Energy Efficiency Potential of the U.S. Freight System: A Scoping Exercise

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Contents

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Executive Summary

Freight movement is a large and growing fraction of transportation sector energy use and greenhouse gas emissions in the United States. In recent years, detailed studies have been conducted of the potential to reduce truck fuel use through technology improvements, and the federal government adopted the first U.S. fuel efficiency and greenhouse gas emissions standards for heavy-duty vehicles in 2011. The potential to reduce freight sector fuel use through system efficiency improvements has not been so carefully investigated, and current federal freight policy does not set improved energy efficiency as a goal.

To better understand freight system efficiency opportunities, we review three studies on greenhouse gas reduction potential in the U.S. transportation sector (by the U.S. Environmental Protection Agency, the U.S. Department of Transportation, and Greene and Plotkin) and extract their findings on reductions in the freight sector through energy efficiency strategies. We also review two studies of energy efficiency and greenhouse gas reduction in the global supply chain (by McKinsey and Company and the World Economic Forum) to see whether they introduce additional opportunities for freight sector savings beyond those considered in the transportation studies.

In order to facilitate the comparison of the studies' results, we use six efficiency "levers" defined in the McKinsey supply chain study to organize the strategies considered in the four remaining studies. The results are shown in Table ES-1.

Table ES-1: Summary of Energy Savings Potential of Freight Movement Found in Five Studies

	Global Supply Chain Studies						U.S. Transportation Studies						
Lever	McKinsey (2020)			WEF ("Medium Term")			EPA (2030)		DOT (2030)		Greene and Plotkin (2035)		
	Low	*Medium*	*High*	*Low*	*Medium*	*High*	*Aggressive*	*Very Aggressive*	*Low*	*High*	*Low*	*Mid*	*High*
Value Density	2%	3%	3%	0%	0%	0%	N/A	N/A*	N/A	N/A	N/A	N/A	N/A
Average Distance	1%	4%	15%	0%	0%	0%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Modal Mix	3%	4%	7%	0%	5%	5%	N/A	7%	0%	1%	N/A	N/A	N/A*
Asset Technology	10%	20%	22%	5%	5%	5%	10%	15%	10%	22%	12%	19%	23%
Individual Usage	7%	12%	17%	7%	12%	12%	3%	6%	1%	4%	0%	2%	3%
Collective Usage	1%	2%	3%	5%	5%	6%	2%	5%	2%	4%	0%	1%	2%
Total	23%	38%	51%	16%	25%	26%	15%	30%	13%	29%	12%	21%	28%
Total without Asset Technology	14%	23%	37%	12%	21%	22%	6%	18%	3%	9%	0%	2%	5%

* Modest reductions in this category reflected under Individual Usage.

This comparison serves to highlight areas that warrant further investigation. In particular, putting aside the "asset technology" lever that includes vehicle technology improvements, the supply chain studies showed greater opportunities for reductions. "Individual usage," which includes a range of strategies that could be employed by freight carriers, was a major area of difference from the U.S. transportation studies. Only the supply chain studies considered moving the location of goods production closer to the final market, but the two studies arrived at different conclusions regarding the energy savings potential of this strategy. The five studies together found potential savings from freight system efficiency improvements ranging from 0 to 37 percent by 2030, implying reductions of approximately 0 to 230 million metric tons of carbon dioxide and 0 to 1.7 million barrels per day in oil use in the U.S.

Introduction

In our globalized economy, it is more likely than not that the goods that we rely on every day—from food to clothing to fuel—come from outside the local area. The movement of these goods relies on a network of planes, trains, trucks, container ships, and barges—all of which consume fuel and emit greenhouse gases and other pollutants. The movement of freight accounts for 18 percent of oil consumption and 9 percent of carbon dioxide emissions in the United States (EIA 2013). Due in large part to the tightening of light-duty vehicle fuel economy and GHG emissions standards for model years 2012-2025, light-duty carbon dioxide emissions will decline by 0.9 percent per year on average between 2011 and 2040, while freight truck emissions will grow an average of 1.2 percent per year over the same period (EIA 2013). Therefore, reducing the consumption of fuel used in the transportation of freight has economic, environmental, and energy security benefits.

In 2011, the U.S. Environmental Protection Agency and the U.S. Department of Transportation adopted fuel efficiency and greenhouse gas standards for medium- and heavy-duty vehicles, to be implemented starting in 2014. These standards are projected to reduce greenhouse gas emissions by 270 million metric tons and to save approximately 530 million barrels of oil over the life of the vehicles covered under the standard (EPA and DOT 2011). While this is a substantial improvement to the fuel efficiency of trucks, the freight system more broadly offers opportunities for additional energy efficiency gains.

This report is driven by two questions. First, what have recent analyses estimated to be the potential to increase the energy efficiency of goods movement in the United States? And, second, do these analyses take into account the full range of strategies that could contribute substantially to reducing freight energy use? There are two broad categories of strategies for increasing the energy efficiency of freight movement: vehicle technology strategies such as improving the efficiency of drive trains and reducing aerodynamic drag; and "system" efficiency strategies that focus on optimizing the movement of goods, such as shifting to more efficient modes of transport and improving logistics. In-depth analyses have been conducted recently to evaluate vehicle technology strategies for improving the fuel efficiency of trucks (see, for example, NESCCAF 2009 and NRC 2010). In this report, we focus on analyses that consider other, system-level efficiency strategies.

Literature Review

Domestic Studies

Our review of the literature on the efficiency of the freight system in the United States revealed that while many studies touch on the subject, they focus either on one piece of the freight system (e.g., heavy-duty trucks) or consider the problem on a limited scale (Lai & Barkan 2006; ARC 2004). We did not find recent work specifically on freight that estimates potential energy savings in the good movement system as a whole from the use of a broad set of strategies.

Several analyses of the energy efficiency potential of the entire transportation sector in the United States are available, however. Some of these studies are greenhouse gas reduction potential studies; in those cases, we excluded from consideration those reductions due to replacement of petroleum fuels with lower-carbon fuels.[1] We reviewed three recent studies on greenhouse gas emissions reductions from the U.S. transportation system as a whole: a U.S. Environmental Protection Agency analysis requested by Senator Kerry (EPA 2010); a Department of Transportation study entitled *Transportation's Role in Reducing U.S. Greenhouse Gas Emissions* (DOT 2010); and a Center for Climate and Energy Solutions study entitled *Reducing Greenhouse Gas Emissions from U.S. Transportation* (Greene and Plotkin 2011). We chose these three as assessments that were likely to be widely referenced by policymakers. The first two studies considered potential reductions in greenhouse gas emissions in 2030, and the third, in 2035.

Each of the three studies addresses reductions in greenhouse gas emissions from passenger and freight transportation in the United States, based on the use of various strategies, economic and technology scenarios, and timeframes. In each of the studies, we considered the subset of strategies that apply to freight modes: medium- and heavy-duty trucks; rail; aviation; and marine. We extracted the potential savings from measures that apply either exclusively to freight (e.g., mode shift from truck to rail freight) or that influence freight efficiency, although not exclusively (e.g., reducing speed limits). We translated the projected emissions reductions from each strategy or group of strategies in each study into percentage reduction in overall freight sector emissions relative to a reference case projection.

The Environmental Protection Agency's (2010) analysis examines the potential impact in 2030 of operational efficiencies and technological improvements on greenhouse gas emissions from all transportation modes. It does not consider policy or market drivers that might be required to bring about these efficiencies, nor does it consider the relative costs of the strategies considered, or impacts of travel time, safety, or the economy. Table 1 shows EPA's projections of potential freight sector emissions reductions, which we express as percentages of total U.S. freight sector emissions. The study presents two scenarios, which it characterizes as "somewhat aggressive" and "very aggressive" (EPA 2010).

The Department of Transportation's (2010) analysis evaluates the potential for six broad strategies to reduce greenhouse gas emissions from transportation: shifting to low-carbon fuels; increasing vehicle fuel economy; improving the efficiency of the transportation system; reducing carbon-intensive travel; using transportation planning; and carbon pricing. Of these, we considered the subset of strategies that improve the fuel efficiency of freight vehicles or affect the individual or collective usage of freight modes. The study discusses the costs and co-benefits of implementing these strategies, but, like the EPA study, does not take a position on which policies should be adopted to bring about these efficiency improvements. DOT's projection of the

[1] The U.S. transportation sector is almost entirely dependent upon petroleum-based fuels. Throughout this report, we treat percentage freight sector energy use and percentage freight sector greenhouse gas emissions as almost interchangeable. While there are differences in the amount of carbon per unit energy in the various petroleum-based fuels used in the freight sector, the differences are insignificant in the context of this report.

emissions reduction potential of each freight strategy is given as a range, the lower and upper bounds of which are shown in Table 2, again expressed as percentages of total freight sector emissions.

Table 1: Freight Sector Greenhouse Gas Emissions Reduction Potential in 2030 from Efficiency Measures, per EPA (2010)

Emissions Reduction Strategy	Somewhat Aggressive	Very Aggressive
Heavy-duty truck technology	6.8%	9.4%
Heavy-duty truck travel efficiency		
Idle reduction	0.5%	0.8%
Driver performance	3.4%	3.0%
Increased capacity		1.2%
Better loading, packaging, routing, and empty mile reduction		3.0%
Intermodal shift		6.0%
Non-road freight technology	3.5%	4.7%
Non-road freight operations	1.4%	5.0%

Source: ACEEE calculation from EPA (2010)

Table 2: Freight Sector Greenhouse Gas Emissions Reduction Potential in 2030 from Efficiency Measures, per DOT (2010)

Strategy	Lower	Upper
Ports and marine operations	0.0%	0.1%
Truck size and weight limits	0.1%	0.1%
Urban consolidation centers	0.0%	0.0%
Truck idling reduction	0.3%	1.0%
Air traffic operations	0.2%	0.6%
Driver education/ecodriving	0.8%	4.4%
Freight modal diversion	0.0%	0.8%
Reduced speed limit	1.3%	2.0%
Intercity tolls	0.0%	0.1%
Technology improvements		
Freight trucks	7.1%	16.0%
Freight rail	1.9%	2.9%
Marine freight	0.6%	2.1%
Air freight	0.5%	1.2%
Total	12.6%	28.9%

Source: ACEEE calculation from DOT (2010)

Greene and Plotkin (2011) evaluate vehicle technologies, system efficiencies, mode shift, and public policies that have the potential to reduce the greenhouse gas emissions from the transportation sector. Of these, we considered improvements to vehicle technologies, logistics, individual usage, and system efficiencies that apply to the freight modes. Greene and Plotkin's projections of savings potential in Low, Mid, and High Mitigation scenarios are summarized in Table 3.

Table 3: Freight Sector Greenhouse Gas Emissions Reduction Potential in 2035 from Efficiency Measures, per Greene and Plotkin (2011)

	Low Mitigation	Mid Mitigation	High Mitigation
Vehicle efficiency			
Freight truck	8.8%	13.5%	15.6%
Rail	0.8%	1.2%	1.6%
Water	2.2%	3.2%	4.3%
Aviation	0.5%	1.2%	1.9%
Truck logistics	0.0%	1.6%	3.4%
Better routing and flight paths for aircraft	0.1%	0.2%	0.5%
Traffic flow improvement (trucks)	0.0%	0.7%	1.3%
Total	12.4%	21.1%	27.3%

Source: ACEEE calculation from Greene and Plotkin (2011)

GLOBAL SUPPLY CHAIN STUDIES

We reviewed two additional studies, both of which estimate the potential for efficiency improvements in global supply chains: "Making Supply Chains Energy Efficient" in *Energy Efficiency: A Compelling Global Resource* (McKinsey 2010); and *Supply Chain Decarbonization* by the World Economic Forum (WEF 2009). Our objective in including these studies was to explore strategies for increasing the energy efficiency of goods movement beyond those that are discussed in the domestic transportation studies, which focus heavily on improvements to vehicle technologies. The two global supply chain studies investigate strategies that receive little attention in the U.S. studies, warranting further exploration as potential sources of efficiency in the freight sector.

While the opportunities for freight efficiency improvements in the United States may differ from those of other nations due to variations in geography, the structure of the economy, and other factors, the global supply chain perspective nonetheless helps to situate the freight system in the United States in a larger context and highlights more expansive thinking about opportunities for improving freight efficiency.

McKinsey (2010) defines six categories of strategies, or "levers," that have the potential to improve supply chain efficiency:

- *Value density*: increasing the ratio of a product's economic value to its weight or volume, such as by redesigning or eliminating packaging, removing filler material, and postponing final assembly.
- *Average distance*: reducing the average distance products travel to market by, for example, moving the production of some components closer to the final market.
- *Modal mix*: shifting the transport of goods from more to less energy-intensive modes, such as from aircraft to container ship.

- *Asset technology*: improving vehicle technologies and design, such as through better propulsion technologies or increasing vehicle capacity.
- *Individual usage*: improving energy efficiency through actions taken by the vehicle operator, such as by optimizing vehicle speed and routing, improving maintenance regimes, and increasing load factor.
- *Collective usage*: improving energy efficiency by altering the collective use of transportation assets and infrastructure, such as through better air traffic control.

McKinsey estimates potential energy savings from each of the six levers under three oil price scenarios, with higher prices incentivizing larger investments in efficiency improvements, leading to greater fuel savings. The percent reductions in energy intensity (quantified in the study in terms of liters of oil consumed per ton-kilometer) by 2020 found by McKinsey under the three scenarios are summarized in Table 4. Overall, the study estimates savings of 23 to 51 percent from the combination of strategies in each lever. The largest savings (10 to 22 percent) are found in improvements to asset technologies. The second largest source of savings (7 to 17 percent) is "behavioral" changes that affect individual usage of specific freight modes.

Table 4: Freight Sector Energy Savings Potential from Global Supply Chain Measures in 2020, per McKinsey Study [2]

Levers	Oil Scenarios		
	Low ($40/bbl*)	Mid ($100/bbl)	High ($200/bbl)
Value density	2%	3%	3%
Average distance	1%	4%	15%
Modal mix	3%	4%	7%
Asset technology	10%	20%	22%
Individual usage	7%	12%	17%
Collective usage	1%	2%	3%
Total	23%	38%	51%

*"$/bbl" refers to the global price of oil in dollars per barrel. Source: McKinsey (2010).

The second global supply chain study we review here, WEF (2009), considers thirteen strategies to reduce carbon emissions along supply chains. We eliminated three of the thirteen as being outside the scope of our review: energy efficient buildings; enabling low carbon sourcing in agriculture; and enabling low carbon sourcing in manufacturing. These strategies reduce emissions only in sectors other than transportation and hence were not included. We excluded a fourth category,

[2] The potential reductions estimated for the first three levers are contingent upon having already implemented changes to asset technology and individual and collective usage.

reverse logistics/recycling, because we were not able to separate the associated transportation reductions, which appear to be minor, from the total reductions assigned to this strategy.

To each strategy, the WEF analysis assigns a carbon abatement potential and a degree of "feasibility" (low, medium, or high), defined as "the opportunity, considering likely barriers to deployment, and the extent to which the potential to deploy is controlled by the various stakeholders in the supply chain." The study does not specify a time horizon; WEF characterizes the time frame for the changes as "medium term."

The WEF analysis finds a potential to reduce transportation emissions from supply chains by up to 25 percent using energy efficiency strategies. Clean Vehicle Technologies, excluding increased use of alternative fuels, contribute moderately (5 percent) to the reductions. Several other strategies provide the same order of savings, as shown in Table 5. WEF projects high GHG reduction potential with Medium feasibility for Packaging Design Initiatives, but the vast majority of the reductions occur in the production phase and hence do not result in transportation sector reductions and are not reflected in Table 5.

Table 5: Freight Sector Greenhouse Gas Emissions Reductions from Supply Chain Efficiency Strategies in the "Medium Term," per WEF Study

Strategy	Reduction	Feasibility
Clean Vehicle Technologies	5.2%	High
Despeeding the Supply Chain	6.9%	High
Optimised Networks	5.0%	High
Packaging Design Initiatives	0.1%	Medium
Training and Communications	4.5%	Medium
Modal Switches	4.7%	Medium
Nearshoring	0.2%	Medium
Increased Home Delivery	0.7%	Medium
Reducing Congestion	1.1%	Low
Total	25.3%	

Source: ACEEE calculation from WEF (2010)

Comparison of Studies: Methodology

Next we compared the results of three U.S. transportation studies, in terms of percentage reduction in greenhouse gas emissions relative to a reference case, with the results of the global supply chain studies.

Because of the broad set of strategies proposed in the McKinsey study, we used it to create an organizing framework for our comparison. We assigned each of the strategies in the U.S. studies and in the WEF study, together with their corresponding reduction potentials, to the six levers defined by the McKinsey study. Appendix A shows the classification of the strategies from each study with respect to the McKinsey levers.

We converted the efficiency or savings potential for each study into common units of tons of carbon dioxide equivalent reduced and, in the case of the global supply chain studies, scaled to the U.S. freight system.[3] We then calculated a percentage reduction in carbon dioxide emissions from the 2009 AEO Reference Case[4] by 2030. Our calculations are multiplicative when they apply to strategies for a single mode, to avoid double counting of savings.

Each study in effect considered more than one scenario. EPA (2010) characterized its scenarios as "somewhat aggressive" and "very aggressive." DOT (2010) gave its results as a range of reductions, which we assigned to the discrete "low" and "high" scenarios. Greene and Plotkin (2011) provided low, mid, and high mitigation scenarios. The McKinsey study, as noted above, defined its scenarios according to a low, medium, and high oil price. We defined three scenarios for the WEF study by using strategies' feasibility indices to place them into low, medium, and high scenarios.

Comparison of Studies: Results

The three U.S. studies calculated potential reductions in carbon dioxide emissions from freight sector energy efficiency measures ranging from 12 to 30 percent by 2030-2035 relative to business as usual. This amounts to reductions of approximately 80 to 190 million metric tons carbon dioxide and 0.6 to 1.4 million barrels per day in oil consumption. The McKinsey study found 23 to 51 percent reductions by 2020 (which would translate to 130 to 290 million metric tons of carbon dioxide and 0.9 to 2.1 million barrels per day for the U.S. freight system) and the WEF analysis found 16 to 25 percent in the "medium term." Table 6 compares the estimates of percentage reductions available in the freight system through the application of a wide variety of technology, behavioral, and system strategies, classified using the McKinsey levers. Appendix A provides further detail on the results presented here and gives results in terms of tons of carbon dioxide and barrels of oil per day reduced. For example, applying the McKinsey results to the United States would result in reductions of 131 to 291 million metric tons of carbon dioxide and 0.9 to 2.1 million barrels per day of oil in 2020.

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[3] See Appendix B for a more detailed summary of our methodology. The validity of this scaling of the supply chain studies projections can certainly be called into question, but the resulting comparison of the results nonetheless yields insights into the relative importance of various approaches across the five studies. Also, it should be noted that the U.S. studies' baseline freight fuel consumption, and our calculations of savings attributed to the various strategies considered, reflect fuel use for international trade to which the United States is a party, as well as fuel use for domestic freight movement.

[4] The U.S. studies used AEO 2009 (or 2010 in the case of Greene and Plotkin) as a reference case. We retained this reference case because, in some instances, it was unclear what the estimated savings would be relative to a more recent AEO reference case.

Table 6: Summary of Freight Sector Energy Savings Reduction Potential, by Study and Lever

Lever	Global Supply Chain Studies						U.S. Transportation Studies						
	McKinsey (2020)			WEF ("Medium Term")			EPA (2030)		DOT (2030)		Greene and Plotkin (2035)		
	Low	*Medium*	*High*	*Low*	*Medium*	*High*	*Aggressive*	*Very Aggressive*	*Low*	*High*	*Low*	*Mid*	*High*
Value Density	2%	3%	3%	0%	0%	0%	N/A	N/A*	N/A	N/A	N/A	N/A	N/A
Average Distance	1%	4%	15%	0%	0%	0%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Modal Mix	3%	4%	7%	0%	5%	5%	N/A	7%	0%	1%	N/A	N/A	N/A*
Asset Technology	10%	20%	22%	5%	5%	5%	10%	15%	10%	22%	12%	19%	23%
Individual Usage	7%	12%	17%	7%	12%	12%	3%	6%	1%	4%	0%	2%	3%
Collective Usage	1%	2%	3%	5%	5%	6%	2%	5%	2%	4%	0%	1%	2%
Total	23%	38%	51%	16%	25%	26%	15%	30%	13%	29%	12%	21%	28%
Total without Asset Technology	14%	23%	37%	12%	21%	22%	6%	18%	3%	9%	0%	2%	5%

* Modest reductions in this category reflected under Individual Usage.

Notes: Percentages are not additive. Figures in parentheses refer to the year in which the estimated potential savings will be realized.

Table 6 also presents savings potential without asset technology improvements, since these other strategies are the primary focus of our review. The global supply chain studies' estimates of total savings potential from levers other than asset technology, especially McKinsey's, are considerably higher than the U.S. studies' estimates as a whole, although EPA's "very aggressive" scenario approaches the WEF "high" result. These other levers could deliver 14 to 37 percent savings according to McKinsey, and 12 to 22 percent savings according to WEF. By contrast, the U.S. studies found 0 to 18 percent savings from these strategies. The biggest contributors to the higher efficiency potential in the supply chain studies are individual usage strategies such as speed and load factor optimization and, in the case of McKinsey, reducing the average distance between production and the final market.

Below we discuss the levers individually.

ASSET TECHNOLOGY

In all the studies except WEF (2011), asset technology improvements provided the largest gains of all the levers in all scenarios, ranging from 10 to 23 percent. These projected savings are relative to a reference case that does not include the federal heavy-duty fuel efficiency and greenhouse gas standards emissions standards adopted in 2011; those standards are in fact projected to reduce heavy truck fuel consumption by approximately 10 percent in 2030 (Khan and Langer 2011).

WEF's study estimates a 5 percent reduction from asset technology efficiency improvements. Aside from vehicle technology improvement, the asset technology category includes increased vehicle size and weight, an example of a strategy whose potential savings vary markedly from country to country. In particular, McKinsey notes that average truck size in most developing countries is less than half that in OECD countries, which results in higher fuel consumption per ton mile. This assumption of adoption of larger trucks in the developing world, where the truck stock is growing rapidly, may help to explain why McKinsey's global analysis assigns high savings to asset technology by 2020, even before vehicle fleets of developed counties will have had a chance to turn over.

INDIVIDUAL USAGE

The "individual usage" lever generally provided the second highest energy efficiency potential. Individual usage refers to strategies that address the actions of the vehicle operator, company, or client, such as speed management, load factor optimization, better vehicle maintenance, and improved route planning. McKinsey and WEF found the largest potential (from 7 to 17 percent and 7 to 12 percent, respectively), while the U.S. transportation studies found savings ranging from 0 to 6 percent. This may reflect a difference in global and U.S. energy efficiency opportunities in this category of strategies, or it may be that the supply chain studies gave greater consideration to these opportunities than the U.S. transportation studies did. In both the individual and collective usage categories, information and communications technologies can be expected to play a large role in the future, and it is unclear to what extent any of the studies factored such technologies into their projections.

MODAL MIX

Changes to the modal mix include outright mode shift and sequential and parallel multimodal transport.[5] McKinsey found 3 to 7 percent energy efficiency improvement potential by 2020, while WEF and EPA found potential savings of 0 to 7 percent. DOT found a savings potential of only one percent potential from mode shift. Greene and Plotkin acknowledged potential savings through mode shift, but folded them in with savings from strategies we have placed under the individual usage lever.

COLLECTIVE USAGE

Collective usage strategies refer to those that increase the efficiency of collective freight assets and infrastructure, such as a network of highways or an air traffic control system. McKinsey (2010)

[5] An outright mode shift involves shifting the movement of goods from one type of transport to another, for example from air to ocean vessel for a trans-Pacific journey. Sequential multimodal transport refers to the use of two or more modes in sequence, for example, replacing a long-haul truck with rail for the longest portion of a journey and then transferring to truck for local delivery. Parallel multimodal transport refers to the use of different transport modes for identical products on the same route, with the slower (typically more efficient) mode used to meet base demand and the faster (typically less efficient) mode used for peak demand.

observes that collective usage strategies serve a largely supporting role for other strategies by enabling improvements in scale of the transportation system. WEF found savings of 5 to 6 percent in the Medium Term from collective usage strategies of network optimization and reduced congestion. Strategies categorized as collective usage achieved savings ranging from 0 to 5 percent in the remaining analyses.

VALUE DENSITY

Perhaps more common in the supply chain literature than in freight transportation literature, "value density" refers to the ratio of a product's value to its area or volume. Therefore, either an increase in a product's value, or a reduction in the amount of space it takes up, will increase value density. McKinsey (2010) estimates that 30 percent of truck space used to transport finished goods is taken up by packaging or empty space, so redesigning packaging is the most obvious way to raise value density. The study found that redesigned packaging and the removal of filler material could yield a 2 to 3 percent improvement in energy efficiency by 2020. While WEF calculated large supply chain savings from reduced packaging, almost all of it was attributed to the packaging production stage (which we exclude) and only a negligible amount to transportation. EPA estimated savings from a set of operational efficiency strategies that included both better packaging and strategies that fall into the individual usage category (better loading, better routing, and empty mile reduction). Because EPA did not provide savings from package improvements alone, we assigned the combined savings, a total of 3 percent, to individual usage. The remaining U.S. studies appear not to have included this strategy in their analyses.

AVERAGE DISTANCE

The final lever, average distance, refers to the distance that materials and products in the supply chain travel in all stages prior to reaching the market. McKinsey's approach to reducing average distance focuses specifically on redesigning supply chains geographically in such a way that production centers for some non-core components (e.g., primary packing and power cables for computers) are located closer to end-user markets. McKinsey found potential savings for this category of strategies from 1 to 15 percent by 2020. WEF considered a similar option ("nearshoring"), which shows moderate reductions in greenhouse gas emissions from ocean shipping, air freight, and intermodal operations (rail and truck). These reductions are offset, however, by increased transport emissions from the nearshore operation itself, perhaps due to the substitution of certain modes by more energy-intensive modes. The result according to WEF was a negligible net reduction in emissions. Average distance reduction was not examined by other studies that we reviewed.

The studies showed a reasonable degree of consistency on the magnitude of estimated savings from most levers, as summarized in Table 7. The two exceptions were average distance and individual usage. Lack of consistency in these two areas reflects differences both in the range of strategies considered within a lever and in estimated savings associated with particular strategies.

Table 7: Range of Efficiency Potential across Studies

Lever	Efficiency potential
Value Density	Low
Average Distance	Low - High
Modal Mix	Low - Medium
Asset Technology	High
Individual Usage	Low - High
Collective Usage	Low - Medium

Discussion

We undertook this comparison of existing analyses of the potential for energy efficiency improvements in the freight system to understand which areas warranted further investigation and, in particular, what insights a supply chain perspective might provide on this topic. A more detailed look would be required to ensure the validity of the comparisons and to develop policy recommendations. Some of the work reviewed, in particular the supply chain studies, does not provide enough information on the methodology used to allow this more detailed review.

In 2013, DOE published the results of its Transportation Energy Futures Project analyzing the possibility of achieving an 80 percent reduction in transportation sector emissions by 2050 (DOE 2013). We did not include the findings in our review, because the time horizon of the study is much longer than those of the other studies, and it quantifies reduction potential only for selected strategies. However, the DOE study explores a wide range of strategies, including supply chain and pricing strategies. Its extensive discussion of policy considerations and the analytical tools it provides for public use should prove valuable for further exploration of freight system efficiency potential.

One essential issue not explicitly included in this report is the cost of the strategies discussed. While the studies in most cases considered only those vehicle technology improvements that pay for themselves in fuel savings, the question of cost-effectiveness for several of the other categories of measures is more complicated, involving a wide array of costs and benefits, and was not necessarily considered in the studies. Indeed, energy savings are unlikely to be the primary driver for an increase in distributed manufacturing, for example, or major mode shifts. Economic development priorities, just-in-time delivery requirements, traffic congestion, and freight industry cost structures, for example, could all be expected to shape future goods movement practices.

EPA notes that it did not consider the costs of the strategies analyzed, except that truck technology improvements should pay for themselves over the life of the vehicle. The DOT report provides a dollars-per-ton-carbon dioxide figure, as well as a discussion of co-benefits for each strategy. WEF describes the measures it considers as “cost-effective” but provides no specifics on this point. McKinsey’s scenarios, which are defined in terms of the cost of a barrel of oil, can be achieved "without adding net cost." A careful look at cost criteria is beyond the scope of this report but would strengthen the comparison of the studies' findings.

McKinsey notes that its first three levers (value density, average distance, and modal mix) are largely under the control of product manufacturers, wholesalers, and retailers, while the others (asset technology, individual usage, and collective usage) are controlled by carriers, logistics providers, equipment manufacturers, infrastructure companies, and governments. The federal government has indeed pushed on asset technology by adopting heavy-duty vehicle efficiency standards, and all levels of government strongly influence collective and individual usage through infrastructure investment. The public sector's impact on the first three levers, while sometimes indirect, can be substantial as well. Investing in intermodal facilities and non-highway modes or providing incentives for shared warehousing development near populated areas and on brownfields, for example, can enhance shippers' abilities to use alternatives to trucking and to reduce average distance.

The freight provisions of the 2012 federal transportation spending law MAP-21 (USGPO 2012) focus almost exclusively on roadways and do not include energy goals. They do include congestion reduction, economic efficiency, and environmental impact reduction goals, however. The agenda for the reauthorization of MAP-21 in 2014 would benefit from a broad, integrated, and well-documented analysis of the opportunities for freight system efficiency beyond eliminating roadway bottlenecks.

Conclusions and Further Research

The five studies analyzed in this scoping study find that there is substantial potential to reduce energy use in the U.S. freight system, not only through improvements to vehicle technologies but also through changes in individual vehicle usage, collective system management, modal mix, and supply chain strategies. The three U.S. transportation studies found potential reductions in freight sector energy use and greenhouse gas emissions in the range of 0 to 18 percent through system efficiency strategies, or approximately 0 to 110 million metric tons of carbon dioxide reductions and 0 to 0.8 million barrels per day of oil, by 2030 or 2035. The two global supply chain studies indicate a greater system efficiency potential of 12 to 37 percent, which would translate to 70 to 230 million metric tons of carbon dioxide and 0.5 to 1.7 million barrels per day of oil in the U.S. This was due in part to those studies' consideration of a broader range of strategies, such as reducing the distance products travel to markets or increasing the use of home delivery. Thus greater attention is warranted to characterizing these strategies' roles in making the U.S. freight system more efficient.

Using the picture of U.S. freight system efficiency potential that emerges from these studies as a starting point, further research might include:

- Conducting a U.S.-based supply chain study that considers the full range of energy savings strategies included in the global chain studies and a level of analytical detail comparable to that used in the U.S. transportation studies.

- Assessing gaps in the types of individual usage and behavioral strategies considered in existing analyses of efficiency potential.
- Quantifying the energy savings potential of strategies to reduce average distance, which are not well addressed in most analyses.
- Providing a first-order estimate of the savings potential from the increased use of information and communications technologies in the freight system.

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Appendix A: Summary of Energy Efficiency Potential Studies

Table A-1: Savings and Categorization of Strategies by McKinsey Lever

Study	Lever	MMT CO2e	Million barrels per day of oil	% CO2 Savings	MMT CO2e	Million barrels per day of oil	% Savings	MMT CO2e	Million barrels per day of oil	% Savings	Strategies Included
McKinsey (2010), in 2020	Scenario	Low Oil Price ($40/bbl)			Mid Oil Price ($100/bbl)			High Oil Price ($200/bbl)			
	Value Density	11	0.1	2%	17	0.1	3%	17	0.1	3%	Redesigned packaging, removal of filler material
	Average Distance	6	0.0	1%	23	0.2	4%	86	0.6	15%	Relocating production of core products closer to markets, nearshoring, use of multiple distribution centers
	Modal Mix	17	0.1	3%	23	0.2	4%	40	0.3	7%	Modal shift, sequential multimodal transport, parallel multimodal transport
	Asset Technology	57	0.4	10%	114	0.8	20%	126	0.9	22%	Increased capacity, improved relative drag, increased payload ratio, improved propulsion system efficiency
	Individual Usage	40	0.3	7%	69	0.5	12%	97	0.7	17%	Optimized speed, optimized load factor, improved maintenance regimes, optimized route planning
	Collective Usage	6	0.0	1%	11	0.1	2%	17	0.1	3%	Decreased traffic bottlenecks, improved traffic management, expanded infrastructure capacity, optimized loading procedures, smart traffic management, utilization-based pricing
	Total	131	0.9	23%	217	1.6	38%	291	2.1	51%	
WEF (2009), in the "Medium Term"	Scenario	Only high feasibility strategies			High and medium feasibility strategies			High, medium and low feasibility strategies			
	Value Density	0	0.0	0.0%	0.8	0.0	0.1%	1	0.0	0.1%	Packaging design initiatives
	Average Distance	0	0.0	0%	1	0.0	0%	1	0.0	0%	Nearshoring
	Modal Mix	0	0.0	0%	29	0.2	5%	29	0.2	5%	Modal shift
	Asset Technology	33	0.2	5%	33	0.2	5%	33	0.2	5%	Increased adoption of energy-efficient road and rail technologies that are currently available
	Individual Usage	44	0.3	7%	74	0.5	12%	74	0.5	12%	Slower speeds and improved fill rates; training and communications; and increased home delivery
	Collective Usage	32	0.2	5%	32	0.2	5%	38	0.3	6%	Optimized networks and reduced congestion
	Total	102	0.7	16%	154	1.1	24%	159	1.1	25%	

Study	Lever	MMT CO2e	Million barrels per day of oil	% CO2 Savings	MMT CO2e	Million barrels per day of oil	% Savings	MMT CO2e	Million barrels per day of oil	% Savings	Strategies Included
EPA (2010), in 2030	Scenario	Somewhat aggressive						Very aggressive			
	Value Density	--	--	--	--	--	--	--	--	--	(Unspecified benefit from packaging improvements included in Individual Usage, below)
	Average Distance	--	--	--	--	--	--	--	--	--	None
	Modal Mix	--	--	--	--	--	--	43	0.3	7%	10% truck share shifted to rail (5%) and marine (5%)
	Asset Technology	65	0.5	10%	--	--	--	96	0.7	15%	Improvements to vehicle aerodynamics, weight, tires, railcars, boat hulls and superstructure, and propulsion systems; increased capacity of trucks
	Individual Usage	21	0.1	3%	--	--	--	39	0.3	6%	Improved driver performance; better loading, packaging, routing, and empty mile reduction
	Collective Usage	12	0.1	2%	--	--	--	33	0.2	5%	Idle reduction, improved logistics, ground operations and air traffic management
	Total	97	0.7	15%	--	--	--	192	1.4	30%	
DOT (2010), in 2030	Scenario	Low end of range						High end of range			
	Value Density	--	--	--	--	--	--	--	--	--	None
	Average Distance	--	--	--	--	--	--	--	--	--	None
	Modal Mix	0.2	0.0	0%	--	--	--	5	0.0	1%	Freight modal diversion through improved rail capacity
	Asset Technology	64	0.5	10%	--	--	--	140	1.0	22%	Retrofits (existing truck fleet), powertrain and rolling resistance reduction technologies (new truck fleet), rail power system modifications, train-car aerodynamic improvements, improved ship design and marine propulsion systems, aircraft engine technology & airframe improvements
	Individual Usage	5	0.0	1%	--	--	--	27	0.2	4%	EcoDriving strategies
	Collective Usage	12	0.1	2%	--	--	--	24	0.2	4%	Urban consolidation centers, truck idling reduction, improved port and marine operations, multiple system and management strategies, reduced speed limit
	Total	80	0.6	13%	--	--	--	182	1.3	29%	
Greene and Plotkin (2011), in	Scenario		Low Mitigation			Mid Mitigation			High Mitigation		
	Value Density	--	--	--	--	--	--	--	--	--	None

Study	Lever	MMT CO2e	Million barrels per day of oil	% CO2 Savings	MMT CO2e	Million barrels per day of oil	% Savings	MMT CO2e	Million barrels per day of oil	% Savings	Strategies Included
2035	*Average Distance*	--	--	--	--	--	--	--	--	--	None
	Modal Mix	--	--	--	--	--	--	--	--	--	(Potential gains folded in with Individual Usage improvements)
	Asset Technology	82	0.5	12%	129	0.8	19%	158	1.0	23%	Truck improvements based on NESCCAF (2009); other major improvements for remaining modes.
	Individual Usage	0	0.0	0%	10	0.1	2%	23	0.2	3%	Reduction in empty truck miles, improved routing and scheduling, speed reduction
	Collective Usage	1	0.0	0%	6	0.0	1%	12	0.1	2%	Improved traffic flow; improved routing and flight paths for aircraft
	Total	83	0.5	12%	142	0.9	21%	184	1.2	27%	

Appendix B: Unit Conversion Methodology

Each study reviewed in this paper provided GHG reduction potential in different ways, either as absolute reductions in carbon dioxide emissions (WEF), or as percentage reductions against a baseline (Greene & Plotkin), or both (EPA, DOT, McKinsey). Where reductions potentials were given for the transportation system as a whole (e.g., aviation), we scaled these figures to the freight system; where reductions potentials applied only to freight modes (e.g., heavy-duty trucks), we used the figures as is. The freight portion of carbon dioxide emissions was calculated by adding together AEO 2009 projections for emissions from freight trucks, rail freight, domestic and international shipping (originating in the United States), and the freight portion of air travel.[6] We then estimated percentage reductions compared to the AEO 2009 Reference Case, as shown in the following table.[7]

[6] The freight portion of air travel was assumed to be 14 percent based on DOT (2010) Volume 1 p.2-12, citing EPA's 2008 GHG emissions inventory.

[7] Reductions in oil consumption (see Appendix A) compared to the AEO Reference Case were estimated in a similar fashion. We assumed that the percentage reduction in GHG emission led to an equivalent percentage reduction in oil consumption relative to the AEO 2009 Reference Case.

Table B-1. Methodology for Comparing Savings Potential across Studies

Study	Type of measure	Original units	[x] Scale factor for freight	[÷] Baseline emissions projection (AEO 2009)
DOT	Freight measures	$MMTCO_2$	N/A	[÷] freight portion of CO_2 emissions
DOT	On-road measures	$MMTCO_2$	[x] % of total on-road CO_2 emissions from freight trucks (AEO)	[÷] freight portion of CO_2 emissions
DOT	Vehicle technology	% reduction in CO_2	[x] % of CO_2 emissions from freight, by mode	Multiplicative approach
EPA	Non-road freight technology	% reduction in CO_2, by mode	[x] freight-related CO_2 emissions, by mode (AEO)	[÷] freight portion of CO_2 emissions
EPA	Non-road travel efficiency	% reduction in CO_2, by mode	[x] freight-related CO_2 emissions, by mode (AEO)	[÷] freight portion of CO_2 emissions
EPA	Heavy duty technology	$MMTCO_2$	N/A	[÷] freight portion of CO_2 emissions
EPA	Heavy duty travel efficiency	% reduction in CO_2	[x] CO_2 emissions from freight trucks (AEO)	[÷] freight portion of CO_2 emissions
Greene & Plotkin	Fuel consumption per mile	% reduction in CO_2, by mode	[x] freight-related CO_2 emissions (AEO[8])	N/A
Greene & Plotkin	Logistics	% reduction in CO_2, by mode	[x] freight-related CO_2 emissions (AEO)	N/A
Greene & Plotkin	VMT reduction	% reduction in CO_2, by mode	[x] freight-related CO_2 emissions (AEO)	N/A
Greene & Plotkin	Improved traffic flow	% reduction in CO_2, by mode	[x] freight-related CO_2 emissions (AEO)	N/A
WEF	All measures	$MMTCO_2$	[x] estimate of freight component of emissions	[÷] freight portion of CO_2 emissions

[8] In the case of Greene & Plotkin (2011), the baseline is AEO 2010 rather than AEO 2009.