# Assessment of Potential Reduction in Greenhouse Gas (GHG) Emissions in Freight Transportation

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## ABSTRACT

Freight transportation accounts for 9% of total greenhouse gas (GHG) emissions in the United States. The contributions of each of five freight transportation modes to total freight transportation GHG emissions are 60, 6, 5, 13, and 16 percent for truck, rail, air, water, and pipeline, respectively. There is growing interesting in reducing GHG emissions in freight transportation. Fifty-nine strategies are identified as potential best practices for these reductions. Total estimated GHG emissions reductions by 2025 for all practices is $4.6\times10^8$ tons $CO_2$ eq., which is 42% of 2025 GHG emissions if no best practice is implemented. For the truck mode, 2025 GHG emissions could be reduced by 28 percent compared to 2003 levels. Of other four modes, 2025 GHG emissions could increase by 20, 8, 22, and 9 percent, respectively, compared to 2003 levels, which is smaller than the increase if no best practices are implemented. For thirteen practices for which costs were assessed quantitatively, ten practices may produce net cost savings concurrent with substantial reductions in GHG emissions. Based on current prices, switching from petroleum to biodiesel can reduce GHG emissions but increase total costs. Inter-modal shifts could lead to potentially larger reductions. For example, a shift from truck to rail modes can reduce GHG emissions per ton-mile by 85 percent, even when truck transport at the start and end of the trip are considered. The results of the assessments are the basis for development of a guidebook that identifies and characterizes these best practices.

## INTRODUCTION

Freight transportation is comprised of five major modes: truck, rail, air, water, and pipeline. Freight transportation accounts for approximately 9% of total GHG emissions in the United States.[1-2] The individual contributions of each of the five freight transportation modes to total freight transportation GHG emissions are 60, 6, 5, 13, and 16 percent for truck, rail, air, water, and pipeline, respectively. Energy use for freight transportation is expected to increase significantly in the next 25 years. GHG emissions are largely based on energy use. Therefore, GHG emissions could also increase significantly.

There is increasing interest in identifying ways to reduce GHG emissions. There are a growing number of technological and operational strategies that could reduce GHG emissions from freight modes. However, knowledge of existing or developing potential best practices and their effectiveness at reducing greenhouse gas emissions is not widespread. Therefore, a comprehensive analysis of these potential best practices is necessary in order to identify and communicate their potential for GHG emissions reductions.

## METHODOLOGY

The methodology includes: (a) reviewing literature to identify Best Practices (BPs); (b) assessing maximum reductions in 2025 GHG emissions, energy or refrigerant use; (c) assessing cost savings (where data are available); and (d) summarizing and reporting assessment results.

### Literature Review

Most data and information were taken from published technical and policy reports, books, and engineering journal papers, although some data was collected from websites. A few representative examples out of more than 120 references are cited here.[3-6] A list of identified BPs for the five modes was developed based on the literature review.

### Assessment of Potential Reductions for Best Practices

For an individual BP, the potential per-device reductions in GHG emissions for each BP are estimated based on the difference in per-device emissions with versus without use of the BP. Strategies based on substitution of alternative fuels are assessed based on life cycle inventories. Each BP may only be applicable to a fraction of all devices within a mode. The reductions in modal GHG emissions and energy or refrigerant use are estimated based on the differences in 2025 modal emissions with or without use of the BP. Best practices are categorized with respect to developmental status: new concepts, pilot tests, and commercially available systems. An assumption is made that each BP reaches a best estimate of maximum market penetration by 2025 without technical, practical and cost barriers, which is an upper bound for purposes of comparison. Actual market penetration may be lower.

BPs within a mode are categorized within subgroups based on similar objectives or methods (e.g., reduce aerodynamic drag, increase engine efficiency). In many cases, aggregate reductions for a subgroup of BPs are estimated based on a linear combination of the BPs. However, in some cases, two or more BPs within a subgroup are mutually exclusive because they cannot be used simultaneously. In this case, the BP with the highest reduction is used in the estimate of total reductions for the subgroup. Some BPs within a subgroup may interact with each other (e.g., multiple approaches for reducing aerodynamic drag), but there is a lack of data to quantify these effects. Thus, the linear combination may tend to overestimate the maximum possible reduction for the subgroup.

### Assessments of Maximum Net Savings of Individual Best Practices

Quantitative assessments for cost effectiveness are performed, where sufficient data are available. Total net cost savings is the difference between annual energy or refrigerant costs savings and the annualized costs, the latter of which include levelized capital costs and annual operation and maintenance costs. Net savings per unit of GHG emissions reductions are estimated by normalizing total net savings with respect to GHG emissions reductions. A positive value of net savings means that the BP will pay for itself over some period of time, whereas a negative value means that the annualized costs exceed savings associated with reductions in energy use or refrigerant use.

### Summarizing and Reporting Results for Individual Best Practices

Quantitative estimates of the reductions in GHG emissions, energy use and refrigerant use were made for all BPs, but quantitative estimates of the cost effectiveness were made only for some BPs for which sufficient cost data were available. Qualitative assessments of BPs were performed where there was a lack of quantitative cost data, and the results are summarized in simplified summary tables. Quantitative cost assessments were performed where sufficient cost data were available, and the results are summarized in standardized reporting tables.

## RESULTS AND DISCUSSION

A total of 59 BPs have been identified to date, which are listed in Table 1. There are 33, 6, 10, 5, and 5 BPs for the truck, rail, air, water, and pipeline modes, respectively. There is substantial variability among the BPs in terms of their potential percentage reductions in modal GHG emissions. The variations in reductions among individual practices range from 0.2 to 5.5 percent for the truck mode, 0.6 to 5.5 percent for the rail mode, 1.0 to 13.0 percent for the air mode, 0.2 to 3.0 percent for the water mode, and 0.1 to 1.9 percent for the pipeline mode.

### Table 1. List of 59 Best Practices for Greenhouse Gas Emissions Reductions in Freight Transportation.

| Mode | Subgroup | Name of Best Practices |
|---|---|---|
| Truck | Anti-idling | Off-board Truck Stop Electrification;[a] Truck-board Truck Stop Electrification;[a] Auxiliary Power Units;[a] Direct-fired Heaters;[a] Direct-fired Heaters with Thermal Storage Units[a] |
| | Air Conditioning System Improvement | Enhanced Air Conditioning System: (I) for Direct Emissions;[b] (II) for Indirect Emissions; Alternative Refrigerants: (I) CO2;[a,b] (II) HFC-152a;[a,b] (III) HC[a,b] |
| | Aerodynamic Drag Reduction | Vehicle Profile Improvement: (I) for Tractor; (II) for Truck Side and Underside;[b] (III) for Trailer (or Van); Pneumatic Aerodynamic Drag Reduction;[a,b] Planar Boat Tail Plates on a Tractor-trailer; Vehicle Load Profile Improvement[a] |
| | Tire Rolling Resistance Improvement | Automatic Tire Inflation Systems; Wide-base Tires;[a] Low-rolling-resistance Tires;[a] Pneumatic Blowing to Reducing Rolling Resistance |
| | Hybrid Propulsion | Hybrid Trucks |
| | Weight Reduction | Lightweight Materials |
| | Transmission Improvement | Advanced Transmission;[b] Transmission Friction Reduction through Low-viscosity Transmission Lubricants[b] |
| | Diesel Engine Improvement | Engine Friction Reduction through Low-viscosity Engine Lubricants; Increased Peak Cylinder Pressures; Improved Fuel Injectors;[b] Turbocharged, Direct Injection to Improved Thermal Management;[b] Thermoelectric Technology to Recovery Waste Heat |
| | Accessory Load Reduction | Electric Auxiliaries;[a,b] Fuel-cell-operated Auxiliaries[a,b] |
| | Driver Operation Improvement | Truck Driver Training Program |
| | Alternative Fuel | B20 Biodiesel Fuel for Trucks |
| Rail | Anti-idling | Combined Diesel Powered Heating System and Auto Engine Start/stop System;[a] Battery-diesel Hybrid Switching Locomotive;[a] Plug-in Units[a] |
| | Weight Reduction | Lightweight Materials |
| | Rolling Resistance Improvement | Lubrication Improvement |
| | Alternative Fuel | B20 Biodiesel Fuel for Locomotives |
| Air | Aerodynamic Drag Reduction | Surface Grooves; Hybrid Laminar Flow Technology; Blended Winglet;[a] Spiroid Tip[a] |
| | Air Traffic Management Improvement | Air Traffic Management Improvement |
| | Weight reduction | Airframe Weight Reduction; Non-essential Weight Reduction |
| | Ground Support Equipment Improvement | Ground-based Equipment as an Alternative to Auxiliary Power Units; Electric or Hybrid Heavy Duty Delivery Trucks |
| | Engine Improvement | Improved Engine Combustion Efficiency |
| Water | Propeller System Improvement | Off-center Propeller;[a] Propeller Boss Cap with Fins;[a] Auxiliary Free-rotating Propulsion Device behind the Main Propeller[a] |
| | Anti-idling | Shoreside Power for Marine Vessels at Ports |
| | Alternative Fuel | B20 Biodiesel Fuel for Ships |
| Pipeline | Process Control Device Improvement | Convert Natural Gas Pneumatic Controls to Instrument Air; Replace High-bleed Natural Gas Pneumatic Devices with Low-bleed Pneumatic Devices |
| | Connecting Method | "Hot Tap" Method |
| | Maintenance | Transfer Compression; Inline Inspection |

[a] Mutually exclusive within a subgroup

[b] Interaction within a subgroup

Within each mode, multiple BPs can be applied simultaneously to achieve total 2025 modal GHG emissions reductions (compared to projected emissions if no BPs are used) of 57, 19, 34, 4, and 4 percent for the truck, rail, air, water, and pipeline modes, respectively, as summarized in Figure 1. The magnitude of the estimated potential GHG emissions reductions (compared to projected emissions if no BPs are used) for each mode in 2025 ranges from approximately 5 million to 412 million tons $CO_2$ eq., as also summarized in Figure 1. Total estimated GHG emissions reductions by 2025 for all practices is $4.6\times10^8$ tons $CO_2$ eq., which is 42% of 2025 GHG emissions if no best practice is implemented.

Most GHG emissions reductions are based on reduction in energy use or the use of alternative fuels. There are four BPs that reduce GHG emissions by reducing refrigerant leakage or use of alternative refrigerants. For the truck mode, if all identified BPs are implemented aggressively, 2025 GHG emissions could be reduced by as much as 28 percent compared to 2003 levels. Of other four modes, 2025 GHG emissions could increase by 20, 8, 22, and 9 percent, respectively, compared to 2003 levels, which is smaller than the increase if no BPs are implemented. The possible net decrease in total freight transportation GHG emissions from 2003 to 2025 is 11%, even if energy use increases as currently projected.

Sufficient information has been obtained to assess the costs of 13 practices quantitatively. A list of these 13 BPs is given in Table 2. There is substantial variability among these BPs in terms of reductions in modal GHG emissions within their individual modes, which are summarized in Figure 2. Four BPs within the truck mode produce substantial GHG emissions reductions. There is substantial variability among these 13 BPs regarding their net cost savings, which are also summarized in Figure 2. Ten of them produce net cost savings because of significant energy cost savings. Three of them have net cost increases because they involve substitution of alternative fuel. Switching from petroleum to biodiesel can reduce GHG emissions but increase total costs, based on recent fuel prices.

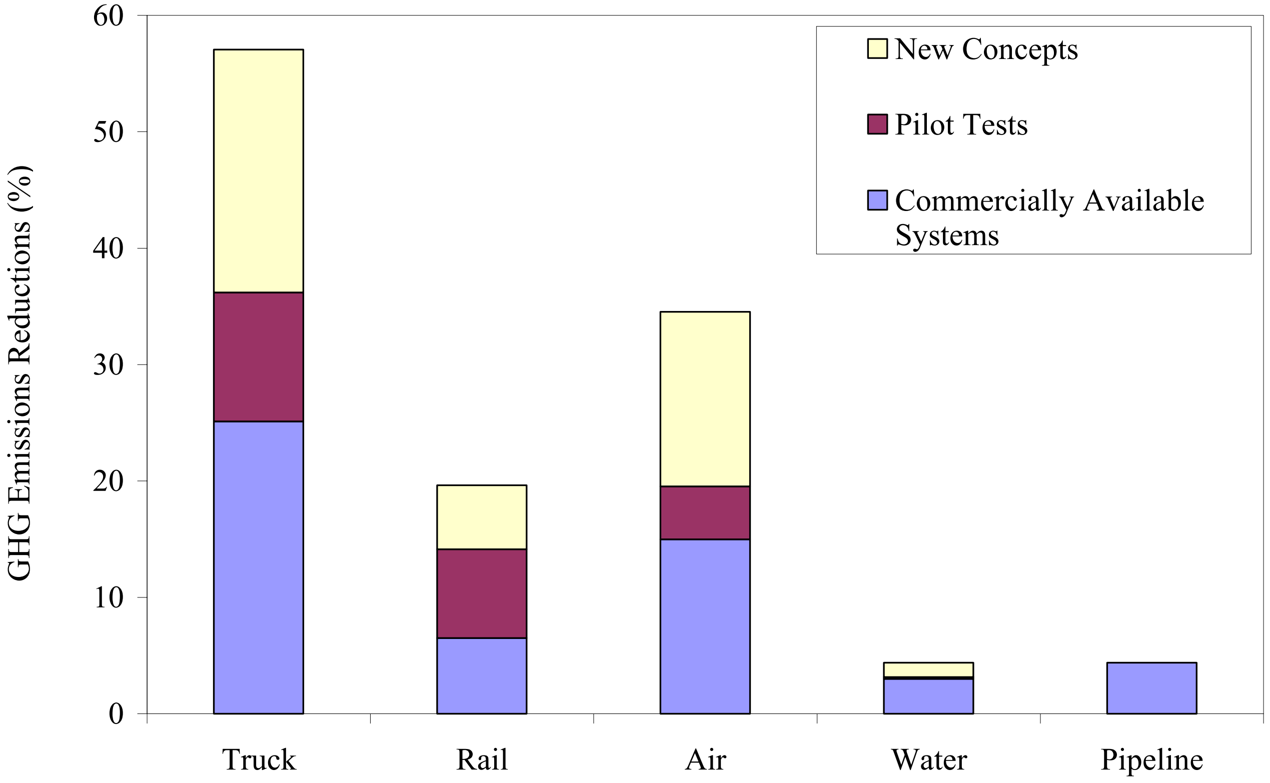
Table 2. **List of 13 Best Practices Whose Costs Are Assessed Quantitatively.**

| Mode | Identification Number | Name of Best Practices |
|---|---|---|
| Truck | 1 | Off-board Truck Stop Electrification |
| | 2 | Auxiliary Power Units |
| | 3 | Direct-fired Heaters |
| | 4 | Hybrid Trucks |
| | 5 | B20 Biodiesel for Trucks |
| Rail | 6 | Combined Diesel Powered Heating and Start/stop System |
| | 7 | Battery-diesel Hybrid Switching Locomotive |
| | 8 | Plug-in Units |
| | 9 | B20 Biodiesel for Locomotives |
| Water | 10 | B20 Biodiesel for Ships |
| Pipeline | 11 | Natural Gas-powered Pipeline Process Control Device: Replaced by Compressed Air-powered Devices |
| | 12 | Natural Gas-powered Pipeline Process Control Device: Replaced by Low-bleed pneumatic Devices |
| | 13 | “Hot Tap” Method |

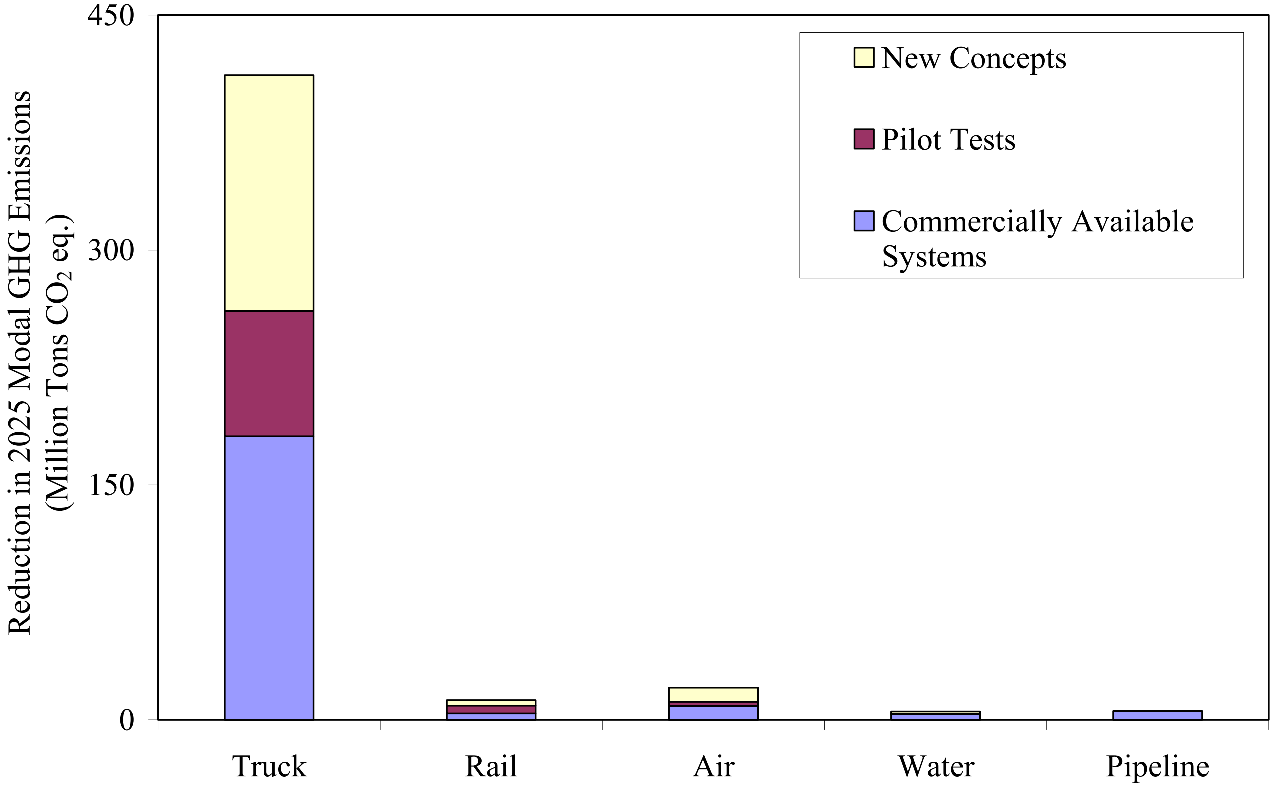
From a national policy perspective, consideration of the potential magnitude of reductions is important. From an individual owner or operator perspective, consideration of cost savings and cost effectiveness may be more important.

Even larger percentage reductions are possible if intermodal shifts, such as from truck to rail, are encouraged. For example, reductions on the order of 85% are possible if long-haul truck transport is replaced with a combination of rail and truck transport. This estimate takes into account a portion of the total freight shipment using truck transport at the start and end of the trip.

**Figure 1. Total Potential Reductions in 2025 Modal Greenhouse Gas Emissions Compared to Projected Emissions if No Best Practices Are Used.**

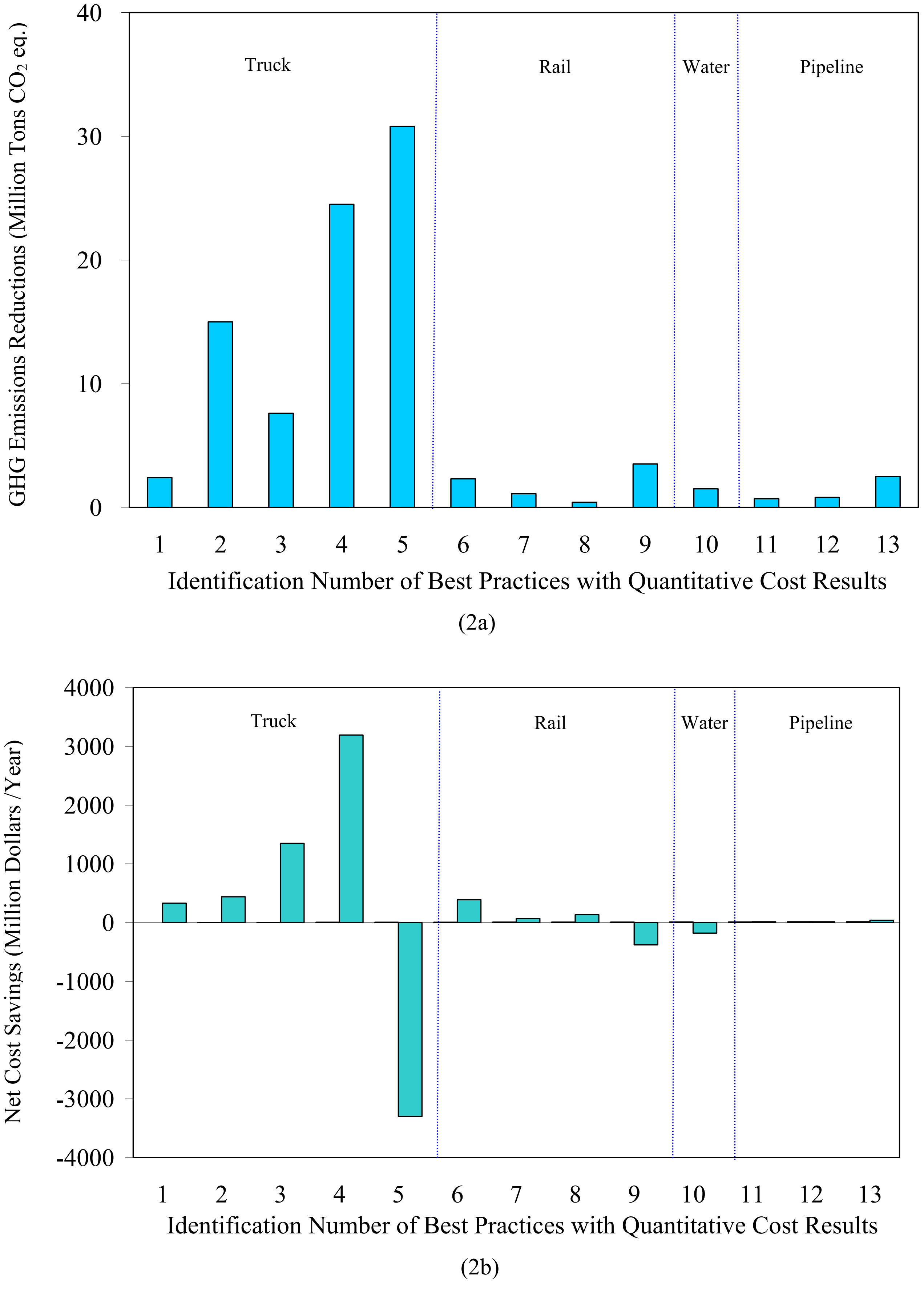


(1a) Percent Reductions



(1b) Magnitude of Estimated Reductions

**Figure 2. Comparisons of Best Practices Whose Costs Are Assessed Quantitatively.**



(2a)

(2b)

## CONCLUSIONS

There are many potential BPs for reducing energy and refrigerant use, which could lead to reductions in GHG emissions. If BPs are aggressively implemented, it is possible for there to be a *net decrease* in total GHG emissions in freight transportation. Even larger percentage reductions are possible if inter-modal shifts (e.g., substitution of rail for truck) are encouraged. There is limited quantitative data upon which to base assessments of BPs. For thirteen BPs for which adequate data are available, the normalized cost savings per unit of GHG emissions reduction was highly variable, mostly depending on the magnitudes of their energy cost savings.

## RECOMMENDATIONS

The key recommendations based on this work are that:

1. Information should be updated as new information becomes available;
2. The impact of variations of key assumptions (e.g., market penetration rates, fuel costs, and capital costs) that influence the selection of best practices should be assessed via sensitivity analysis; and
3. Tools should be developed to support decision making regarding selection of best practices. These tools may include a web-based decision tree that can guide users toward promising best practices appropriate to their situations, and a decision tool that enables users to compare multiple best practices based on their own data and assumptions.

## ACKNOWLEDGEMENTS/ DISCLAIMER

This work is supported by the U.S. Department of Transportation via Center for Transportation and the Environment. The authors are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of either the U.S. Department of Transportation or the Center for Transportation and the Environment at the time of publication. This report does not constitute a standard, specification, or regulation.

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## KEY WORDS

Freight Transportation, Best Practice, Greenhouse Gas, Mode, Truck, Rail, Air, Water, Pipeline, Energy, Refrigerant, Cost Savings, Cost Effectiveness, Intermodal Shift.