ANL/ESD-17/12

An Evaluation of the Potential for Shifting of Freight from Truck to Rail and Its Impacts on Energy Use and GHG Emissions

Energy Systems Division

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An Evaluation of the Potential for Shifting of Freight from Truck to Rail and Its Impacts on Energy Use and GHG Emissions

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GENERAL ACRONYMS, INITIALISMS, AND ABBREVIATIONS

The following is a list of acronyms and abbreviations used in this document. Some acronyms used only in tables may be defined only in those tables.

AEO	Annual Energy Outlook
Argonne	Argonne National Laboratory
Btu	British thermal unit(s)
CFS	Commodity Flow Survey
CO_2	carbon dioxide
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EIA	Energy Information Administration
FAF	Freight Analysis Framework
FHWA	Federal Highway Administration
GHG	greenhouse gas
GREET	Greenhouse gas, Regulated Emissions, and Energy use in Transportation
NEAT	Non-light duty Energy and GHG emissions Accounting Tool
SCTG	Standard Classification of Transported Goods
TEDB	Transportation Energy Data Book
VTO	Vehicle Technologies Office

AN EVALUATION OF THE POTENTIAL FOR SHIFTING OF FREIGHT FROM TRUCK TO RAIL AND ITS IMPACTS ON ENERGY USE AND GHG EMISSIONS

1 INTRODUCTION

The truck mode is the dominant freight-carrying mode in the U.S., carrying nearly three-quarters of the annual tonnage transported (Davis et al. 2016). In addition, except for the aviation mode, truck is the least energy-efficient mode for freight transportation. However, truck's ability to provide door-to-door service without any additional investment in infrastructure makes it a preferred mode for shippers.

The Federal Highway Administration (FHWA), in its Freight Analysis Framework (FAF) version 3.5, projected a 1.56% average annual growth in truck tonnage between 2015 and 2040 (FHWA 2015). In terms of ton-miles, the rate of growth during the same period was even higher, at 2.19%, which indicated more tonnage carried over longer distances. In its recently released FAF version 4 (FHWA 2016), FHWA projects a 1.22% average annual growth in truck tonnage and a 1.63% annual growth in truck ton-miles between 2015 and 2045.

The U.S. Government, through its Department of Energy (DOE), has sponsored projects that reduce dependence on petroleum and reduce emissions of greenhouse gases (GHG). DOE sponsors projects that increase the energy efficiency of various transportation modes, including intercity freight-carrying trucks. The Energy Information Administration (EIA) within DOE accounts for the impacts of such future energy efficiency technologies and projects energy consumption by various transportation modes in its Annual Energy Outlook (AEO). In its 2016 AEO, EIA projected an average annual growth of 0.51% in heavy (class 7 & 8) truck energy use between 2015 and 2040 (EIA 2016). This increase contrasts with the projected average annual declines of 0.82% and 1.31% in energy use by cars and light trucks, respectively. Heavy trucks are the third-largest energy consumers among highway vehicles, behind light trucks and cars. Although the FAF and AEO projections are not matched exactly, EIA reviews FHWA's FAF projections while developing its AEO projections.

Five modes are used to transport intercity freight in the U.S.: (1) heavy truck, (2) freight rail, (3) marine (water) freight, (4) freight aviation, and (5) pipeline. For the pipeline mode, EIA's transportation energy projections in AEO and historical transportation energy data in the Transportation Energy Data Books published by Oak Ridge National Laboratory cover only the energy consumption by natural gas pipelines. In 2014, the last year for which detailed freight energy consumption data by mode are available, heavy trucks accounted for 67% of total energy use by freight transportation (Davis et al. 2016). The next largest energy-consuming mode, natural gas pipeline, accounted for 13.5%. In the 2016 AEO, heavy trucks are projected to account for 65.2% of total energy use by freight modes in 2040 and the next largest energy-consuming mode, natural gas pipeline, is projected to account for 14.6% (EIA 2016). Thus, heavy trucks consume two-thirds of total energy use by freight transportation modes now and will consume nearly the same share in 2040.

One option to reduce energy consumption and the resulting GHG emissions from heavy trucks is to shift freight from trucks to a more energy-efficient mode, like rail. Domestic marine, consisting of transport on the Great Lakes, inland waterways, and coastal waterways, is also energy-efficient. However, its infrastructure is limited. In addition, various industries have adopted just-in-time delivery strategies that can be best served by trucks and to some extent by rail.

This report summarizes our evaluation of the potential energy-use and GHG-emissions reduction achieved by shifting freight from truck to rail under a most-likely scenario. A sensitivity analysis is also included. The sensitivity analysis shows changes in energy use and GHG emissions when key parameters are varied. The major contribution and distinction from previous studies is that this study considers the rail level of service (LOS) and commodity movements at the origin-destination (O-D) level. In addition, this study considers the fragility and time sensitivity of each commodity type.

2 LITERATURE REVIEW

Different modes of transportation are used for different types of freight services and commodities. Domestic marine and rail modes are often used for long-distance freight that travels more than 300 miles and for bulk cargo transport services, often when cargo is not time-sensitive. These modes are capable of moving large volumes with the least energy use per unit work. Trucks are used for shorter trips, time-sensitive cargo, and delivery to locations where ship and rail infrastructure is not available. Airplanes are typically used for time-sensitive shipments where transportation costs are a small percentage of overall cargo value (Winebrake and Corbett 2010). Energy consumption by freight modes depends on a number of factors, such as type of power plant used by the mode, energy sources, transportation routes, speed, operation (e.g., idling pattern), and logistics. Among the surface transportation modes, truck ranks the highest in energy intensity, about 5 to 8 times greater than rail. Air freight energy intensities are even higher, about 6 to 10 times greater than truck.

Intermodalism and mode-shifting are often looked upon as providing significant opportunities for energy and emissions reduction in the freight transportation sector (Komor 1995; Kreutzberger et al. 2003; NPWI 2004; Patterson et al. 2008; Winebrake et al. 2008). Komor (1995) noted that present trains and trucks do compete in some long-haul markets, and additional savings of up to 0.2–0.5 EJ (0.19–0.47 quad) may possibly be achieved by shifting more long-haul freight from trucks to trains. Kreutzberger et al. (2003) provided a review of studies that analyzed the environmental benefits of intermodal transport in comparison with unimodal road transport. The overview clearly shows that intermodal transport has substantially better environmental performance than unimodal road transport. Winebrake et al. (2008) presented an energy and environmental network analysis model, named Geospatial Intermodal Freight Transport, designed to explore trade-offs among such attributes as time and distance, cost, energy, and emissions for alternative route selection across different freight mode combinations. This study identified cost penalties and emissions penalties for long-haul freight when considering time-of-delivery by route as the main objective through three case studies. However, the case studies were limited to three regional freight movements. In addition, results of such models are very dependent on origin and destination routes, requiring a detailed network for each freight mode. In a follow-up study, Winebrake and Corbett (2010) concluded that freight modal shifts offer large side-by-side benefits in terms of energy consumption and emissions reduction. However, system benefits vary depending on vessel, vehicle, locomotive, and route characteristics and are constrained by compatibility, feasibility, and practicality of mode shift. Practicality includes both infrastructure capability and time sensitivity of different commodity types. Winebrake and Corbett (2010) briefly discussed an IF-TOLD model, which is a framework for considering freight options such as intermodalism/mode-shifting, clean fuels, technology efficiency, best practices in operation, supply chain management and demand (ton-miles). However, their book chapter does not detail the model. Patterson et al. (2008) estimated the potential for CO_2 emission reductions in the freight transportation sector by estimating demand for premium-intermodal services for five different categories of shipments between 18 city pairs; this study was based on a stated-preference carrier-choice survey of shippers in the corridor to develop mode-share models. Nealer et al. (2011) developed an input-output analysis, which estimated ‘‘total embodied ton-kilometers’’ across the supply chain of products. Using this model, the study of Nealer et al. indicated that targeting the trucking industry and analyzing the trucking share of each industry may suggest that non-road alternative modes of transportation are sufficient, thus reducing traffic congestion on our already crowded roads.

3 METHODOLOGY

We used Argonne's Non-light-duty Energy and GHG Emissions Accounting Tool (NEAT) for our evaluation of the potential energy and GHG emissions impacts of shifting freight from truck to rail. NEAT uses FHWA's FAF projections with some modifications. First, some of FAF's 43 commodities are combined to form 30 groups of commodities. Next, six energy-related sub-commodities are separated from this group and added to form 36 commodities (Vyas 2014). FAF's ton-mile projections are used for non-energy commodities, while EIA's AEO projections are used for energy commodities. NEAT is populated with energy intensity estimates developed at Argonne (Vyas 2014) and with GHG emissions rates from Argonne's Greenhouse gases, Regulated Emissions, and Energy Use in Transportation (GREET) model (https://greet.es.anl.gov/). NEAT develops energy use and GHG emissions estimates by freight mode and fuel type. More information, including documentation and past presentations, is available at http://www.anl.gov/energy-systems/project/neat-non-light-duty-energy-and-ghg-emissions-accounting-tool. NEAT is updated periodically with data from the latest available FAF and AEO. For this analysis, we used the 2015 version of NEAT, which reflected FAF version 3.5 (FHWA 2015) and AEO 2015 (EIA 2015).

For evaluating the potential of shifting freight from truck to rail, we first evaluated commodity tonnage originating from FAF zones. FAF 3.5 data (FHWA 2015) were available for 131 zones, of which 123 were domestic zones and eight were external zones. Because two zones in Hawaii did not have any rail service, we eliminated them and analyzed commodity data for the remaining 121 domestic zones. We used three criteria to select the commodities that have the potential to be shifted from truck to rail at the zone level: 1) average originating commodity tonnage, 2) transport distance, and 3) time sensitivity of the commodities. We selected originating commodity tonnage for the year 2040 transported over 300 miles by truck. We first computed the average of originating tonnage from all zones and eliminated two commodities that averaged less than 90,000 tons transported by truck over 300 miles. These commodities were tobacco products (<12,000 tons) and crude petroleum. In addition, three commodities—gravel, gasoline, and logs—did not have any tonnage transported over 300 miles by truck. Next, we eliminated commodities that had relatively low originating tonnage. For this elimination, we dropped 16 commodities that originated from fewer than 30 FAF zones (out of 121) and had average originating tonnage of less than 100,000. Very low-tonnage commodities may not shift to rail because railroads tend to allocate rail cars first to large-tonnage shipments, resulting in long waiting times for low-tonnage shipments. Of the remaining 22 commodities, we dropped three time-sensitive and/or delicate commodities. These were meat/seafood, electronics, and precision instruments.

We noted that FAF projects substantial tonnage of these 19 selected commodities being transported over long distances by truck. These projections indirectly reflect historical data, which form the basis for FAF methodology. They also mean that shippers prefer the truck mode over other modes because of either the commodity type or the delivery requirements. That meant that some commodities could not be shifted 100% to rail even where good rail service existed between an O-D pair. We used technical judgment to assign a potential mode shift percentage to each commodity. Table 1 lists the commodities selected and the potential mode-shift tonnage

TABLE 1 Commodities Selected for Mode Shift Analysis and Potential Shiftable Tonnage (%)

SCTG Code	Commodity	% of Tonnage That Can Be Shifted
03	Other agricultural products	30
06	Milled grain products	50
07	Other foodstuffs	50
14	Metallic ores	100
20	Basic chemicals	30
21	Pharmaceuticals	50
23	Chemical products	50
24	Plastics and rubber	100
27	Newsprint and paper	100
28	Paper articles	100
29	Printed products	50
30	Textile/leather	100
32	Base metals	100
33	Articles of base metal	100
34	Machinery	100
36	Motorized vehicles	50
37	Transportation equipment	100
39	Furniture	30
40	Miscellaneous manufacturing products	80

percentage assigned. The standard classification of transported goods (SCTG) codes are described in a publication (CFS 2006).

We also evaluated the availability of rail service in FAF zones. Each FAF zone received one of the five rail-LOS assignments in accordance with our evaluation of the current rail service, including quality of infrastructure, capacity, and frequency of service. The five levels of service were (1) excellent, (2) good, (3) moderate, (4) poor, and (5) none. We evaluated each O-D pair and assigned the pair a rail LOS that was the lower of the values at the origin and destination. For example, if the origin of an O-D pair had an excellent rail LOS and the destination had a moderate rail LOS, the O-D pair was assigned a moderate rail LOS. Because "poor" and "none" levels of rail service would not offer better service than the truck mode, we assigned zero potential for mode shift to such O-D pairs. In addition, because truck mode is the preferred mode in FAF projections, we assigned less than 100% mode shift potential in accordance with the rail LOS between O-D pairs. Table 2 lists our assigned potentials for mode shift based on rail LOS.

TABLE 2 Mode Shift Percentage Based on Rail Level of Service

Rail Level of Service Between O-D Pair	% of Tonnage Shifted to Rail
Excellent	66
Good	30
Moderate	10

For the rail-LOS assignment, we assumed that railroads would continue to serve the areas they serve currently and all their infrastructure improvements would maintain the current LOS. In addition, we assumed that railroads would have enough capacity to handle the additional tonnage shifted as a result of our analysis. Table 3 shows the rail LOS assigned to each FAF zone.

TABLE 3 Rail Level of Service Assigned to FAF Zones*

FAF Zone #	FAF Zone Name	Rail Level of Service
011	Birmingham-Hoover-Cullman, AL CSA	Excellent
012	Mobile-Daphne-Fairhope, AL CSA	Excellent
019	Remainder of Alabama	Good
020	Alaska	Poor
041	Phoenix-Mesa-Scottsdale, AZ MSA	Moderate
042	Tucson, AZ MSA	Good
049	Remainder of Arizona	Moderate
050	Arkansas	Good
061	Los Angeles-Long Beach-Riverside, CA CSA	Excellent
062	Sacramento--Arden-Arcade--Truckee, CA-NV CSA (CA Part)	Good
063	San Diego-Carlsbad-San Marcos, CA MSA	Moderate
064	San Jose-San Francisco-Oakland, CA CSA	Good
069	Remainder of California	Excellent
081	Denver-Aurora-Boulder, CO CSA	Excellent
089	Remainder of Colorado	Moderate
091	Hartford-West Hartford-Willimantic, CT CSA	Excellent
092	New York-Newark-Bridgeport, NY-NJ-CT-PA CSA (CT Part)	Excellent
099	Remainder of Connecticut	Good
100	Delaware	Moderate
111	Washington-Arlington-Alexandria, DC-VA-MD-WV MSA (DC Part)	Excellent
121	Jacksonville, FL MSA	Excellent
122	Miami-Fort Lauderdale-Pompano Beach, FL MSA	Good
123	Orlando-Deltona-Daytona Beach, FL CSA	Excellent

TABLE 3 (Cont.)

FAF Zone #	FAF Zone Name	Rail Level of Service
124	Tampa-St. Petersburg-Clearwater, FL MSA	Good
129	Remainder of Florida	Good
131	Atlanta-Sandy Springs-Gainesville, GA-AL CSA (GA Part)	Excellent
132	Savannah-Hinesville-Fort Stewart, GA CSA	Good
139	Remainder of Georgia	Excellent
151	Honolulu, HI MSA	None
159	Remainder of Hawaii	None
160	Idaho	Moderate
171	Chicago-Naperville-Michigan City, IL-IN-WI CSA (IL Part)	Excellent
172	St. Louis-St. Charles-Farmington, MO-IL CSA (IL Part)	Excellent
179	Remainder of Illinois	Excellent
181	Chicago-Naperville-Michigan City, IL-IN-WI CSA (IN Part)	Good
182	Indianapolis-Anderson-Columbus, IN CSA	Excellent
189	Remainder of Indiana	Good
190	Iowa	Good
201	Kansas City-Overland Park-Kansas City, MO-KS CSA (KS Part)	Excellent
209	Remainder of Kansas	Good
211	Louisville/Jefferson County-Elizabethtown-Scottsburg, KY-IN CSA (KY Part)	Excellent
219	Remainder of Kentucky	Good
221	Baton Rouge-Pierre Part, LA CSA	Excellent
222	Lake Charles-Jennings, LA CSA	Good
223	New Orleans-Metairie-Bogalusa, LA CSA	Excellent
229	Remainder of Louisiana	Good
230	Maine	Moderate
241	Baltimore-Towson, MD MSA	Excellent
242	Washington-Arlington-Alexandria, DC-VA-MD-WV MSA (MD Part)	Good
249	Remainder of Maryland	Good
251	Boston-Worcester-Manchester, MA-NH CSA (MA Part)	Good
259	Remainder of Massachusetts	Good
261	Detroit-Warren-Flint, MI CSA	Excellent
262	Grand Rapids-Muskegon-Holland, MI CSA	Good
269	Remainder of Michigan	Good
271	Minneapolis-St. Paul-St. Cloud, MN-WI CSA (MN Part)	Excellent
279	Remainder of Minnesota	Good
280	Mississippi	Good
291	Kansas City-Overland Park-Kansas City, MO-KS CSA (MO Part)	Excellent
292	St. Louis-St. Charles-Farmington, MO-IL CSA (MO Part)	Excellent
299	Remainder of Missouri	Good
300	Montana	Moderate
310	Nebraska	Good
321	Las Vegas-Paradise-Pahrump, NV CSA	Poor

TABLE 3 (Cont.)

FAF Zone #	FAF Zone Name	Rail Level of Service
329	Remainder of Nevada	Moderate
330	New Hampshire	Poor
341	New York-Newark-Bridgeport, NY-NJ-CT-PA CSA (NJ Part)	Excellent
342	Philadelphia-Camden-Vineland, PA-NJ-DE-MD CSA (NJ Part)	Excellent
349	Remainder of New Jersey	Moderate
350	New Mexico	Moderate
361	Albany-Schenectady-Amsterdam, NY CSA	Excellent
362	Buffalo-Niagara-Cattaraugus, NY CSA	Good
363	New York-Newark-Bridgeport, NY-NJ-CT-PA CSA (NY Part)	Excellent
364	Rochester-Batavia-Seneca Falls, NY CSA	Good
369	Remainder of New York	Moderate
371	Charlotte-Gastonia-Salisbury, NC-SC CSA (NC Part)	Excellent
372	Greensboro--Winston-Salem--High Point, NC CSA	Excellent
373	Raleigh-Durham-Cary, NC CSA	Good
379	Remainder of North Carolina	Good
380	North Dakota	Excellent
391	Cincinnati-Middletown-Wilmington, OH-KY-IN CSA (OH Part)	Excellent
392	Cleveland-Akron-Elyria, OH CSA	Excellent
393	Columbus-Marion-Chillicothe, OH CSA	Good
394	Dayton-Springfield-Greenville, OH CSA	Moderate
399	Remainder of Ohio	Excellent
401	Oklahoma City-Shawnee, OK CSA	Moderate
402	Tulsa-Bartlesville, OK CSA	Moderate
409	Remainder of Oklahoma	Moderate
411	Portland-Vancouver-Beaverton, OR-WA MSA (OR Part)	Excellent
419	Remainder of Oregon	Moderate
421	Philadelphia-Camden-Vineland, PA-NJ-DE-MD CSA (PA Part)	Excellent
422	Pittsburgh-New Castle, PA CSA	Excellent
429	Remainder of Pennsylvania	Good
440	Rhode Island	Good
451	Charleston-North Charleston-Summerville, SC MSA	Good
452	Greenville-Spartanburg-Anderson, SC CSA	Good
459	Remainder of South Carolina	Good
460	South Dakota	Poor
471	Memphis, TN-MS-AR MSA (TN Part)	Excellent
472	Nashville-Davidson--Murfreesboro--Columbia, TN CSA	Good
479	Remainder of Tennessee	Moderate
481	Austin-Round Rock, TX MSA	Good
482	Beaumont-Port Arthur, TX MSA	Good
483	Corpus Christi-Kingsville, TX CSA	Moderate
484	Dallas-Fort Worth, TX CSA	Excellent

TABLE 3 (Cont.)

FAF Zone #	FAF Zone Name	Rail Level of Service
485	El Paso, TX MSA	Good
486	Houston-Baytown-Huntsville, TX CSA	Excellent
487	Laredo, TX MSA	Moderate
488	San Antonio, TX MSA	Excellent
489	Remainder of Texas	Good
491	Salt Lake City-Ogden-Clearfield, UT CSA	Excellent
499	Remainder of Utah	Moderate
500	Vermont	Moderate
511	Richmond, VA MSA	Excellent
512	Virginia Beach-Norfolk-Newport News, VA-NC MSA (VA Part)	Excellent
513	Washington-Baltimore-Northern Virginia, DC-MD-VA-WV CSA (VA Part)	Good
519	Remainder of Virginia	Excellent
531	Seattle-Tacoma-Olympia, WA CSA	Excellent
539	Remainder of Washington	Excellent
540	West Virginia	Moderate
551	Milwaukee-Racine-Waukesha, WI CSA	Excellent
559	Remainder of Wisconsin	Good
560	Wyoming	Good

*MSA = Metropolitan Statistical Area; CSA = Combined Statistical Area

4 SCENARIO AND DATA DEVELOPMENT

We developed a baseline scenario with a minimum tonnage criterion, to select O-D pairs within a commodity for further analysis. The specific minimum tonnage requirement for an O-D pair to be selected within a commodity was 10,000 tons. Any lesser tonnage was deemed as not attractive enough to induce the shippers to choose the rail mode over truck. Each O-D pair was evaluated for commodities listed in Table 1, and pairs that met the minimum tonnage criterion specific to the baseline scenario were selected. This selection process provided an O-D matrix for each commodity. These matrices contained tonnage transported by truck over 300 miles that met the minimum tonnage requirement.

Next, we estimated implied average length of haul (LOH) for the truck mode between each selected O-D pair. We applied the factors in Tables 1 and 2 to arrive at the tonnage that would be shifted to rail. All the selected O-D pairs had rail shipments that were used to estimate implied average LOH by rail. This provided us with estimates of truck ton-miles that would be shifted to rail for each commodity and the resulting rail ton-miles. This step helped us develop preliminary ton-mile inputs necessary for NEAT. Truck and rail ton-miles by commodity for each selected O-D pair are estimated using the following equations:

Truck ton-miles (scenario case) = Truck ton-miles (base case) - LOH_{truck}*shifted tons;
Rail ton-miles (scenario case) = Rail ton-miles (base case) + LOH_{rail}*shifted tons.

As explained earlier, many FAF commodities are combined to form commodity groups for NEAT. We developed ton-mile estimates by mode for each commodity group resulting from reductions in truck ton-miles and increases in rail ton-miles. By using these new estimates, we revised total ton-miles and mode share inputs for NEAT. Table 4 shows the truck and rail mode share of ton-miles for each selected commodity in the base case and the baseline scenario case.

TABLE 4 Mode Share (of ton-miles) for Commodities Selected

SCTG Code	Commodity	2025 Base Case		2025 Scenario		2040 Base Case		2040 Scenario	
		Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail
03	Other agricultural products	62.08%	12.22%	56.48%	19.66%	62.74%	10.80%	56.62%	19.29%
06	Milled grain products	75.04%	24.34%	65.03%	34.43%	75.43%	23.81%	64.91%	34.45%
07	Other foodstuffs	75.38%	24.06%	65.59%	33.90%	74.98%	24.46%	65.08%	34.42%
14	Metallic ores	12.69%	54.38%	10.77%	56.52%	11.71%	56.58%	9.64%	58.86%
20	Basic chemicals	40.79%	48.47%	37.12%	52.21%	44.98%	46.89%	40.41%	51.54%
21	Pharmaceuticals	83.61%	11.90%	78.09%	18.03%	83.97%	11.58%	76.29%	19.83%
23	Chemical products	78.03%	19.94%	67.45%	30.77%	77.76%	20.10%	66.60%	31.51%
24	Plastics and rubber	64.61%	34.92%	47.42%	52.16%	64.67%	34.85%	46.58%	52.98%
27	Newsprint and paper	53.06%	46.02%	41.33%	57.87%	52.31%	46.66%	40.50%	58.61%
28	Paper articles	75.90%	23.71%	61.97%	37.66%	75.62%	23.90%	60.74%	38.79%
29	Printed products	90.23%	8.72%	82.49%	16.47%	89.83%	8.91%	80.95%	17.80%
30	Textile/leather	82.57%	15.69%	60.59%	37.74%	81.75%	16.31%	59.81%	38.37%
32	Base metals	65.32%	31.29%	49.37%	47.60%	65.33%	31.25%	48.57%	48.35%
33	Articles of base metal	77.96%	21.13%	59.14%	40.08%	75.37%	23.65%	55.40%	43.74%
34	Machinery	79.96%	16.92%	57.99%	38.98%	78.56%	18.09%	55.34%	41.41%
36	Motorized vehicles	66.93%	32.56%	58.34%	41.16%	67.17%	32.36%	58.30%	41.24%
37	Transportation equipment	57.67%	38.93%	49.88%	46.76%	56.10%	40.40%	47.16%	49.39%
39	Furniture	85.37%	14.21%	78.48%	21.15%	83.56%	15.98%	76.08%	23.52%
40	Miscellaneous manufacturing products	84.45%	14.31%	68.79%	30.29%	84.73%	14.08%	67.43%	31.69%

5 RESULTS AND ANALYSES

In this section, we present our results on the impact of mode shift on five aspects: (1) ton-miles, (2) energy consumption, (3) cumulative energy savings, (4) upstream energy consumption, and (5) GHG emissions.

5.1 CHANGES IN TON-MILES, ENERGY USE, UPSTREAM ENERGY USE, AND GHG EMISSIONS

The base case in this study is what we derived from AEO 2015 and FAF 3.5 as described earlier. To the extent possible, the NEAT base case reflects data from FAF projections and EIA's AEO projections. However, there are differences. First, both the FAF 3.5 and AEO 2015 projections are only to 2040. In NEAT, projections are made to 2050 by using growth rates derived from the two projections. Second, the FAF projections include ton-miles by multiple modes and unknown/other modes. Analysts at Argonne developed a methodology to allocate these ton-miles to five known modes. Third, neither FAF nor AEO provides commodity-level energy intensities. Commodity- and mode-level energy intensities were developed at Argonne from historical and survey data (Vyas 2014). These values were adjusted so that total modal energy use matches the known data in the Transportation Energy Data Books published by Oak Ridge National Laboratory. Future energy intensities reflect improvements projected in the AEO for each mode. Fourth, neither FAF nor AEO estimates full-fuel-cycle GHG emissions or upstream energy consumption for freight modes. To generate such estimates, NEAT uses feedstock, fuel production, and exhaust GHG emissions and upstream energy use rates from Argonne National Laboratory's GREET model.

Figure 1 shows the change in ton-miles resulting from shifting freight from truck to rail under the baseline scenario (10,000 tons) compared to the NEAT's base case. The change is shown in the form of a small wedge between truck and rail ton-miles. Mode shift from truck to rail reduces total ton-miles by 4.1 % owing to the shift away from truck, and increases total ton-miles by 4.4 % owing to the shift to rail, resulting in an overall increase of 0.3% in total ton-miles in 2040. The reason for this 0.3% increase is that even though the total freight tonnage did not change, transporting freight by rail, on average, resulted in a longer LOH than truck between the same origin and destination.

This small increase in total ton-miles would not imply an increase in total energy consumption because rail mode is much more energy-efficient than truck mode. Figure 2 shows the total energy use by mode in our baseline scenario as well as the changes from the base case. The higher energy efficiency of rail mode resulted in a 1.7% increase in total energy use in 2040, even though the mode shift caused a 4.4% increase in total ton-miles because of the shift to rail. Relatively, the 4.1% decrease in total ton-miles due to the shift away from truck in 2040 resulted in a 6.0% reduction in total energy use. The net effect was a 4.3% reduction in total freight energy use.

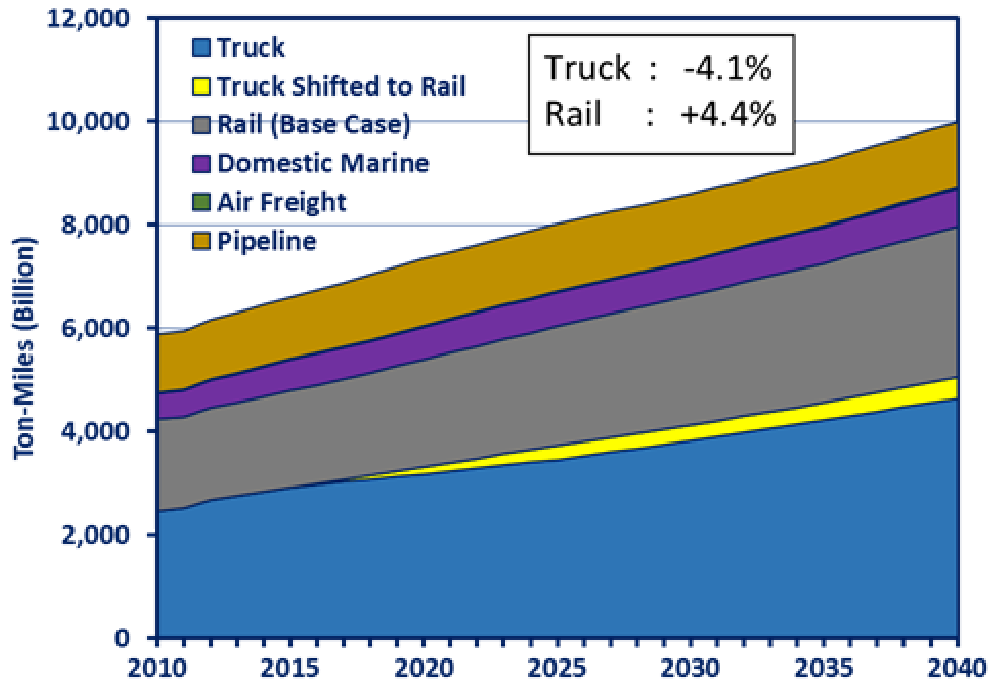

FIGURE 1 Ton-miles Projection of Each Freight Mode

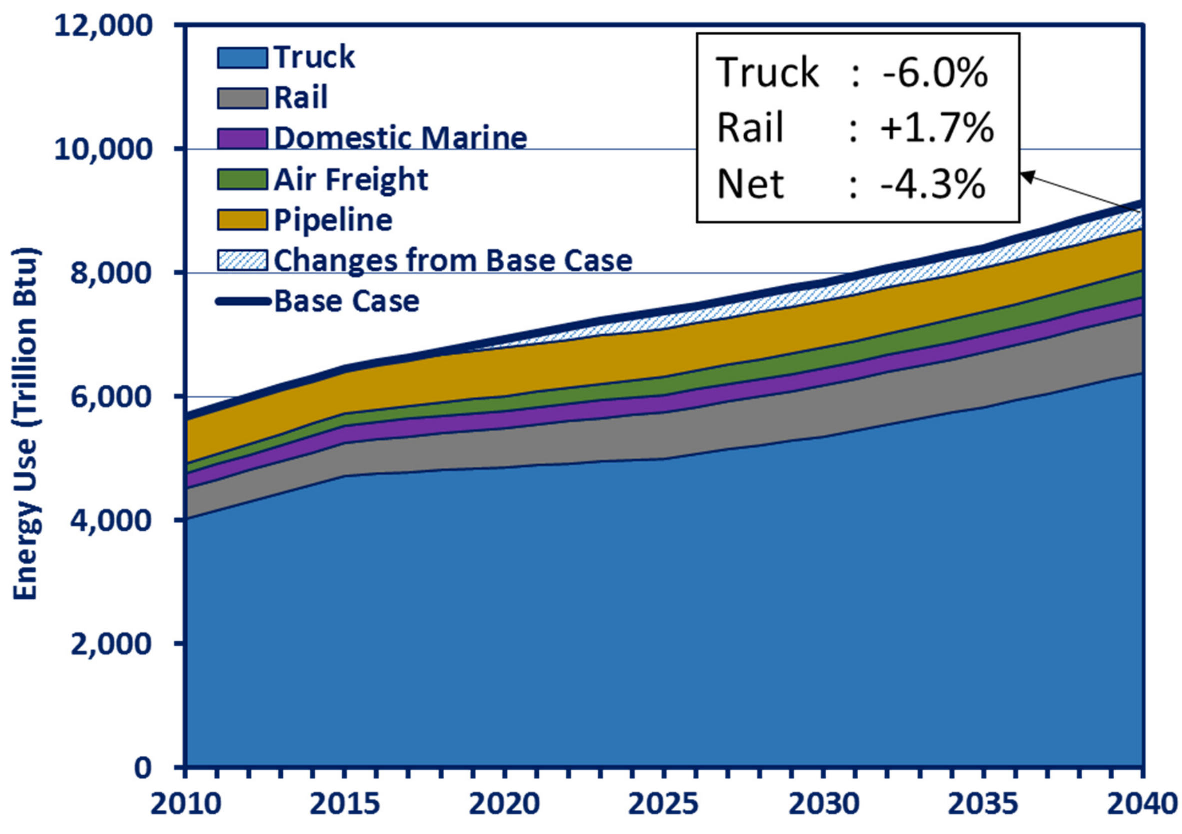

FIGURE 2 Energy Use by Mode (2010–2040)

Figure 3 shows cumulative energy savings by year due to the mode shift from truck to rail. The Figure shows that the energy savings rise sharply after relatively small increases during the initial years. This is because we have assumed a linear change in ton-miles between 2018 and 2025. The cumulative energy savings are only 1,475 trillion Btu by 2025, but rise to 6,350 trillion Btu by 2040.

The use of bio-fuels by the truck mode affects upstream energy use significantly. The truck mode uses bio-diesel blends, while rail mode uses only petroleum diesel. From Figure 4, we observe a slightly larger total upstream energy reduction brought about by a modal shift: a 6.3 % reduction in total upstream energy use attributed to truck and a 1.5 % increase in total upstream energy use attributed to rail, which leads to about a 4.9% net reduction in total upstream energy use[1]. The larger upstream energy reduction (4.9% compared to the 4.3% reduction in end-use energy) occurs because trucks would use less bio-diesel as a result of the mode shift. Bio-diesel is a significant contributor to upstream energy consumption.

The reduction in total energy and upstream energy usage leads to a similar magnitude of reduction in total GHG emissions, as shown in Figure 5. Total GHG emissions would be reduced by 4.4% by 2040, combining a reduction of 6 % from truck and an increase of 1.6 % from rail.

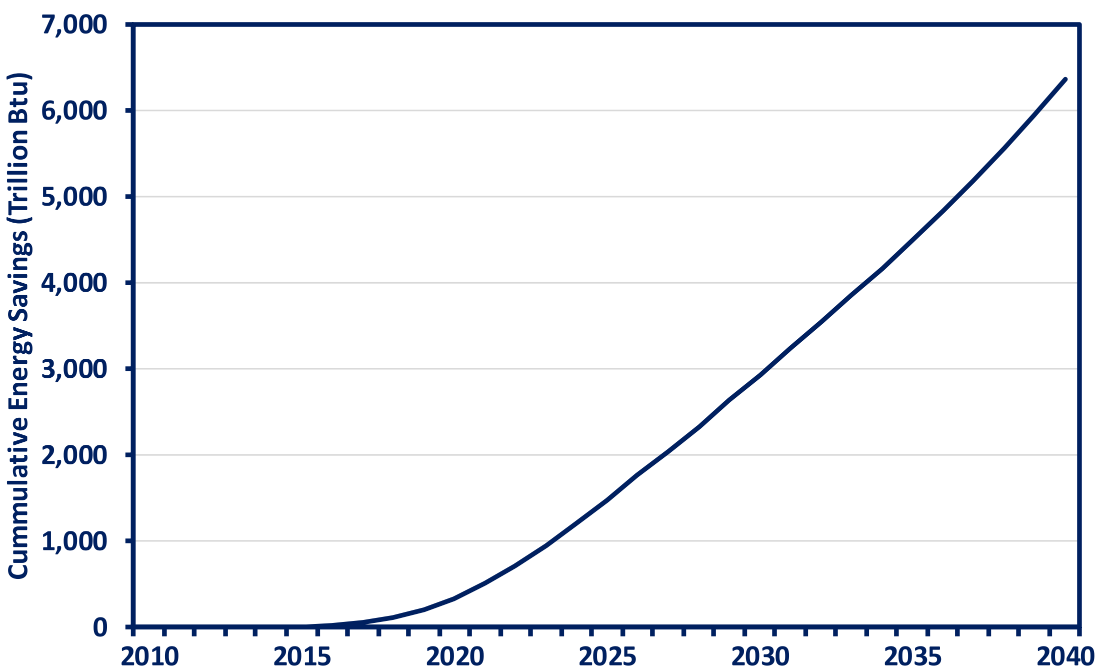

FIGURE 3 Cumulative Energy Savings by Year

[1] Calculation contains a rounding error of +/- 0.1.

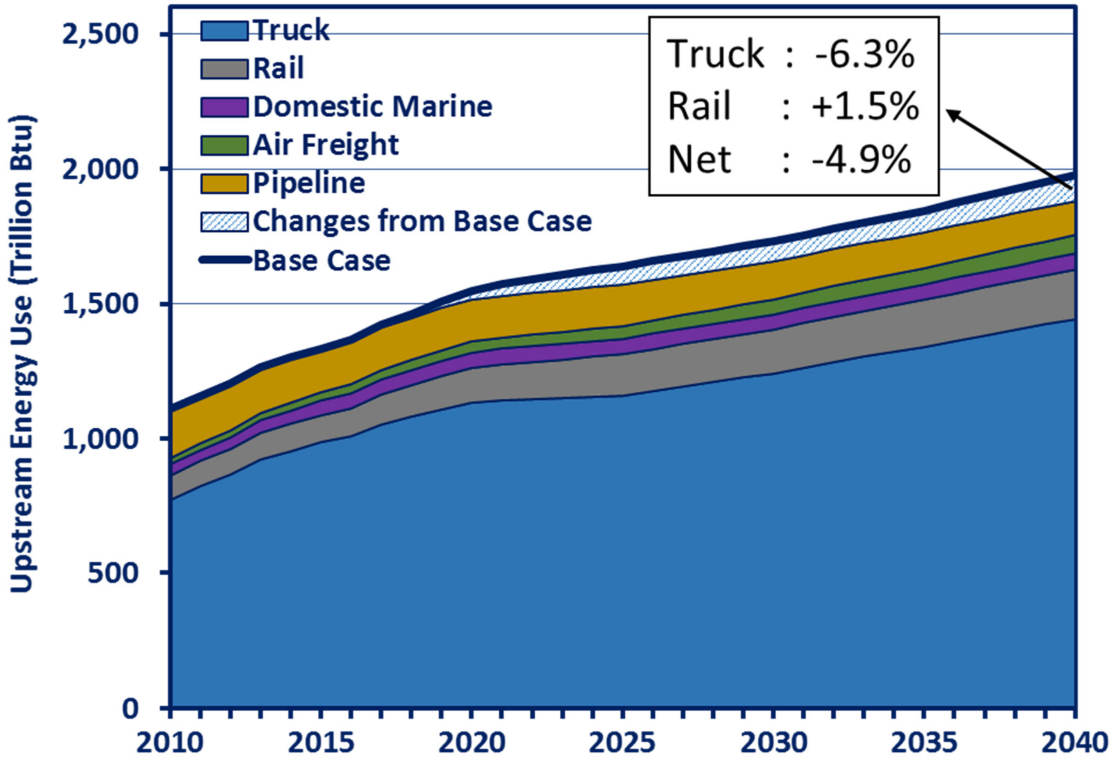

FIGURE 4 Upstream Energy Use by Mode (2010–2040)

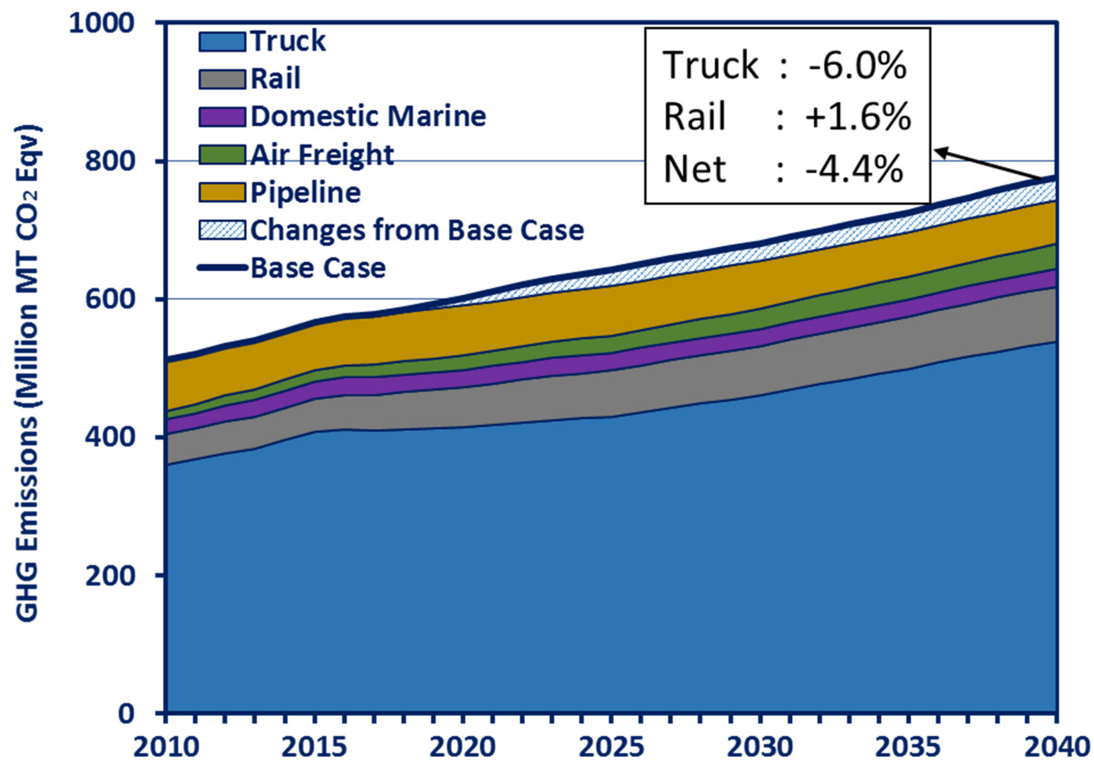

FIGURE 5 GHG Emissions by Mode (2010–2040)

5.2 SENSITIVITY ANALYSIS

Sensitivity analyses play a crucial role in assessing the robustness of the findings and the impacts of changes in key assumptions or parameters. The baseline scenario detailed so far is dependent on several assumptions. These assumptions resulted in fixed values or limits on key parameters and provided the baseline scenario results. However, all our baseline-scenario assumptions could have a range of values. Sensitivity analysis would allow us to estimate the results with different values of key parameters.

Our key assumptions for the baseline scenario included mode shift potential for each rail LOS, the percent of tonnage of a commodity that can be shifted from truck to rail, the truck LOH for selecting an O-D pair, and the minimum tonnage for selecting an O-D pair. We conducted the sensitivity analysis by changing each of these input parameters individually by +/- 50% of the values used in the baseline scenario. Note that we refer to the above-described analysis as the baseline scenario in this section. The following four parameters were changed:

1. **LOS-based mode shift percentage**, in accordance with the rail LOS between an O-D pair (the baseline-scenario values are shown in Table 2). The potential for mode shift from truck to rail under the sensitivity analysis ranged from 99% to 33% for an excellent LOS, 45% to 15% for a good LOS, and 15% to 5% for a moderate LOS.

2. **Commodity level percentage of tons** that can be shifted, which is based on commodity type. Table 1 gives the baseline-scenario values, which ranged from 30% to 100%. We varied mode shift percentage for each commodity by +/- 50%, making sure that the values remained less than or equal to 100% and greater than or equal to 0%.

3. **The minimum LOH** of a truck shipment that can be considered for mode shift, selecting truck LOHs of 150 and 450 miles (the baseline-scenario value is 300 miles).

4. **The minimum tonnage** required between an O-D pair to make it a candidate for mode shift. The baseline-scenario value of 10,000 tons was varied from 5,000 to 15,000 tons.

Results of the sensitivity analysis are presented in Figures 6 to 9. The vertical line in Figures 6 to 9 represents the baseline scenario. The orange bars show changes relative to the baseline resulting from +50% values of the parameters, while the blue bars show changes resulting from -50% values of the parameters. Each result is shown both as actual-value deviation from the baseline and percentage deviation from the baseline.

The first group (top two bars) in the figures shows the combined effect of parameters 1 and 2. We vary **percent tons shifted** depending on **both rail LOS** and **commodity type** (shown as “Comm” in the figures) by +/- 50% of the baseline-scenario values. For example, the percent of potential mode shift due to rail LOS, under the +50% case, increases to 99%, 45% and 15% for Excellent, Good and Moderate, respectively. Simultaneously, the percent of potential mode shift of tons for each selected commodity was increased/decreased by 50%, where possible. For example, under the +50% case, the value for milled grain products would be 75%, but the value for metallic ores will remain unchanged at 100%. The second and third groups (from the top) in the figures look at the effects of percent shifted by rail LOS and percent shifted depending on commodity types individually. The next two sets of bars show the effect of varying minimum LOH for truck, and the bottom two bars show the effect of varying minimum tonnage for selecting an O-D pair.

Figure 6 shows the results, in terms of total energy change relative to the baseline scenario in 2040, of varying the parameters as explained above. The combined effects of varying percent shifted on the basis of rail LOS and commodity type range from -303 trillion Btu (less savings) for the -50% case to +312 trillion Btu for the +50% case. The +50% case provides 7.8% total energy savings, 3.4% more than the baseline scenario, which provides 4.4% total energy savings. The -50% case provides 1.1% total energy savings, 3.3% less than the baseline scenario. The +50% case for combined rail LOS and commodity provides higher savings because more tons are shifted to the rail mode, which has lower energy intensity relative to truck. The total energy reduction in 2040 is expected to vary by about +/- 200 trillion Btu compared to the baseline scenario when percent shifted based on rail LOS alone is varied. The impact of percent shifted on the basis of commodity type alone is much smaller than that of rail LOS for the "High (+50%)" case. This is because the percentages of tonnage shifted to rail for some commodity types were already 100% under the baseline scenario and remained unchanged here. Percentages of tonnage shifted for the commodity types that had baseline-scenario values higher than 66% were restricted to 100% here as well. The fourth and fifth sets (from the top) show the sensitivity analysis results for the **minimum LOH** (shown as "Min LOH") and **minimum tonnage** (shown as "Min Ton"). Their impacts are relatively small compared to the impacts of percent tonnage shifted based on rail LOS and commodity types. When the minimum tonnage threshold was

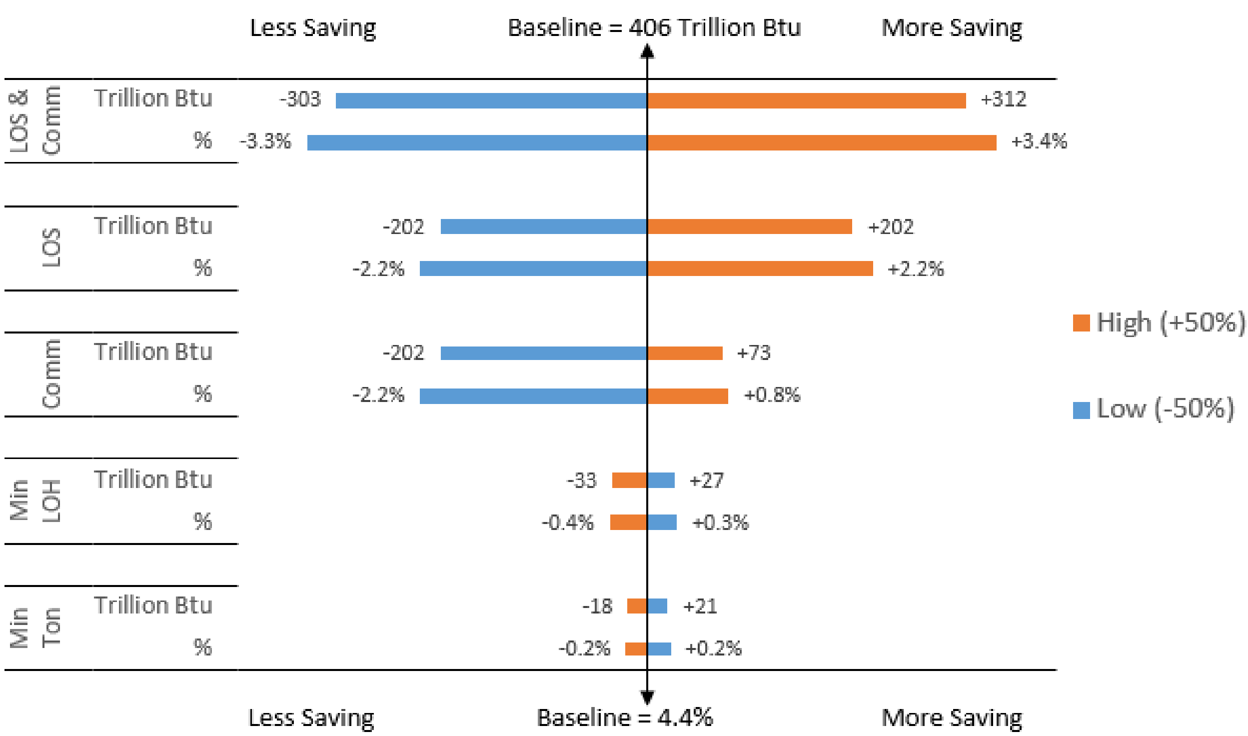

FIGURE 6 Sensitivity for Total Energy Savings in 2040

lowered to 5,000, very few additional O-D pairs were added. On the other side, increasing the minimum tonnage threshold resulted in fewer O-D pairs.

Figure 7 shows how cumulative energy savings from 2016 to 2040 would change as a result of changes in inputs. Cumulative energy savings is sensitive to **percent tons shifted** depending on **rail LOS** and **commodity type.** When both of these inputs are changed, the cumulative energy savings by 2040 is expected to vary by about +/- 5000 trillion Btu compared to the baseline scenario. The +50% case provides 5% cumulative energy savings, 2.2% more than the baseline scenario, which provides 2.8% cumulative energy savings. The -50% case provides 0.6% cumulative energy savings, 2.2% less than the baseline scenario. When varied individually, the cumulative energy changes from the baseline are symmetrical at +/- 3,370 trillion Btu for percent tonnage shifted based on rail LOS. However, the cumulative energy savings changes are not symmetrical for percent tonnage shifted based on commodity. The cumulative energy savings are increased by 1,192 Btu from the baseline for the +50% case and reduced by 3,372 Btu for the -50% case. This is because many commodities had a value of 100% under the baseline scenario and could not be increased by 50%, while the percent tonnage shifted could be reduced by 50% for all selected commodities. The cumulative energy savings changes for changing truck LOH and minimum tonnage for selecting an O-D pair are much smaller. The change from the baseline savings as a result of changing the truck LOH is -613 trillion Btu for the +50% case and +504 trillion Btu for the -50% case. The cumulative energy savings changes as a result of changing the minimum tonnage are even smaller, at -357 trillion Btu for the +50% case and +424 trillion Btu for the -50% case.

Figure 8 shows the GHG emissions results of the sensitivity analysis. GHG emissions (CO_2 equivalent) changes, relative to the baseline, could be +/-26 million MT in 2040 when both percent tonnage shifted based on rail LOS and commodity type are varied by +/- 50%. The +50% case provides 7.8% total GHG reduction, 3.4% more than the baseline scenario, which provides 4.4% total GHG reduction. The -50% case provides 1.1% total GHG reduction, 3.3% less than the baseline scenario. When only the percent shifted due to change in rail LOS is varied, the effect is +/- 17 million MT relative to the baseline scenario. When percentages shifted based on the commodity type are varied, the effect is -17 million MT for -50% and +6 million MT for +50%, relative to the baseline scenario. Varying truck LOH results in a -3 million MT change from the baseline value for the +50% case and a +2 million MT change from the baseline value for the -50% case. Varying minimum truck tonnage results in a -2 million MT change for the +50% case and a +2 million MT change for the 50% case.

Figure 9 shows changes in cumulative GHG emissions during the period 2016–2040, relative to the baseline in million MT CO_2 equivalent. Cumulative GHG emission change could be +/- 430 million MT CO_2 equivalent (+/-2.2%) by 2040 when both percentage shifted based on rail LOH and by commodity type are varied. The effect of +/-50% change in the percent tonnage shifted based on rail LOS alone is +/-287 million MT relative to the baseline. The effect of changing the percent shifted based on commodity type is -287 million MT for the -50% case and +101 million MT for the +50% case. The effect of a +/-50% change in truck LOH is +43 million MT for the -50% case and -52 million MT for the +50% case. The effect of changing minimum tonnage for selecting an O-D pair is +36 million MT for the -50% case and -30 million MT for the +50% case.

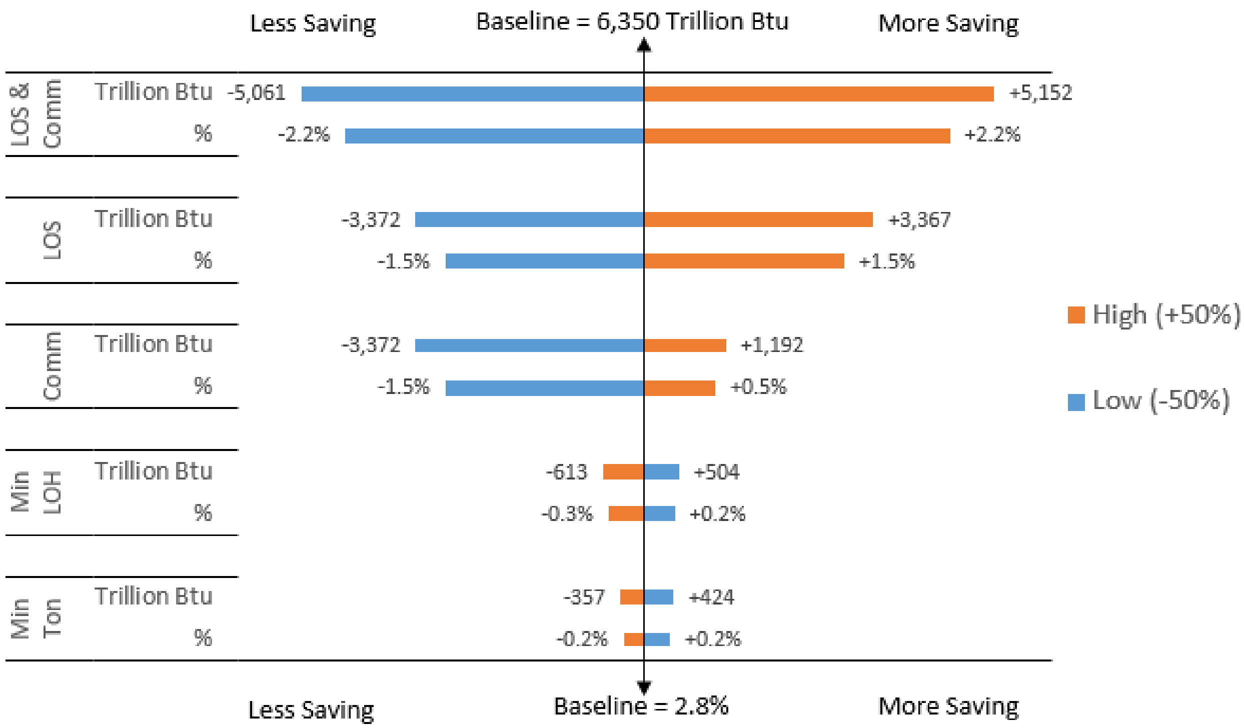

FIGURE 7 Sensitivity for Cumulative Energy Savings (2016–2040)

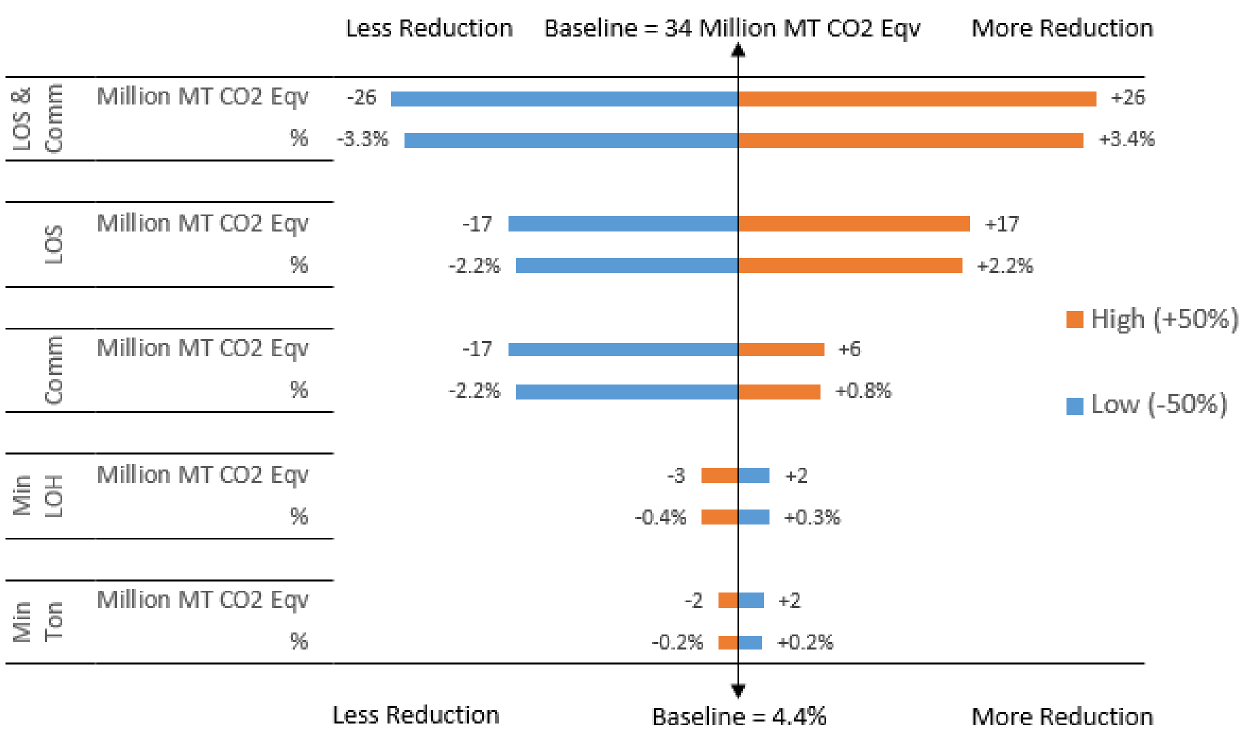

FIGURE 8 Sensitivity for GHG Reduction in 2040

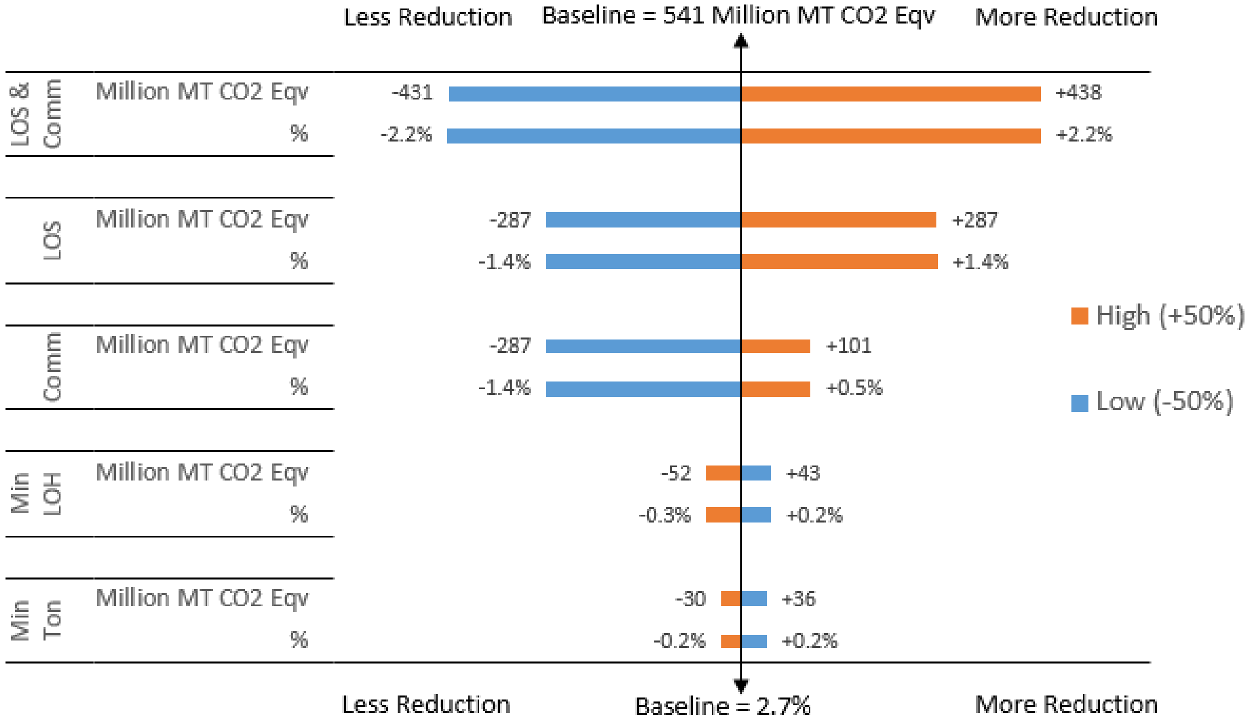

FIGURE 9 Sensitivity for Cumulative GHG Reduction (2016–2040)

6 DISCUSSION

The objective of the analyses presented here was to investigate the extent to which a reasonable shift of freight from truck to rail would result in energy and GHG emissions changes. Because the rail mode is more efficient than truck, the potential shift could save energy and reduce GHG emissions. FHWA's FAF projections, EIA's energy commodity projections in AEO, and Argonne's NEAT model were used for this purpose. The FAF projections show a substantial increase in truck tonnage, which in turn reflects survey data. The survey data and FAF projections indicate that most shippers prefer the truck mode. There could be several reasons for this preference. Among them are the shift by manufacturers to just-in-time delivery of parts and components, the development of distribution systems that reduce retailers' inventory cost and require stocking their retail outlets only as needed, and the projected increase in on-line shopping in the future.

The baseline-scenario development involved a conservative approach to estimating shift of freight tonnage from truck to rail. Several low-volume, time-sensitive, and delicate commodities were omitted. Mode shift for the remaining commodities depended on four parameters: (1) Commodity-level mode shift percentage: Each selected commodity was evaluated for its extent of shift to rail and was assigned a mode shift percentage. (2) Rail LOS-based mode shift percentage: A rail LOS category was assigned to each O-D pair and a potential mode shift percentage was assigned to each LOS category. (3) Minimum truck LOH: Only the O-D pairs involving a longer truck LOH ($\geq$300 miles) were considered. (4) Minimum tonnage at O-D level: Only the large-volume ($\geq$10,000 tons) O-D pairs were selected. A conservative approach was followed while assigning potential shifts to rail based on commodity and rail LOS.

A sensitivity analysis was conducted. This analysis involved changing each of the four parameters individually by +/- 50%. The +50% analysis would represent optimistic values for mode shift percentage based on commodity and rail LOS. This would involve increasing mode shift potential and provide maximum energy savings and reduction in GHG emissions. However, increasing minimum truck LOH and minimum tonnage would result in fewer O-D pairs being selected. Because each parameter was varied individually, it was possible to see both the favorable and unfavorable impacts.

Our analysis shows that the mode shift percentage allocated on the basis of the rail LOS influences the freight sector energy and GHG emissions savings the most. While allocating mode shift percentage based on rail LOS, we took into account the fact that commodity flow surveys and FAF methodology show truck mode as a preferred mode for most commodities. Our intention was to present a reasonable scenario for shifting freight from truck to rail. We believe that the evaluation based on the baseline scenario is reasonable under the current conditions. The sensitivity analysis showed more energy savings, with a 50% increase in mode shift potential based on the rail LOS.

For allocation of percentage of tons that can be shifted from truck to rail, the commodity was the next most influential parameter. Out of nineteen selected commodities, we had assigned

100% mode shift potential to nine commodities. One commodity was assigned 80%, while the remaining nine commodities were assigned varying lower percentages. Here too, the sensitivity analysis showed that energy use and GHG emissions could be reduced substantially by increasing mode shift potential for the nine commodities further. The baseline scenario is appropriate under the current conditions.

7 CONCLUSIONS

Under the baseline scenario, we found that only a 4.3% net energy savings and a 4.4% reduction in GHG emissions could be achieved by 2040. These small numbers are the results of restrictions imposed while developing the baseline scenario. First, we omitted many commodities owing to the low volume of their transport by truck traveling over 300 miles. Second, we assigned less than 100% mode shift potential to 10 out of 19 selected commodities. Third, we assigned 66% mode shift potential to excellent rail LOS, 33% to good rail LOS, and 10% to moderate rail LOS. Fourth, we selected truck freight going a distance longer than 300 miles. Finally, we selected O-D pairs with 10,000 tons or more going by truck. Note that the 4.3% energy savings and 4.4% GHG reduction represent the national totals. Some individual O-D pairs may exhibit much higher percentages of energy savings and GHG reduction.

Here, we highlight some key conclusions.

- Under the baseline scenario, cumulative energy savings (upstream included) during the period 2016–2040 due to mode shift from truck to rail is about 1,475 trillion Btu by 2025, but rises to 6,350 trillion Btu by 2040.

- Under the baseline scenario, the use of bio-fuels by the truck mode affects upstream energy use significantly. About a 6.3 % reduction in total upstream energy use is attributed to truck and a 1.5 % increase in total upstream energy use is attributed to rail, leading to about a 4.9% net reduction in total upstream energy use.

- The baseline scenario shows a reduction in total GHG emissions that is similar in magnitude to the reduction in total energy and upstream energy usage, about 4.4% by 2040.

- Sensitivity analysis shows that the total energy savings and GHG reduction are more sensitive to percent tonnage shifted depending on rail LOS and commodity type. When varying percent tons shifted based on rail LOS and commodity type together by +/- 50% (of the baseline-scenario values), total energy savings and GHG reduction would range from 1.1% to 7.8% in 2040.

- Sensitivity analysis shows that the total annual energy savings in 2040 would vary from 2.2% to 6.6% when percentage shifted based on rail LOS alone is varied by +/-50% of the baseline scenario value.

- Sensitivity analysis shows that the cumulative energy savings (upstream included) by 2040 would vary by about +/- 5000 trillion Btu (+/- 2.2 %) from the baseline scenario value of 6,350 trillion Btu when percent tons shifted based on rail LOS and commodity type are varied.

- Sensitivity analysis shows that cumulative GHG emissions during the period 2016–2040 could be +/- 430 million MT CO_2 equivalent (+/-2.2%) relative to the baseline when both percent shifted based on rail LOH and commodity type are varied.

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