in the U.S., as it has for the last six decades (6). A small share of coal consumed domestically is used in other industries, including the steel industry and for cement production. In 2011 the U.S. also imported about 10 million tons of coal, primarily from South America (6). Besides coal produced for domestic consumption, the share of coal produced for export has increased in recent years. In 2000, coal exports accounted for approximately 5 percent of production. By 2011, 10 percent of all U.S. coal production was exported, with South American, European, and Asian markets the primary destinations.

For the nation's freight transportation system, coal is a significant commodity. Because coal is one of the single largest commodities (by tonnage) moved in the U.S., its importance extends to all three surface modes of the transportation network — railways, waterways, and highways. More important facts about coal are listed below:

- In the rail industry, coal is the single largest ton-mile commodity. In 2011, it accounted for 43.3 percent of rail tonnage and 24.7 percent of rail gross revenue (7). Of all domestic coal shipments in 2011, over 71 percent were by rail (7).
- Coal is the second leading ton-mile commodity in the barge industry, just behind petroleum products. In 2009, coal accounted for nearly 24 percent of all commodities shipped on the nation's inland waterways (8). Of all domestic coal shipments in 2011, waterways accounted for nearly 11 percent of trips. This percentage is even higher when including exported coal (particularly through the ports of Mobile, New Orleans, and on the Great Lakes).
- For the trucking industry, coal shipments travel shorter distances than they do on the other two modes. In 2011, about 11 percent of all coal shipments went by truck. This percentage is even higher when accounting for partial trips from mine to ports, tipples, or other loading facilities.
- An additional 6 percent of coal was delivered directly by tram or conveyor from mine to power plant.

The geography of U.S. coal production is divided into three distinct coal producing regions (8). The Western Region is the largest, with total coal production at 587.6 million tons in 2011. It consists of the Powder River Basin of Wyoming and Montana, the largest coal producing basin in the country, in addition to mines stretching from the Dakotas to Arizona. The Interior Region is the second largest in terms of volume, producing 336.0 million tons of coal in 2011. It extends from the Illinois Basin of Illinois, Indiana, and western Kentucky, to the mines of eastern Texas. The Appalachian Region is the third largest in terms of volume, at 170.3 million tons of coal in 2011. The Appalachian Region includes mines stretching from

Pennsylvania and eastern Ohio, through the Appalachian Mountains of West Virginia and eastern Kentucky, and includes mines in Mississippi and Alabama in the south.

Among states, Wyoming is by far the largest producer of coal (8). In 2011, it produced 438 million tons of coal, or 40 percent of the total U.S. production. The next largest producer was West Virginia, at 135 million tons (12 percent). Kentucky, Pennsylvania, and Texas round out the top five producers of coal. The top domestic consumer of coal is Texas, followed by Midwest states lining the inland waterways: Illinois, Indiana, Ohio, and Missouri.

When modeling coal movement patterns, the intermodal character of coal distribution must be taken into account. In some instances, coal moves by unit trains directly from mine to power plant. Other times, coal from several mines is mixed together before delivery to meet the specific requirements of individual power plants. Most shipments that spend at least a portion of their trip on water are multimodal, meaning the coal will travel on more than one mode as it goes from the production site to destination. Rail cars or trucks deliver coal to ports for transloading onto the waterways. In some cases, coal is also transloaded off the water at the end of the trip before it is delivered by rail or truck to power plants. Many rail shipments are likewise multimodal because mines without direct rail access dispatch coal by truck to tipples, where it is then transloaded onto rail. Understanding and translating the complexity of coal transportation into an integrated freight network model is a challenging endeavor, but one that may result in significant value for transportation planners and policy makers at all levels by illuminating the spatial and temporal variability of movements and their implications on the economic health of various regions and industries.

Intermodal Network Modeling

Since it was signed into law, MAP-21 has increased the attention paid to freight movements on surface transportation modes. Its provisions have also motivated researchers to undertake projects focused on modeling freight shipments. Federal agencies, including the U.S. Department of Transportation, USACE, and the Environmental Protection Agency, have invested considerable resources toward these purposes, with some notable results. A number of models have been generated as a result of this push.

One model, referred to as Geospatial Intermodal Freight Transportation (GIFT), is a GIS-based intermodal network model that was developed to model intermodal freight flows in the California and the Great Lakes region (9, 10). GIFT calculates optimal freight routing across the surface transportation modes. Additionally, GIFT explores possibilities for modal substitution for shippers, and it evaluates both energy and environmental impacts of freight movements across regions. Another intermodal network model, prepared for the USACE, models shipments of grain from croplands to river locations and other destinations within the Ohio River Valley (11). This model utilizes early-year aerial photography of croplands to estimate the production and eventual shipment of grains. The model incorporates methods of barge-costing and rail-costing to integrate shipping rates and to optimize route choice for shippers.

The USACE developed the Regional Routing and Multi-Ports Analysis Model for the purposes of understanding the relationship between freight flows on the waterways and their associated costs (12). This model analyzes the movement of specific commodities to uncover how transportation costs and modal choice reflect changing trends in production and consumption. This model incorporates shipper response surveys to better understand and model how these changes manifest on the ground. Other studies have also leveraged shipper response to analyze and calculate modal elasticities for shippers who rely on the inland waterway system (13, 14).

Researchers have developed predictive models for a number of commodities, including coal. One such model incorporates transportation rates, coal production, coal consumption, and coal exports to estimate the predicted demand for barge transportation on the inland waterway system (15). This model is used to assist planners and policymakers in deciding where to make infrastructure improvements that will maximize the existing network's efficiency. Because this model has a national scale, it is most applicable to planning efforts at the federal or state level, particularly those implicated in the development of national freight strategies.

These modeling efforts have helped inform the data and methods used to develop the intermodal freight network model for this project. Whereas many of the models discussed here are predictive and estimate freight flows, the coal model in this project uses fully developed data, including origin, destination, volume, and modal type to simulate the routing of coal shipments in the U.S. In calibrating the model to accurately replicate existing patterns of coal distribution, the model captures and spatially translates current coal movement data across highways, railways, and waterways.

Methods — Network Model

The project team built the network model with ESRI ArcMap 10.1 using the program's Network Analyst toolset. The Network Analyst toolset lets users model data flows across a network with assigned impedances. The network is comprised of a set of shapefiles that represent highway, railway, and waterway segments, as well as a collection of nodes that represent intermodal access points, such as river ports, loading facilities, and rail interchanges.

The network data sources used in this model, which represent the transportation systems available for the shipment of coal, are described in the table below.

Data	**Source**
Highways	Oak Ridge National Highway Network
Rail	National Transportation Atlas Dataset (NTAD) 2012 Network • We created separate rail networks for each of the seven Class I carriers operating in the U.S. These include BNSF, Union Pacific, CSX, Norfolk Southern, Kansas City Southern, Canadian National, and Canadian Pacific. The remaining class II and short line railways that handle coal were combined into a separate and single railway network.
Waterways	National Waterway Network (NWN) • Data were obtained from the USACE's Navigation Data Center and included navigable rivers, intercoastal waterways, and the Great Lakes.
Ports	Multiple Sources • KTC and the University of Louisville conducted a survey of river ports along the inland navigable waterways. Survey results helped inform the locations of coal handling facilities in these areas. • Detailed river port information for West Virginia was obtained from its Department of Transportation. • Additional inland river ports data were obtained from Crounse Corporation, a barge operator throughout much of the inland waterway network.
Rail Loading Facilities	Trade Publications • Data came from trade publications of all the Class I rail carriers as well as Class II and short line carriers that handle coal.

Coal movement data used to populate the network were obtained from the U.S. Energy Information Administration (EIA). EIA releases monthly and annual reports on the production and distribution of energy-related fuels, including coal, natural gas, and petroleum. For this model, the team collected data from Form 923 for the year 2010, as this dataset was the most recent full set available when the project began. The coal movement dataset includes the full origin and destination of each coal shipment as well as the mode(s) of transportation used to move them. For the origins, this includes the mine name, operator, county, state, and identification number. For the destinations, this includes the power plant name, identification number, operator, and state identification number. The mode(s) of transportation include the primary mode type — the mode the shipment spent the longest duration on — and the secondary mode type, if applicable. The modes documented in the dataset are rail, water (i.e. river, Great Lakes, tidewater pier and coastal port), road, and conveyor. Coal shipments that traveled solely by conveyor from mine to a neighboring power plant were excluded because they were not captured by transportation networks in the model. Additionally, only coal shipments involving the contiguous 48 U.S. states were included.

The EIA data used in this model describe the shipments of just under one billion tons of coal, or approximately 89 percent of coal produced in 2010. Additional data included in the model was the 80 million tons produced for export, or about 7 percent of coal production. For these shipments, data capturing the volumes produced at origins and the volumes received at ports were available from other sources, but particular origin-destination combinations, modal selection, and routes traversed were not included in EIA Form 923. Routes for these shipments were calculated with the network model as part of a linear programming problem that minimized shipping cost across the network. The remaining coal produced for other domestic industries, which accounts for approximately 4 percent of production, was omitted from this model, as data pertaining to these shipments were not publicly available.

These data sources served as the starting point for developing the network. The team edited the network to produce separate rail networks for each Class I rail carrier. Additionally, connectivity rules and logic were developed to achieve proper network function. For example, the model restricts network flows by mode or by rail carrier, and only enables diversions through specified nodes, such as ports, transloading facilities, or rail interchanges. Some measure of impedance, captured through a shipping "rate", have been added to prevent the model from switching modes arbitrarily.

In the freight industry, shipping rates may vary significantly and are affected by mode, geography, distance, volume, and other factors. Shipping rates are also largely proprietary. When they are obtainable, the data are typically insufficient to describe network segments. For these reasons, estimated shipping rates were calculated by order of magnitude, wherein rates by water were equal to the trip distance, rail rates were calculated as three times the trip distance, and highway rates were calculated as five times the trip distance. These factors were adopted following conversations with industry experts.

Additionally, the price to switch modes, such as through a port, loading facility, or rail interchange, introduced additional trip costs. Rates for modal switches were estimated based on conversations with industry representatives and data obtained from industry publications. The rate to move through a truck-to-rail loading facility was set at 150, while the rate to move through a river port was placed at 300. In the model, these rates resulted in shipping via road, rail, and waterways as equal in cost at a distance of 150 miles when both the origin and destination were only directly accessible by truck (with rail and water loading/unloading facilities also located in between the origin and destination). As distances increased, rail, and where available, inland waterways, became more cost-effective. The rate for rail interchanges was placed significantly higher, particularly between competing Class I railways. The relative rate structures used here reflected those described in industry publications.

To test the accuracy of this shipping rate structure, all routes from origin to destination as identified in the EIA data were computed in the model without referencing the modal selection identified in the data. Routes were solved based on lowest cost from origin to destination across the entire network. The modal selection of the resulting modeled routes was compared to the modal selection as identified in the EIA data, where available. Comparison of the modeled routes to the actual routes yielded an accuracy of 85 percent of total routes, or 87 percent of volume of coal. A number of factors explain this discrepancy. Shipping decisions by utilities are influenced by factors beyond shipping costs, including modal reliability, existing business relationships, temporary disruptions in the supply chain, and others. In addition, the calculated shipping costs used by the model are only estimates, and cannot possibly reflect with complete certainty the actual shipping costs, which may be influenced by a wide range of external issues. Data entry errors within Form 923 also likely contribute to these inconsistencies.

Results

For demonstration purposes, the following figures aggregate coal mine origins at the county centroid. In other words, all coal produced from mines within a given county are displayed with a shared origin at the county's centroid.

Overall Model Results

Figure 1 shows the modeled routes and aggregate volume of coal shipped by truck across the U.S. In 2010, 197 million tons of coal, or 19 percent of all coal produced, was transported by a truck for at least a portion of its total shipment route. Of these, only 54 percent of the shipments by volume (107 million tons) were solely by truck, while the remaining 46 percent (89 million tons) were multimodal, primarily truck to barge or to rail loading facility. As Figure 1 shows, the majority of coal shipments by truck occur east of the Mississippi River. One reason for this is the close proximity of coal mines to the inland waterway system. Often, coal moves relatively short distances from mine to river port before being transferred onto barge for longer hauls. Second, the number and density of coal burning power plants in the Illinois and Appalachian Coal Basins is greater than elsewhere. In instances where coal only needs to move short distances from mine to power plant, trucks are more competitive with other shipping modes in terms of shipping rates.

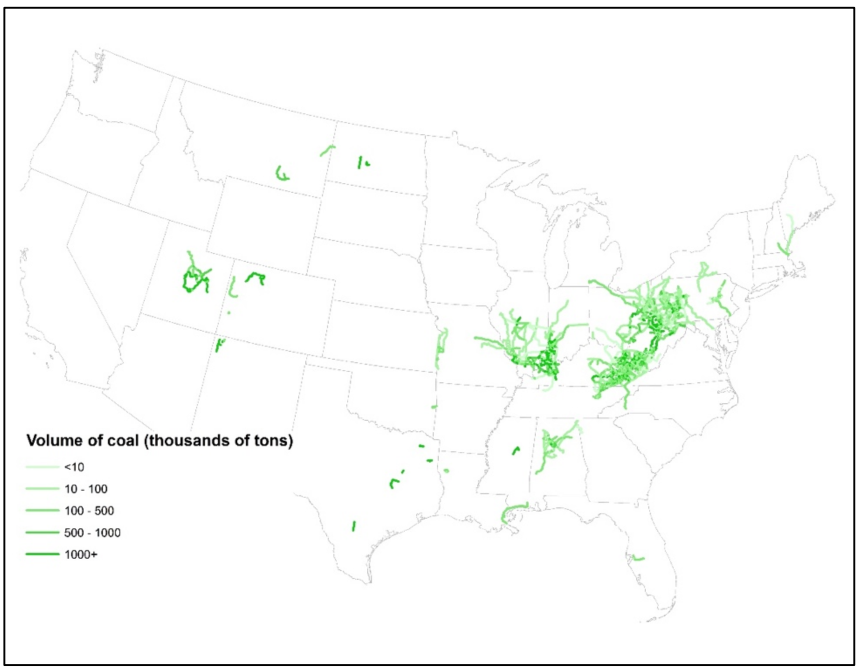

Figure 1 Volume and Distribution of Coal by Truck in 2010

Figure 2 illustrates the modeled routes and aggregate volume of coal shipped on the water to and around the U.S. In 2010, 191 million tons of coal, or 18 percent of all coal produced, traveled by water for at least a portion of its route. This includes shipments on the inland river systems, the Great Lakes, and through tidewater piers or coastal ports. Immediately evident is the importance of the Ohio River system to the shipment of coal. Not only does the river flow through the coal fields of the Appalachian and Illinois Basins (easy access from coal mines), but it is also home to a large number of coal burning power plants, many of which receive coal directly via the inland waterway system. The model shows over 30 million tons of coal moved on the Ohio River near its mouth during 2010. The Mississippi River also conveyed nearly 25 million tons of coal, most of which headed downriver toward Louisiana. Also notable is the movement of coal on the Great Lakes. A large amount of coal journeys by rail from the western U.S. before it is transloaded onto the water, particularly through the port of Superior, WI. Model results indicate that over 15 million tons of coal moved through Superior in 2010. In comparison to data from the USACE Waterborne Commerce Statistics Center, which reported 17 million tons of coal moving through Superior during this time frame, the model estimates slightly less. Other notable waterways include the Black Warrior — Tombigbee River corridor in Alabama, the Kanawha River in West Virginia, the Green River in Kentucky, the Cumberland and Tennessee Rivers in western Tennessee and Kentucky, and the Monongahela River of Pennsylvania and West Virginia.

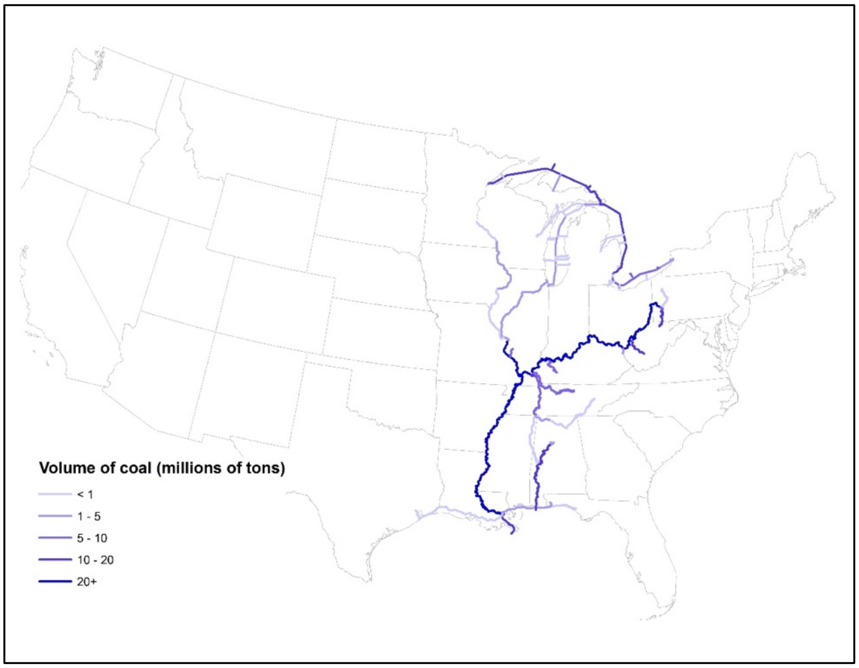

Figure 2 Volume and Distribution of Coal on Inland Waterways in 2010

Figure 3 depicts the modeled routes and aggregate volume of coal shipped via rail within the U.S. In 2010, 771 million tons of coal, or 74 percent of all coal produced, went by rail for at least a portion of its total route. This is evident in Figure 3, as the rail is the dominant mode of transport for coal throughout most of the United States.

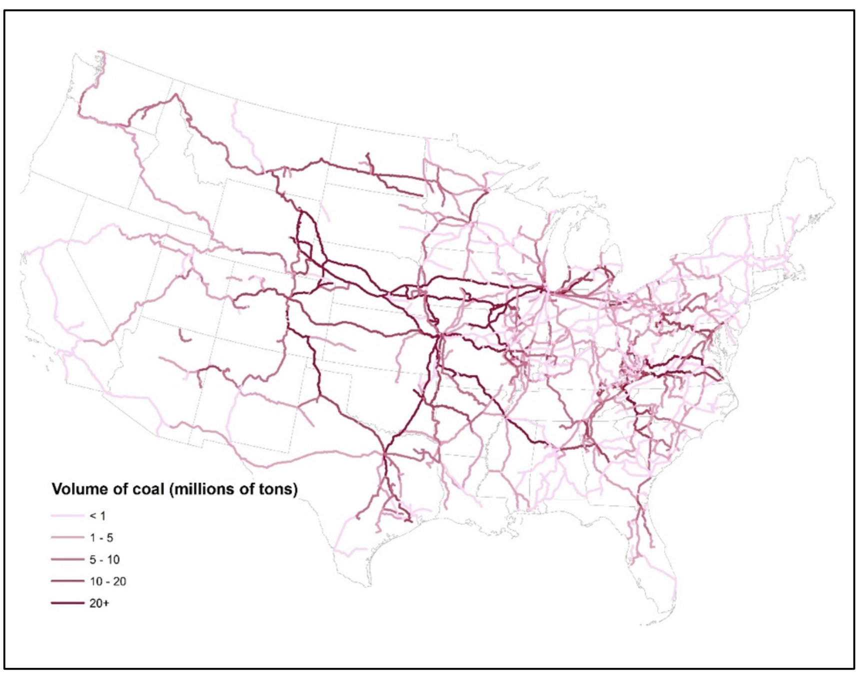

Figure 3 Volume and Distribution of Coal by Rail in 2010

Results by Origin

Figure 4 shows the modeled routes and aggregate volume of coal by rail and water that originates from the Powder River Basin. In 2010, the PRB produced 462 million tons of coal, or just over 44 percent of the total production in the U.S. Of this, 444 million tons (96 percent) left the basin by rail. The Joint Line, a 103-mile segment of rail through the Powder River Basin used by both BNSF and Union Pacific, is the busiest and highest freight density railroad in the world when measured by gross ton-miles (16). The largest rail corridor moves through Nebraska before dividing up to serve destinations throughout the Midwest and Great Plains. The second largest rail coal movement is , primarily destined for Texas and the Southwest. A third corridor moves coal toward the Pacific Northwest, destined for coal burning plants or for export through the Seattle district and terminals in British Columbia. A fourth corridor moves coal toward the upper Midwest, destined for coal burning plants or onto the Great Lakes through the port of Superior, Wisconsin. Figure 4 demonstrates the significant geographical reach of Powder River Basin coal throughout the U.S.

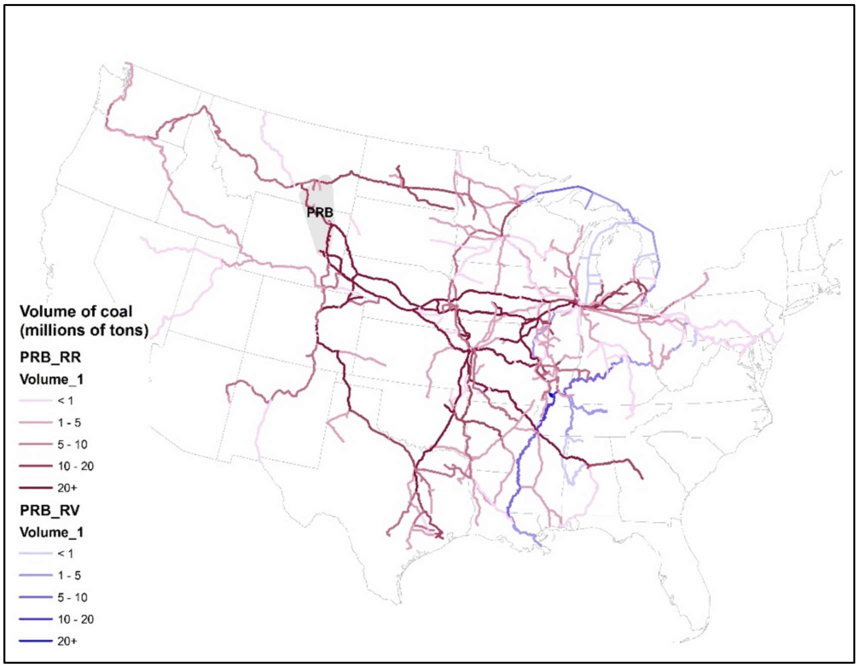

Figure 4 Volume and Distribution of Coal Originating in the Powder River Basin (PRB) in 2010 by Rail and Water

Figure 5 shows the modeled routes and aggregate volume of coal moved by rail and waterways from the Central Appalachian Basin. Several rail corridors accommodate high volume shipments of coal. One carries coal directly eastward toward the mid-Atlantic seaboard, destined largely for export through Norfolk or for consumption in mid-Atlantic power plants. Another significant rail corridor runs southeast toward coal burning plants in the Carolinas, Georgia, and Florida. C oal from the Central Appalachian Basin moves mostly toward the east and southeast, with comparatively less coal moving either northward or westward. This indicates a smaller market reach for Central Appalachian Basin produced coal as compared to Powder River Basin coal. A final observation is the importance of the inland waterway systems in moving coal west and south out of the Central Appalachian Basin. Both the Ohio and Mississippi Rivers provide significant waterborne connections to power plants and for export through New Orleans.

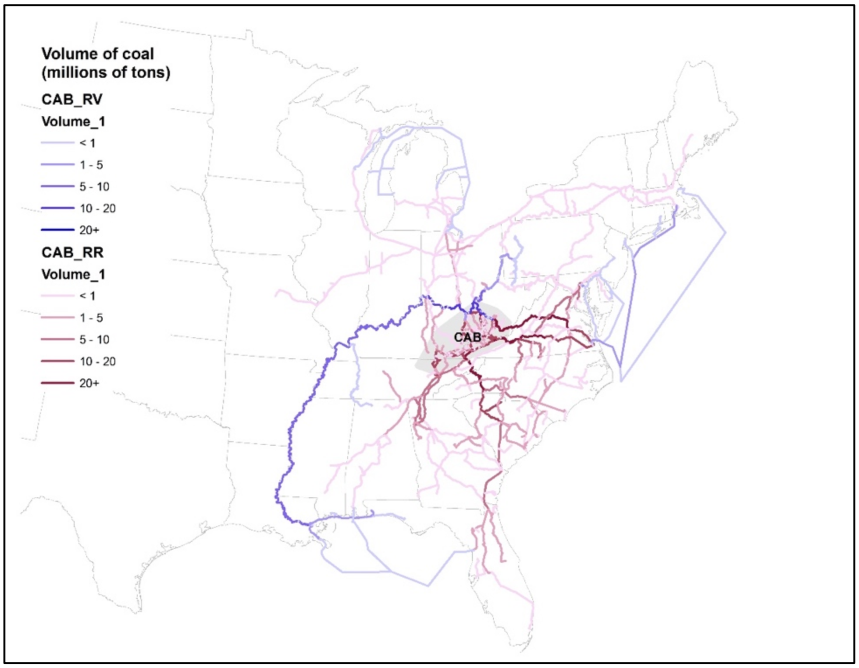

Figure 5 Volume and Distribution of Coal Originating in the Central Appalachian Basin in 2010.

Results by Destination

Figure 6 shows the modeled rail routes and aggregated volume of coal to Texas and Illinois. Texas is the largest consumer of coal in the U.S. at over 91 million tons in 2010. Forty million tons of this coal is produced within Texas, with the balance of 51 million tons imported from other states. Here, nearly all of that originated in the Powder River Basin, and smaller amounts from Colorado. This rail corridor from the north moves through the Dallas-Ft. Worth area before dividing up for destinations at coal burning power plants throughout the eastern half of Texas. Smaller amounts of coal are also consumed in north-west and western Texas.

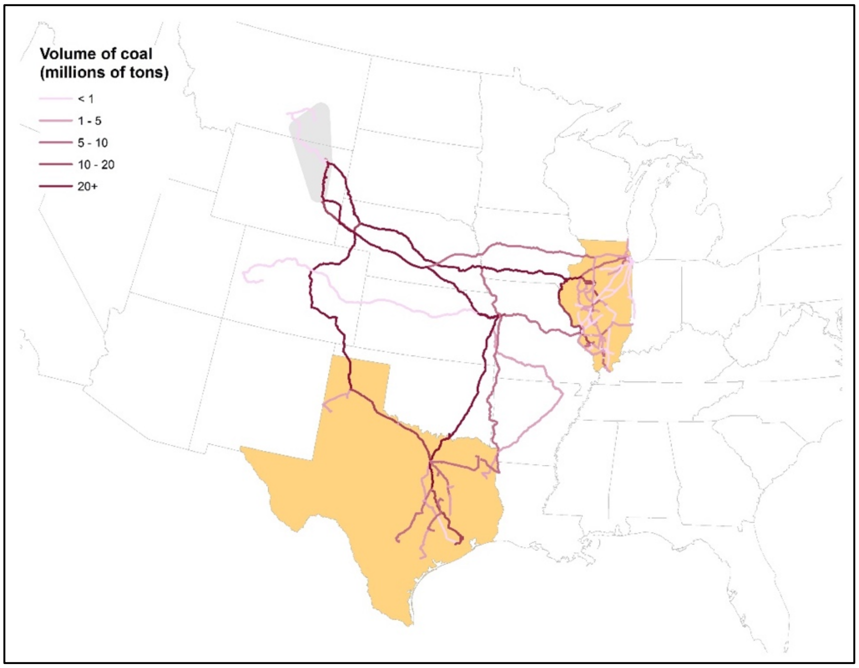

Figure 6 Volume and Origins of Coal Consumed in Texas and Illinois — the two Largest Coal-Consuming States in 2010.

Illinois is the second largest consumer of coal in the U.S. at just over 58 million tons in 2010. From this total, almost 5 million tons of coal were both produced and consumed in Illinois, leaving a net of 53 million tons of coal imported from other states. Figure 6 shows how nearly all of the coal burned in Illinois originates from the Powder River Basin and other mines in the western U.S. Only a small amount of coal (about 300 thousand tons) originated in the bordering areas of western Kentucky or Indiana, the only areas east of the Mississippi River from where coal was imported to Illinois. Figure 6 illustrates the significant reach of the Powder River Basin coal across the U.S. Even in areas such as Illinois, which are home to the Illinois River Basin and not too distant from the Appalachian Basins, Powder River Basin coal holds a monumental competitive advantage because of its low price.

Figure 7 shows the modeled routes and aggregate volume of coal exported from the U.S. in 2010. The largest port, in terms of volume of exported coal, was Norfolk at 32.0 million tons, with the coal primarily originating from the Central Appalachian Basin of southern West Virginia, eastern Kentucky, and Virginia. The second largest port for volume was Baltimore at 13.9 million tons of coal, primarily originating in the Northern Appalachian Basin of Pennsylvania, Maryland, and West Virginia. The third largest port was Mobile at 9.7 million tons of coal, primarily originating in the Southern Appalachian Basin of Alabama. The fourth largest was New Orleans at 9.4 at million tons, with coal originating from throughout the United States before largely being transported to New Orleans via the inland waterways. Figure 7 reveals the significant disparity in coal distributions across states. States like West Virginia, which produce higher priced and higher valued coal, and have reasonable access to international markets and export a higher percentage of their production. In 2011, West Virginia exported 27 percent of its total production compared to Wyoming, which only exported 1 percent (17).

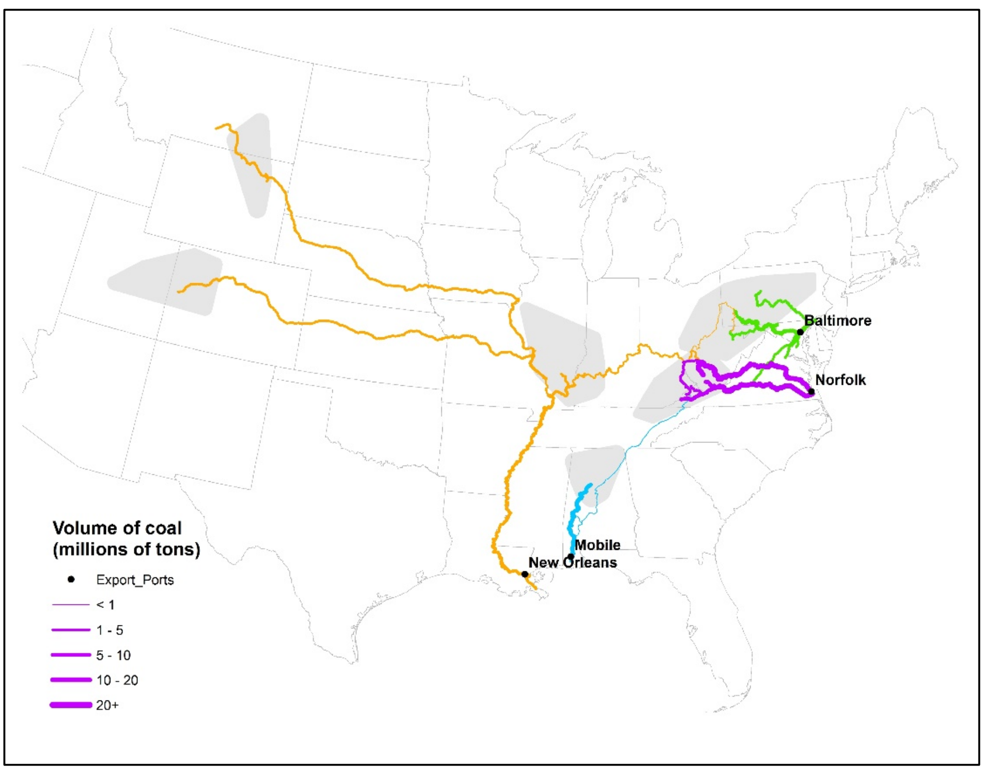

Figure 7 Volume and Modeled Routes of Coal for Export Through the Four Largest Volume Ports for Coal in 2010 — Norfolk, Baltimore, New Orleans, And Mobile. Note: line thickness corresponds to the volume of coal passing througha network

Discussion

Taken together, the figures above help to demonstrate the geographic patterns of coal distribution in the U.S. The Powder River Basin has the most abundant and competitively priced coal on the market, and so its market reach covers the entire western half of the United States, including Texas — the largest coal consumer — and much of the Midwest. Most of the coal originating in the Powder River Basin is transported entirely by rail, with much of the balance being transloaded onto waterways: the Great Lakes, Mississippi River, or Ohio River. Coal from the Central Appalachian Basin, the second largest production region is primarily destined for areas of the U.S. Southeast. Further, in 2010 the four largest ports for export coal primarily sourced it from the Appalachian coal fields. This suggests that, while Appalachian coal was less competitive at the national scale, this coal is still highly valued in international markets. Indeed, metallurgical coal produced in the Appalachian Basin, which is used in the steel industry throughout the world, accounts for well over half of coal exports. Recent trends suggest that increasing amounts of coal will be destined for export, particularly to Europe and China. To accommodate the growing demand for coal in China, the industry is developing and improving infrastructure to ship more coal through western U.S. ports, particularly in the Pacific Northwest.

The movement of coal throughout the U.S. revealed by the network model ties into a broader narrative about the economic implications of resource extraction and the fate of local and regional economies. This narrative is intensely relevant for Kentucky and the Appalachian Region (historically an important coal-mining region in the U.S.), and the inland waterways, where the numbers of coal shipments have tumbled. Rail (88.9%) and truck (1.3%) accounted for over 90% of coal ton-miles in 2010. The inland waterways accounted for 9.2% of coal ton-miles, while the Great Lakes accounted for 0.6% of coal ton-miles. Thinking about the current situation more expansively, while the coal industry has boomed — relatively speaking — in the Powder River Basin, its fortunes have continued to decline in eastern Kentucky and Appalachia. This network model demonstrates that the majority of domestic coal shipments originate in the Powder River Basin of Wyoming and Montana. This boom should be contextualized, however, by examining longer-term trends in energy usage. Between 2008 and 2012, coal use declined 24%, while the amount of electricity generated with natural gas jumped 40% (18). Preliminary estimates of 2015 production indicate that production continued to drop sharply. Production fell by 109 million short tons, or 11% over 2014 (19). The Appalachian region suffered cutbacks in production on the order of 15%, while production fell in the i.e., Powder River Basin by 9%, dropping to levels unseen since 1998. The EIA attributes declining production to the lower price of natural gas, which has driven up electricity generation at natural gas facilities (19). Another factor that comes into play is the retirements of coal-fired power plants. More plants are going offline each year due to changing environmental regulations and the proliferation of natural gas facilities.

Like elsewhere, coal production in Kentucky has steadily eroded. Although final numbers are not yet available for 2015, production fell 3.6% in 2014 over 2013, bottoming out at its lowest level since 1962 (19). By the end of 2014, just 11,586 people worked in Kentucky's coal mines. These trends apparently continued throughout 2015, with preliminary estimates suggesting Kentucky would produce less than 64 million short tons of coal in 2015 (in 2008, the state produced 121.1 million short tons). During the second quarter of 2015, approximately 9,600 people were employed in the coal industry (20). However, year-end totals remain unavailable at this juncture. Although the trends in Kentucky are consistent with patterns observed at the national level, several factors place the state and the Central Appalachian Basin in a vulnerable position economically. Of course, production and use have declined because of natural gas pricing, but equally — if not more — damaging for the state is its inability to compete with the price of coal mined elsewhere in the U.S.

Tables 1–3 (located at the end of this report) speak to the coal pricing disparities that are encountered around the country. The aggregated figures indicate the cost per British Thermal Unit (BTU) of coal as reported by coal-burning power plants on EIA Form 923. The costs, then, are reflective of the production costs, transportation costs, and particular characteristics of the fuel and its delivery. Table 1 summarizes the volume and cost of coal by basin for 2010. The Powder River Basin's dominance immediately jumps out. The average cost per BTU is $169. Conversely, coal extracted from the Appalachian Basins is significantly more expensive, with the price per BTU more than double what it is for Powder River Basin coal. Table 2 also captures 2010 pricing for coal, however, from a state-based perspective. Again, coal mined from the Central Appalachian Basin is much pricier than coal produced in the West. For example, the average cost per BTU in Kentucky was $317, while this was only $169 in Wyoming. Table 3 summarizes the volume and cost of coal by basin origin and by mode of transport for 2010. The regions where coal production is most saturated (e.g., the Mountain West) rely overwhelmingly on land-based surface transportation methods. Figure 8 visualizes 2015 coal production within a broader temporal context, showing the rapid decline over the past five years. The accompanying image that indicates weekly fluctuations in coal prices reinforces the narrative of the Appalachian Region being at a severe competitive disadvantage, with prices of coal mined from the Powder River Basin hovering at roughly one-quarter the cost of Appalachian products. Kentucky's coal industry thus faces two mounting pressures — first, its coal is priced much higher than coal produced elsewhere, and second, the natural gas industry continues to eat away at the economic viability of coal. This introduces the question of whether falling coal shipments in the Appalachian Basin will have negative consequences for the inland waterways industry.

There is no clear evidence that the coal industry's bleak fate will markedly impact the inland waterways' economic performance. Because overall shipments via inland waterways have continued to increase — with the losses in coal made up for by other commodities — tracing the impact of coal is exceedingly difficult. Since activity on the waterways is projected to climb over the next 20 years, irrespective of coal's performance, it is likely the effects are negligible (21). However, this is not to suggest carriers or port facilities will not suffer because of the transition away from coal. Facilities and companies that previously specialized in moving coal will need to recoup lost revenues. While short-term expenses are likely to mount, they are likely to be offset by gains accrued by shipping other goods (20).

This model has demonstrated the possibility of capturing and spatially translating EIA coal movement data across highways, railways, and waterways with reasonable accuracy. Even though EIA specifies the origin, destination, and primary mode of transportation, considerable additional work is required to produce a unified, coherent, and reasonable translation of that onto the freight systems in the U.S. In order to execute the data properly, all available modes must be represented reasonably accurately and their shipping characteristics adequately captured. When this is accomplished, it becomes much easier to conduct a wide variety of spatial network analyses regarding sources, destinations, modes, regions, and even flow across subsets of the network.

Kentucky's close ties with the Ohio River and Appalachian Basin underline the importance of thoroughly understanding the movement of coal and other energy commodities in and through the state and region. It also highlights the impacts on surrounding states, and the impact of the state's broader integration with the domestic and world economies. Future modeling could translate the remainder of the EIA movement data: petroleum and natural gas in particular, as they can be interchangeable and have different handling and shipping characteristics. If the current trend of lower natural gas prices persists, the pattern of favoring it over coal-powered electricity generation will continue, and new destinations for natural gas will be served by a wider variety of freight modes. For example, certain power plants in the Upper Midwest have already announced plans for shuttering coal generation capacity and/or shifting to natural gas generation. Due to this and other demands for natural gas, the rate of pipeline construction and barge tankers designed to haul natural gas has increased, signifying new dynamics in energy transportation.

The baseline model has the capacity to accommodate freight movements of any kind if the appropriate data are available. It can also accommodate movement volumes and capacities, for example, state truck freight models that reflect truck volumes but not commodity types, origins, or destinations. Similarly, detailed inland waterways movements could be represented, including data gathered regarding the likely behavior of shippers under conditions of inland navigation interruption. Currently, such efforts focus on the costs to industry of the (temporary) loss of the mode. However, decisions made by industry also have impacts on public sector modes such as highways in the form of congestion, safety, maintenance, and air quality. Ultimately, a successful model will need to include a reasonably accurate estimation of the full transportation context: rates, time and timing, distance, reliability, and so forth, in order to begin the process of understanding how shippers make decisions and thus create the commodity movements that form a significant portion of the nation’s transportation traffic. The current model of coal movements demonstrates some of the potential of the larger process.

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Table 1 Amount of Coal Derived from Major U.S. Coal-Producing Basins

Basin	Tons	Tons w/Cost	Tons w/o cost	% Tons w/o Cost	Avg. Cost Per BTU
Powder River Basin	454,319,544	336,078,078	118,241,466	74%	$169
Uinta Basin	36,583,574	34,449,539	2,134,035	94%	$218
Illinois Basin	97,966,198	90,881,684	7,084,514	93%	$229
Northern Appalachian Basin	117,134,061	55,445,814	61,688,247	47%	$240
Southern Appalachian Basin	8,177,173	8,005,594	171,579	98%	$324
Central Appalachian Basin	119,171,958	101,381,307	17,790,651	85%	$364
TOTALS	833,352,508	626,242,016	207,110,492	75%	$221

Table 2 Volume and Price of Coal by State of Origin in 2010

State	Tons	% Tons w/Cost Data	Avg. Cost Per BTU
Oklahoma	405,176	0%	$-
Mississippi	3,611,601	0%	$-
North Dakota	22,665,974	100%	$123
Montana	35,311,142	59%	$158
Wyoming	436,087,217	76%	$169
Arizona	7,761,183	100%	$170
Utah	17,284,364	88%	$186
New Mexico	21,963,214	98%	$195
Ohio	26,517,293	77%	$198
Texas	40,411,916	18%	$209
Indiana	32,603,127	95%	$214
Missouri	346,077	100%	$216
TOTALS	966,881,371	74%	$216
Louisiana	3,929,433	100%	$223
Maryland	1,913,047	42%	$240
Colorado	19,590,826	99%	$243
Illinois	29,728,334	86%	$255
Kansas	138,068	100%	$264
Pennsylvania	45,710,742	25%	$299
West Virginia	95,560,206	69%	$309
Kentucky	91,402,824	92%	$317
Alabama	8,177,173	98%	$324
Imports	14,610,235	69%	$326
Virginia	9,519,782	72%	$357
Tennessee	1,632,417	99%	$431

Table 3 Volume and Price of Coal in 2010 by Basin Origin and Mode of Transport

Basin	Mode	Tons	% Tons w/Cost Data	Avg. Cost Per BTU
Powder River Basin	Great Lakes	7,560,634	92%	$185
Illinois Basin	Great Lakes	310,120	89%	$331
Central Appalachian Basin	Great Lakes	434,170	76%	$363
Uinta Basin	Great Lakes	892,873	86%	$428
Northern Appalachian Basin	Great Lakes	322,466	45%	$433
Powder River Basin	Railroad	443,130,969	76%	$170
Illinois Basin	Railroad	49,307,754	93%	$233
Uinta Basin	Railroad	24,671,858	95%	$251
Northern Appalachian Basin	Railroad	46,219,410	43%	$293
Southern Appalachian Basin	Railroad	4,917,735	99%	$294
Central Appalachian Basin	Railroad	99,205,908	83%	$377
Northern Appalachian Basin	River	40,472,638	65%	$213
Powder River Basin	River	27,407,244	59%	$215
Illinois Basin	River	37,362,782	96%	$238
Central Appalachian Basin	River	18,129,369	94%	$307
Uinta Basin	River	4,581,505	100%	$314
Southern Appalachian Basin	River	3,692,621	100%	$381
Northern Appalachian Basin	Tidewater Piers/Coastal Ports	1,286,539	4%	$361
Central Appalachian Basin	Tidewater Piers/Coastal Ports	5,083,785	0%	$405
Powder River Basin	Tram/Conveyor	10,624,951	5%	$72
Uinta Basin	Tram/Conveyor	1,969,540	100%	$169
Northern Appalachian Basin	Tram/Conveyor	6,491,824	27%	$181
Central Appalachian Basin	Tram/Conveyor	469,259	35%	$289
Uinta Basin	Truck	19,297,096	90%	$182
Powder River Basin	Truck	934,672	40%	$205
Illinois Basin	Truck	83,655,488	94%	$224

Northern Appalachian Basin	Truck	102,789,694	51%	$239
Central Appalachian Basin	Truck	114,139,934	86%	$365
Southern Appalachian Basin	Truck	4,093,882	96%	$370