Analysis of heavy-duty vehicle fuel efficiency technology uptake in California and Canada

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ICCT CONSULTING REPORT

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1. INTRODUCTION

The intensifying need to mitigate climate change and local air pollution is motivating governments around the world to more aggressively pursue measures to accelerate fuel-saving and advanced technologies into commercial vehicle fleets. As part of the Canadian government's efforts to reduce air pollutant and greenhouse gas (GHG) emissions from the transportation sector, Environment and Climate Change Canada (ECCC) is exploring additional policy measures targeting on-road commercial vehicles. For several decades, California has been at the forefront of developing and implementing policies to reduce fuel use and emissions from mobile sources and heavy-duty trucks (HDTs)[1] in particular. Lessons learned from California's extensive experience with deploying several innovative regulations and incentive programs to accelerate HDT technology uptake can be instructive as the federal government of Canada considers whether it might be advantageous to use California as an example for future policy developments.

The primary motivation for this collaborative study between the International Council on Clean Transportation (ICCT) and the North American Council for Freight Efficiency (NACFE) is to analyze the adoption of HDT fuel-saving technologies in Canada and the United States over the past 10 years and examine the role policy in shaping this evolution. The objectives of this paper are to:

- Summarize the regulatory programs that have been enacted in California, the United States, and Canada to increase the fuel efficiency of HDTs;
- Profile HDT technology advances and provide qualitative and quantitative evidence of the unique aspects of California's trucking fleet;
- Survey a cross section of trucking fleets of various types and sizes and representatives from HDT original equipment manufacturers (OEMs) and parts suppliers;
- Conduct in-depth interviews with key staff from the California Air Resources Board (CARB) about incentive and regulatory programs to accelerate the deployment of fuel-saving technologies and zero-emission HDTs; and
- Synthesize the findings from the surveys and interviews into information and recommendations that are relevant for policymakers in Canada.

The paper is organized as follows. In Section 2, we begin by providing an overview of the types of policies that can accelerate technology adoption, and then we outline the regulatory programs and voluntary measures that California, the United States, and Canada have implemented to reduce fuel consumption and GHG emissions from HDTs. Section 3 discusses some of the technology advancements in tractor-trailers over the past 10 years and regional disparities in adoption rates that have been driven by different climate conditions and a non-uniform regulatory environment. In Section 4, we summarize the results from industry interviews and surveys. Finally, Section 5 summarizes the key findings from the study that are relevant for Canada as the federal government considers additional policy measures targeting HDTs. For reference, Appendices A and B contain the questionnaire templates for trucking fleets and manufacturers, respectively.

1 In this paper, heavy-duty trucks (HDTs) refers to on-road trucks and vans with a gross vehicle weight rating of over 3,856 kg (8,500 lbs).

2. POLICY LANDSCAPE IN CALIFORNIA, THE UNITED STATES, AND CANADA

Fuel costs represent a significant expense for commercial trucking fleets, and there is a strong incentive to use fuel as efficiently as possible. There are several fuel-saving technology options for both trucks and trailers, but for a myriad of reasons, some of these technologies have had slow or limited uptake in the market. Based on a review of the literature and ICCT research in various regions around the world, these barriers to technology adoption generally fall into four broad categories: uncertainty about technology performance and return on investment, capital cost constraints, split incentives, and lack of technology availability. These barriers can have a critical impact in slowing the uptake of fuel-saving technologies in the trucking sector.

To counter these barriers, there are three primary types of policy measures: regulations, market-based approaches, and fiscal measures. As illustrated in Figure 1, these three types of policy measures can work to overcome barriers to adoption and accelerate the deployment of efficiency technologies.

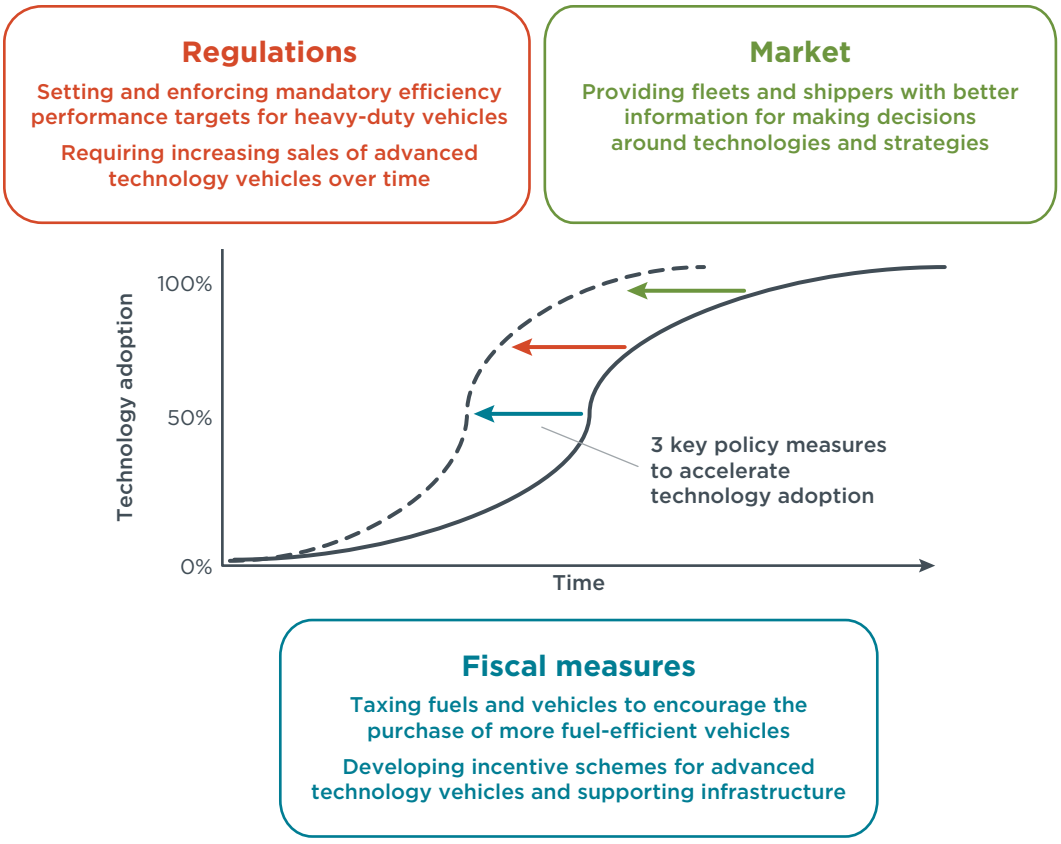

Figure 1. Three primary types of policies that accelerate the uptake of fuel-saving technologies.

The remainder of this section discusses the measures that California,[2] the United States, and Canada have taken in each of these three policy areas to promote improve fuel-efficiency, reduce GHGs, and accelerate electrification of the trucking sector. For context, the total population of heavy-duty trucks and buses in the United States is roughly 29 million vehicles, and Canada and California have 3 million and 2 million vehicles, respectively.

The policies discussed in this section are by no means an exhaustive list. These are simply the most noteworthy policies and programs that have been enacted at the state and federal level to curb GHGs and promote zero-emission vehicles (ZEVs). The focus is on actions taken by the California Air Resources Board, the U.S. Environmental Protection Agency (EPA), and Environment and Climate Change Canada.

We begin in Section 2.1 by describing the regulations that target heavy-duty vehicle manufacturers[3] and then turn the focus to regulations where fleets are the regulated entity in Section 2.2. Figure 2 summarizes the regulatory programs that are discussed in Sections 2.1 and 2.2. In Section 2.1.1, we outline the basic framework and performance requirements of the first and second phase GHG regulations for new heavy-duty vehicles. Each of the three governments has its own distinct Phase 1 and 2 regulations, though the regulations are virtually identical in the most meaningful design elements, such as rule structure, test procedures, and stringency levels. The following subsection (2.1.2) discusses CARB's ZEV sales requirements for HDT manufacturers. As shown in Figure 2, this regulation for increasing sales of zero-emission trucks over time is unique to California. Section 2.2.1 provides an overview of CARB's tractor-trailer GHG regulation for trucking fleets, and Section 2.2.2 briefly describes the upcoming ZEV purchase requirement for fleets that is still under development. All of the regulations for fleets are exclusive to California. In Section 2.3.1, we summarize voluntary market-based programs for promoting fuel efficiency in the across the three jurisdictions. We then profile a major incentive program in Section 2.3.2 that California has had in place for the past 10 years to promote advanced technology and zero-emission commercial vehicles. Finally, Section 2.3.3 summarizes incentive programs that have been implemented in Québec and Manitoba to accelerate the deployment of fuel-saving technologies in HDT fleets.

2 Due to its vehicle regulations that preceded the U.S. Federal Clean Air Act of 1970 and its particularly severe motor vehicle-related air quality air issues, the state of California retains the unique authority as a U.S. state to set emission standards that are equivalent to or more stringent than federal standards. Section 177 of the Clean Air Act authorizes other states to adopt California's more stringent standards.

3 Environment and Climate Change Canada's regulation targets heavy-duty vehicle manufacturers and importers.

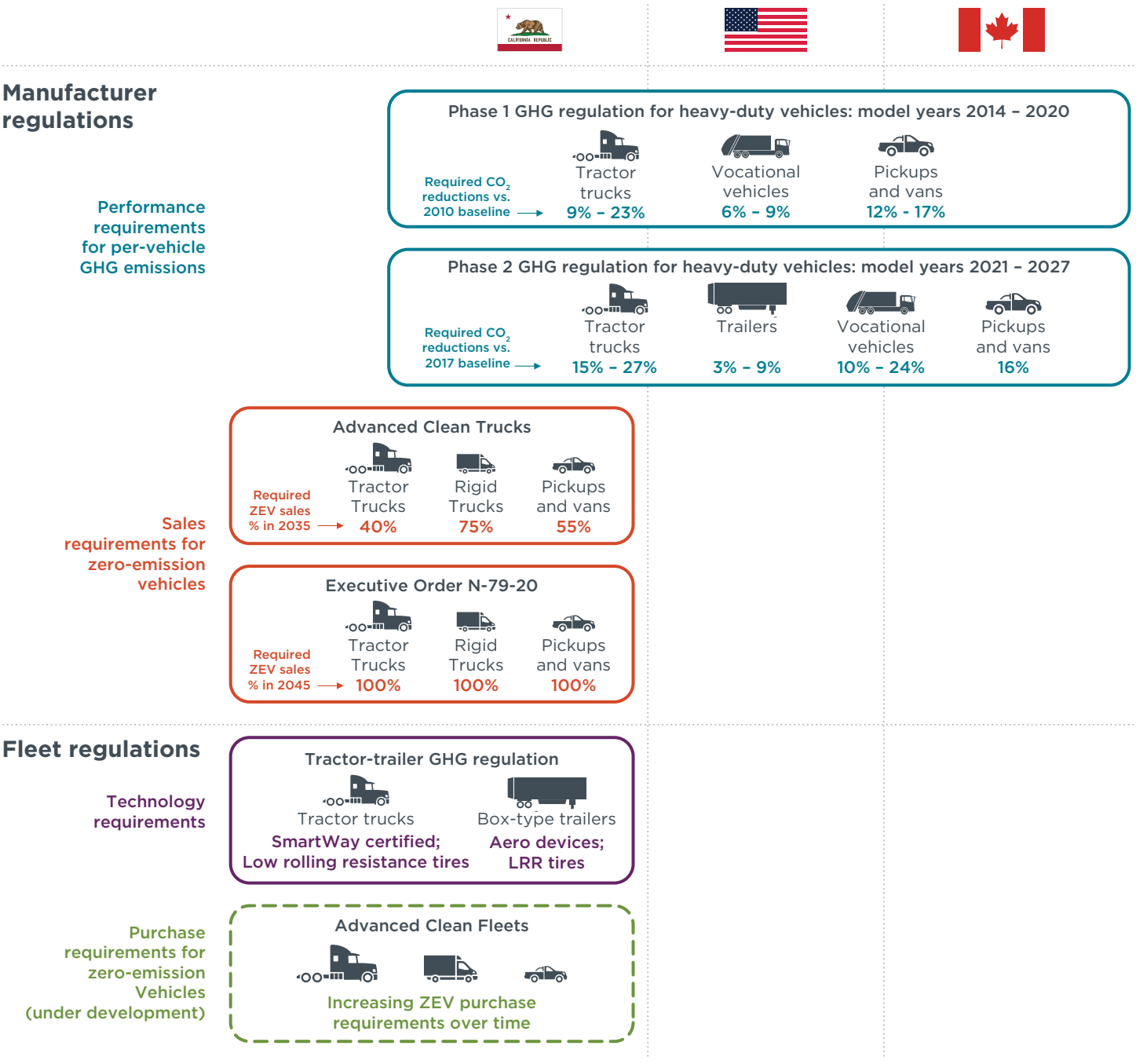

Figure 2. Summary of heavy-duty vehicle regulations to reduce greenhouse gas emissions and accelerate electrification in California, the United States, and Canada.

2.1. REGULATIONS FOR HEAVY-DUTY VEHICLE MANUFACTURERS

2.1.1. Performance standards for new heavy-duty vehicle fuel efficiency and GHG emissions

In August 2011, the U.S. EPA and the U.S. Department of Transportation jointly[4] released the country's first regulation for fuel efficiency and GHG performance of on-road heavy-duty vehicles and engines (Federal Register, 2011). The Phase 1 regulation segmented heavy-duty vehicles into three major categories: Class 7 and 8 tractor trucks, Class 2B and 3 pickup trucks and vans, and vocational vehicles. Within these three vehicle groups, the stringency levels of the regulation vary based on subcategories that are defined by weight classes and vehicle attributes. The Phase 1 rule began implementation in model year (MY) 2014, and the required improvements for per-vehicle fuel consumption reductions range from 6% to 23% in MY 2017 as compared to a MY 2010 baseline. The required consumption targets for some of the vehicle subcategories in Phase 1 are shown on the left side of Figure 3.

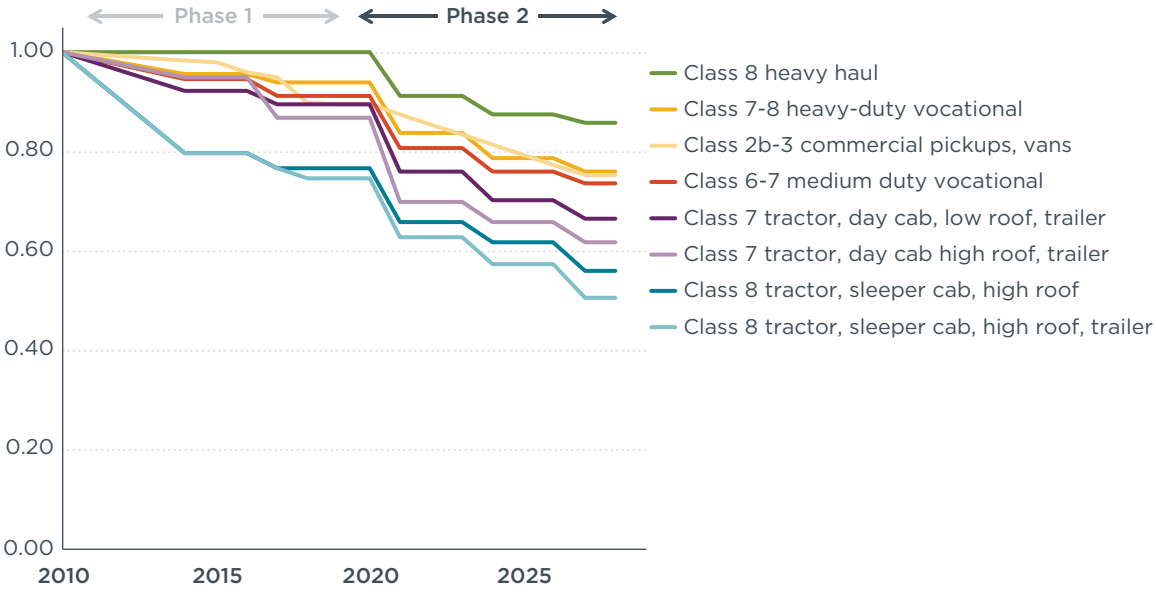

Figure 3. Estimated fuel consumption and CO_2 emission levels required in the Phase 1 and 2 regulations in California, the United States, and Canada relative to a model year 2010 baseline.

Subsequent to the United States finalizing its Phase 1 program, both ECCC and CARB each developed their own GHG regulations for heavy-duty vehicles that are mostly identical to the U.S. rule (California Air Resources Board, 2014; Canada Gazette, 2013). There are some Canada- and California-specific elements in the respective regulations, but, by intention, the key elements and protocols of the programs in the three jurisdictions are harmonized.

In 2016, the United States finalized its Phase 2 rulemaking, and, as with Phase 1, Canada and California followed up with highly-aligned Phase 2 regulations (Federal Register 2016;

4 The EPA and National Highway Traffic Safety Administration (NHTSA) worked collaboratively to develop regulations under their respective authorities: the EPA developed GHG emission standards under the Clean Air Act, and NHTSA developed fuel efficiency standards under the Energy Independence and Security Act (EISA). The standards in the EPA and NHTSA programs are identical, based on conversion factor for fuel consumption to CO_2 emissions. In addition, the EPA standard also includes limits on engine N_2O and CH_4, as well as limits on emissions of refrigerant from air conditioning systems.

Canada Gazette 2018; California Air Resources Board 2019). Phase 2 introduced several new elements to the program, including updated test procedures and increased stringency for each of the vehicle categories. As shown in Figure 3, these additional vehicle performance requirements are expected to reduce per-vehicle fuel consumption and CO_2 rates by up to 50% in MY 2027 compared to the MY 2010 baseline. In addition, Phase 2 introduced an entirely new equipment category: commercial trailers that are pulled by tractor trucks. As with the other three major equipment categories, trailers are further segmented into subcategories based on physical attributes. The technology advancements driven by the trailer provisions in the Phase 2 regulation are expected to yield up to a 9% reduction in per-trailer fuel use and CO_2 emissions by MY 2027, but thus far, this portion of the Phase 2 program has not been implemented in any of the three jurisdictions.[5]

2.1.2. Sales requirements for zero-emission vehicles

On June 25, 2020, CARB adopted a final rule for manufacturers that requires the sale of zero-emission HDTs starting in MY 2024 (California Air Resources Board, 2020a). The Advanced Clean Trucks (ACT) regulation is the first of its kind in the world to require manufacturers to sell increasing percentages of zero-emission trucks. As shown in Figure 4, sales requirements are defined separately for three vehicle groups: Class 2B and 3 trucks and vans, Class 4-8 rigid trucks, and Class 7-8 tractor trucks. By 2035, the rule requires that 75% of Class 4-8 rigid truck sales in California be zero-emission. For Class 2B and 3 vehicles and Class 7 and 8 tractors, these ZEV sales levels in 2035 will be 55% and 40%, respectively.

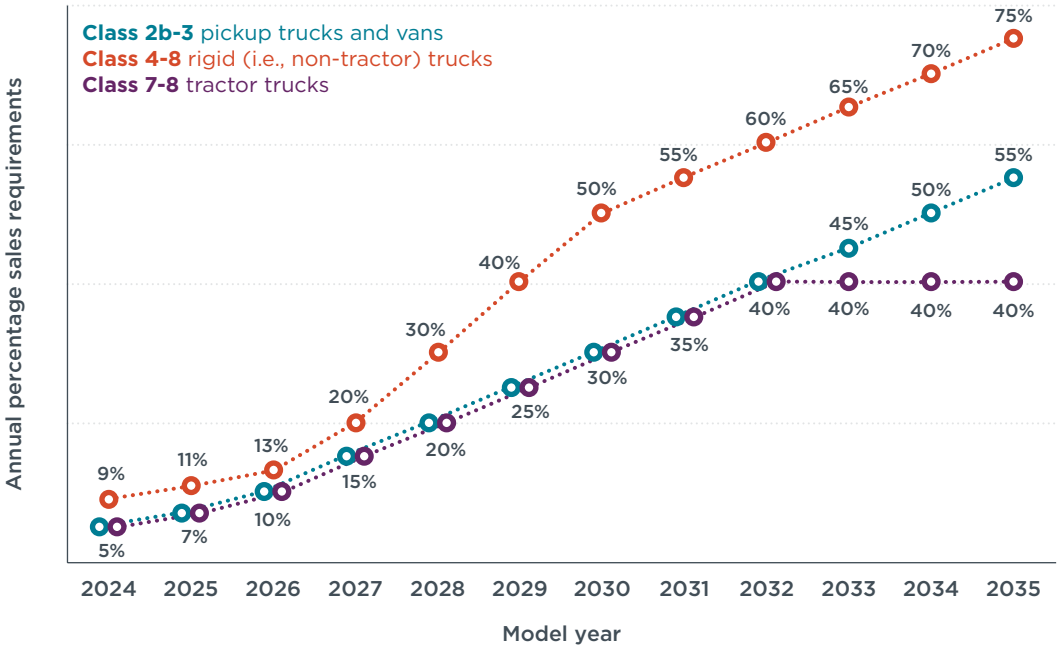

Figure 4. Zero-emission sales percentage schedule by vehicle group and model year.

As an addendum to the ACT regulation, CARB issued Resolution 20-19, which instructs it staff to continue to take steps to determine how to best achieve a zero-emission fleet of

5 At present, the trailer-specific requirements of the Phase 2 regulation are not being enforced in the U.S. or Canada, as this portion of the rulemaking has been tied in legal proceedings for several years. It is uncertain if the trailer standards will be reinstated and, if so, if the same level of regulatory stringency and timing that was outlined in the original Phase 2 regulations will still apply. However, California's trailer standards have been in effect since MY 2020, but CARB suspended its enforcement until at least January 1, 2022.

HDTs by 2045 (California Air Resources Board, 2020b). The resolution identifies earlier transition goals for certain market segments:

- Drayage trucks, last mile delivery, and government fleets: 100 percent zero-emission vehicle fleets by 2035
- Refuse trucks and local buses: 100 percent zero-emission vehicle fleets by 2040
- Utility fleets: 100 percent zero-emission capable vehicles by 2040

On September 23, 2020, the Governor of California issued Executive Order N-79-20, which declares that all passenger vehicles sold in the state must be zero-emission by 2035 (Office of the Governor of California, 2020). For commercial vehicles, the Order states that medium- and heavy-duty vehicle sales in the state must be 100% zero-emission by 2045 for all applications where feasible. For drayage trucks, this 100% ZEV requirement is pulled forward by 10 years to 2035.

2.2. REGULATIONS FOR HEAVY-DUTY VEHICLE FLEETS

2.2.1. California's tractor-trailer GHG regulation

In December 2008, the California Air Resources Board adopted the Heavy-Duty Vehicle Greenhouse Gas Emission Reduction Regulation, a measure that requires tractor-trailer fleets to install fuel efficient tires and aerodynamic devices on their vehicles (California Air Resources Board, 2008). The tractor-trailer GHG regulation applies to owners of 53 ft. or longer box-type trailers, including both dry-van and refrigerated-van trailers, and owners of the tractor trucks that pull them on California highways. Fleets are responsible for replacing or retrofitting their affected vehicles with compliant aerodynamic technologies and low rolling-resistance tires. All fleets are subject to the regulation when they operate their vehicles on California highways, regardless of where their vehicles are registered.

Starting on January 1, 2010, all MY 2011 tractor trucks pulling 53-foot or longer box-type trailers have to be a U.S. EPA SmartWay certified tractor (see Section 2.2.1 below). Additionally, as of January 1, 2013, all tractor trucks are required to use SmartWay verified tires. As with tractor trucks, the requirements for trailer are based on the MY and the type of equipment. Since 2010, there have been unique tire and aerodynamic device provisions and compliance deadlines based on whether the trailer is refrigerated or a dry van as well as the trailer's MY. There are specific requirements for large fleets, which are defined as any fleet operating 21 or more trailers. Fleets operating 20 or fewer trailers are regulated under the small fleet provisions.

2.2.2. California's forthcoming purchase requirements for zero-emission vehicles

As part of the regulatory development process for the Advanced Clean Trucks regulation, CARB indicated its intention to create a companion rule for trucking fleets. This Advanced Clean Fleets (ACF) regulation is currently under development. In a September 2020 public workshop, CARB staff outlined various concepts for the regulation and a proposed timeline that would be phased in between 2023 and 2045 (California Air Resources Board, 2020c). The purchase requirements of the ACF regulation will be designed to correlate to the ZEV sales timelines of the ACT. This rulemaking is expected to be presented to the Board for consideration in December 2021, and implementation is envisioned to begin in 2023.

2.3. VOLUNTARY AND INCENTIVE PROGRAMS

2.3.1. SmartWay

The SmartWay Transport Partnership is a collaborative voluntary program between the U.S. EPA and the goods movement industry designed to improve energy efficiency and lower GHG emissions and local air pollution (United States Environmental Protection Agency, 2016). Started in February 2004, SmartWay aims to create strong market-based incentives that challenge companies shipping products and the truck and rail companies delivering these products, to improve the environmental performance of their freight operations. The SmartWay program has served as a model for similar programs in many regions around the world, and in 2012, Natural Resources Canada launched a SmartWay program for Canada that is harmonized with several elements of its U.S. counterpart (Natural Resources Canada, 2020).

From its inception, one of the earliest and most influential elements of the SmartWay program was the focus on technologies for reducing fuel use and emissions from tractor-trailers. The work done to test and verify the fuel consumption profiles of equipment and vehicle configurations lead to the *SmartWay* designation, which has become the de facto trademark that is somewhat analogous with the U.S. Department of Energy's Energy Star label for household goods and appliances.

The significant amounts of tractor-trailer testing data amassed in the SmartWay program were an essential building block for the Phase 1 and 2 fuel efficiency and GHG regulations for tractor-trailers. And, as is discussed in Section 2.2.1, the SmartWay program was an essential building block of CARB's tractor-trailer fleet regulation.

2.3.2. Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)

The Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) was originally established by the California legislature in 2009. The purpose of HVIP is to encourage the purchase of advanced technology trucks and buses by offsetting about half of the incremental cost of these vehicles. The program is structured such that end-user fleets apply for funding vouchers on a first-come, first-served basis, and fleets are able to redeem the incentive amount for an eligible vehicle at the dealership at the time of purchase. HVIP is administered through a partnership between CARB and CalStart (California HVIP, 2021).

Through the end of 2020, over 7,000 vehicles and projects across the state have been supported with nearly $390 million USD of HVIP funding. This HVIP funding has been bolstered by an additional $2 billion of public and private funds that have gone towards these vehicle and infrastructure purchases. In addition to HVIP, several other state-level funding sources are supporting low-carbon and zero-emission HDVs and infrastructure. In fiscal year 2019–2020, HDV-specific funding (all in USD) included revenues from the Low Carbon Fuel Standard ($190 million), the cap-and-trade Greenhouse Gas Reduction Fund ($156 million), the Volkswagen Mitigation Trust ($117 million), and the California Energy Commission's Clean Transportation Program ($30 million) (California Legislative Analyst's Office, 2021).

Figure 5 summarizes the HVIP funding that has supported the purchase of zero-emission trucks and buses. As shown in the top part of the figure, the total value of the HVIP vouchers redeemed has grown substantially since 2011—from about $3 million USD in 2011 to $57 million in 2020—to $133 million cumulatively over the 10 years. The colors in

the columns of all three charts correspond to the class of the commercial vehicle. Class 8 vehicles accounted for nearly 80% of the redeemed vouchers in 2020. The middle portion of the figure shows the distribution of HVIP funding in 2020 across various truck and bus categories. School, shuttle, and transit buses made up just over 80% of the vouchers that were redeemed in 2020. The bottom of the figure is the cumulative number of zero-emission trucks and buses that have been funded by HVIP since 2011. Roughly 660 shuttle buses have received funding, which is nearly 300 more units than the next most popular HVIP project, transit buses. In 10 years, just over 2,000 ZEVs have received HVIP funding, and roughly two-thirds of these vehicles have been buses. For context, the roughly 260 ZEV projects funded in 2019 represent about 0.4% of the roughly 69,000 heavy-duty trucks and buses that were registered in California in 2019 (California Air Resources Board, 2021). However, focusing in on the leading segment in ZEV deployment, transit buses, about 120 vouchers were redeemed in 2020, which represents over 20% of the roughly 530 transit buses registered in the state in 2020.

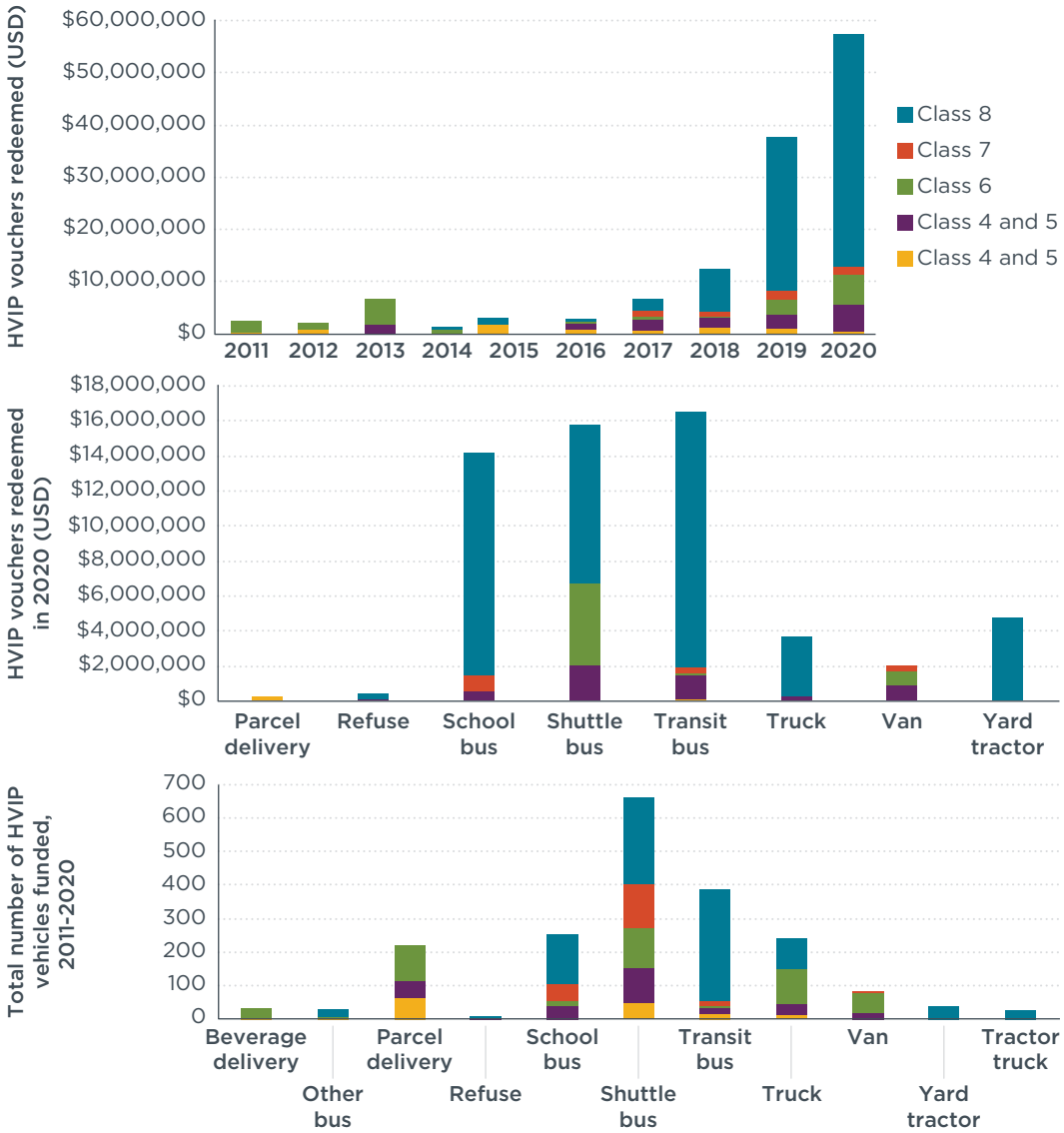

Figure 5. Zero-emission vehicle funding summary from California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP).

2.3.3. Trucking-targeted incentive programs in Quebec and Manitoba

The provinces of Québec and Manitoba have provided trucking fleets with incentive funding to support in the acquisition of fuel and emission reduction technologies. Québec's program – Programme d'aide Écocamionnage – began in 2013, and the second phase of the funding that started in November 2017 has a maximum of $76 million CAD that fleets can apply for through March 31, 2021 (Transports Québec, 2021). The government of Québec provides a list of products that are eligible for funding in the following technology areas (Government of Québec, 2019).

- anti-idling;
- auxiliary power units;
- telematics;
- aerodynamics;
- hybrid-electric or full electric vehicle; and
- alternative fuel engines or vehicles.

In 2020, the Canadian federal government and the province of Manitoba jointed announced the beginning of the application process for the Efficient Trucking Program, which will provide fleets with up to 50% rebate on fuel-saving technologies (Environment and Climate Change Canada, 2020). Both the federal government and Manitoba are each contributing $5.9 million CAD to the program. Class 5 through 8 vehicles are eligible for ETP funds for tire (air pressure management systems and low rolling-resistance tires) and aerodynamic technologies, as well as auxiliary power units.

3. TRUCKING TECHNOLOGY UPTAKE IN CALIFORNIA, THE UNITED STATES, AND CANADA

In this section, we assess how technology has evolved for HDTs over the past decade and, specifically, examine the differences in the HDT fleets in California compared to those in the United States and Canada. In the policy analysis in the previous section, we highlighted two distinct areas where California policy measures are distinct from the United States and Canada: 1) fleet regulation for tractor-trailers, and 2) regulations and incentive funding to promote accelerated zero-emission truck deployments.

Section 3.1 discuss tractor-trailer technology areas in the context of how regulatory disparities and Canada's harsher winter conditions are impacting adoption rates and the efficacy of various technologies in California, the United States, and Canada. In Section 3.2 we describe our real-world trailer survey in which we quantified the use of various aerodynamic devices on tractor-trailers operating on major trucking highways in California and Oregon.

3.1. TRACTOR-TRAILER TECHNOLOGY UPTAKE IN CALIFORNIA, THE UNITED STATES, AND CANADA

In Figure 6, we group tractor-trailer technologies into 3 categories based on adoption rates or technology efficacy being:

- Different in Canada
- Roughly equivalent across Canada and the United States (including California)
- Different in California

This technology assessment is based on the extensive fleet outreach carried out by the North American Council for Freight Efficiency (NACFE) over the past 10 years. For each of the technology areas highlighted in Figure 6 (and several other technologies), NACFE has developed comprehensive 'Confidence Reports' that detail real-world fleet experiences and lessons learned (North American Council for Freight Efficiency, 2020).

Special considerations for Canada

Severe winters may limit the ability for fleets to use certain **idle reduction technologies**. Main engine idling is more common in winter—especially since most fleets have temperature thresholds for operation that will allow main engine idling when below these set points.

Tire inflation systems can be very valuable to Canadian fleets with routes that extend to the southern U.S. states or Mexico due to the portions of the year where the ambient temperatures at the two ends of the route are significantly different, which results in tire pressure changes.

It is difficult to heat large spaces like sleeper compartments with electricity. **Space heating for zero-emission trucks** could require diesel-powered heaters—especially in places with severe cold.

Programmable engine parameters: Ontario and Quebec require vehicle speed limiters.

Some provinces limit the axle loads that trucks can carry using **wide base tires**.

In Canada, fleets may give more importance to **weight reduction** given the higher use of tandem trailers and the higher prevalence of tractor-trailers at the heavier end of the spectrum.

6x2 axle configurations have become more common in U.S. in recent years, but some weight and dimensions regulatory restrictions exist in Canada depending on provincial or territorial jurisdictions.

Similar adoption rates in Canada and the U.S.

Truck aerodynamic features and the most popular technologies and vehicle models are roughly equivalent across the U.S. and Canada.

There has been increased adoption of **engine downspeeding** over the past 15 years.

Automated manual transmissions have come to dominate the transmission market in the U.S. and Canada over the past 10 years due to ease of driving and fuel efficiency benefits.

NACFE estimates that roughly 20% of fleets in the U.S. and Canada are using **low-viscosity engine lubricants**.

Higher adoption rates in California

California's fleet requirements for **trailer aerodynamic devices** have resulted in higher uptake of these technologies.

With several incentive programs at the state and local level to promote **zero-emission truck** deployment, California is home to roughly 40% of all zero-emission commercial vehicles in the U.S. and Canada

Figure 6. Tractor-trailer fuel efficiency technology areas: factors for variability in uptake in Canada, the United States, and California.

3.1.1. Additional unique characteristics of the Canadian tractor-trailer market

Differences in regulated weight allowances and other operating parameters can lead to differences in truck specifications. For example, most operations within the United States are limited to 80,000 pounds, but certain provinces in Canada allow fleets to haul up to 120,000 pounds with a single tractor-trailer. Canada also has more common operation of double trailers, including twin 53-foot trailers. With tractor-trailers that are

heavier, on average, than those in the United States, fleet managers in Canada tend to opt for engines with larger displacement and horsepower. Larger tractor-trailers can also influence a fleet to spec transmissions with more gears and higher rear axle ratios to facilitate acceleration of heavy loads in challenging situations. Heavier axles are needed for heavier loads, and additional axles require additional tires, wheels, and brakes.

The climate-related challenges of operating in Canada or in U.S. states with heavy winters can also change specifications. Not only are winters colder and more severe in terms of wind, snow, and ice, but also there are other challenges. Operating in sparsely populated areas means that maintenance assistance is not always nearby. Sleeper tractors must have reliable heating systems and often "arctic package" insulation to ensure driver safety and survival in severe weather. Longer winters and more sub-freezing weather also mean more distance and time on roads that are being treated for ice. Most of these road treatments are known to cause corrosion of metal and are especially difficult on the many electrical connections on tractors and trailers.

3.2. OBSERVATIONS OF TRAILER AERODYNAMIC DEVICE USAGE IN CALIFORNIA AND OREGON

In November 2020, we surveyed tractor-trailers on highways in California and Oregon to quantify the use of trailer aerodynamic technologies. Our methodology was relatively simple and consisted of the following:

- Count the total number of 53-foot box-type trailers (excluding container chassis) in both traffic directions
- For each 53-foot box-type trailer, count if the trailer has:
  - Side skirts
  - Underbody devices
  - Rear-end devices
  - Combination of side skirts and rear-end devices[6]

In Oregon, the trucking corridors where we surveyed trailers included Interstate 84 between Portland and Mosier (segment 1 in Figure 7), as well as Interstate 5 between Portland and Eugene (segment 2). The final trailer surveying occurred in California between Mt. Shasta and Sacramento (segment 3).

Findings

- Side skirts were by far the most prevalent trailer aerodynamic device, accounting for nearly 95% of all the devices surveyed.
- On average, 68% of 53-foot box trailers in Oregon had at least one aerodynamic device, compared to 85% in California.
- Only 4 trailers (0.4%) had both side skirts and rear-end devices.

6 In practice, the only combination of devices we observed was side skirts and rear-end devices. We did not observe any trailers that had both an underbody device and a rear-end device.

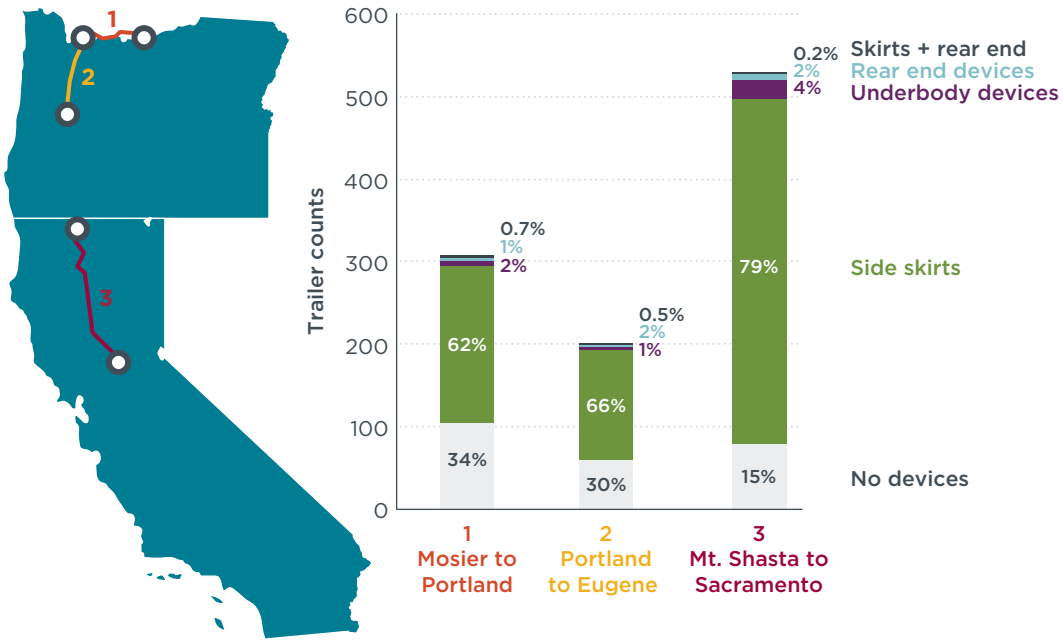

Figure 7. Trailer aerodynamic device counts for high trucking volume highways in California and Oregon in November 2020.

For context as to how the adoption rates of trailer aerodynamic devices have changed over time, we can draw from a National Research Council report that has trailer survey data from 2013 (Transportation Research Board and National Research Council 2014). For that study, nearly 5,000 trailers were surveyed at 10 locations in seven states throughout the United States. The counts are summarized for California and other states in Figure 8. For California, 43% of 53-foot box trailers had aerodynamic devices in 2013, versus 29% for the states outside of California.[7] While we do not have more recent trailer data from these same 10 survey locations, our trailer counts for this study provide a useful point of comparison—particularly for California and Oregon. From these data, we can draw the following conclusions:

- Side skirts have remained the dominant choice for trailer aerodynamic technology
- Side skirt deployment has increased significantly since 2013 and, based on the 2020 counts in Oregon, it's reasonable to assume that this growth has happened across the United States.
- Use of side skirts and other trailer aerodynamic devices remains more common in California.

7 From Annex Table 6B-1 in the NRC report, 24% of trailers in Oregon had at least one aerodynamic device in 2013.

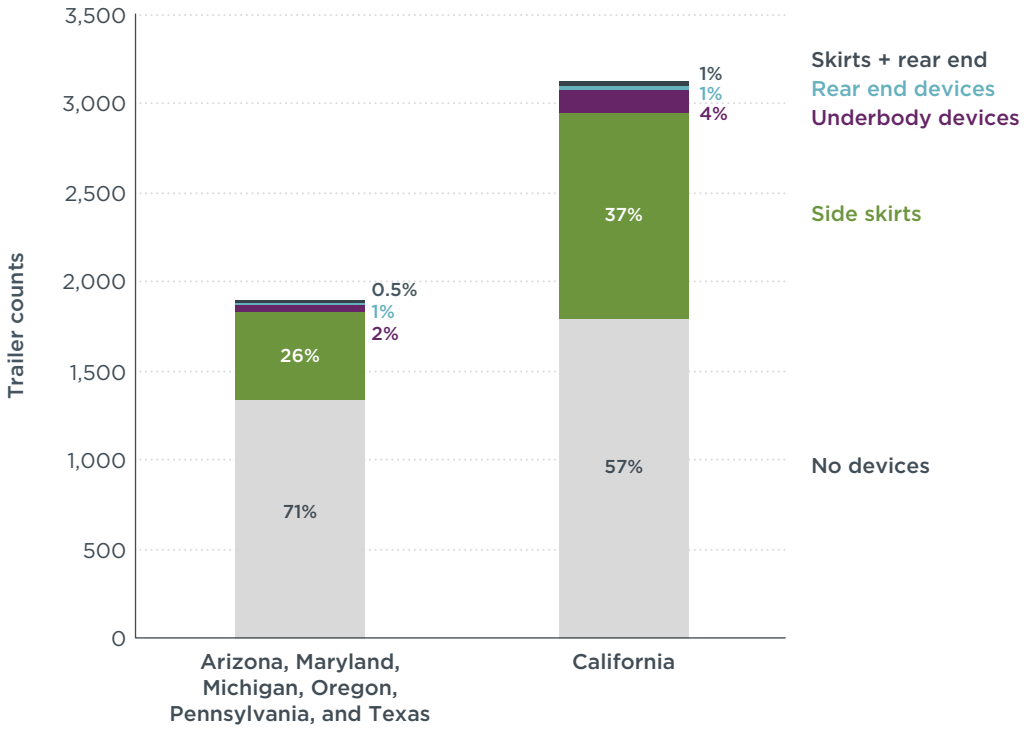

Figure 8. Trailer aerodynamic device counts for high trucking volume highways in California, Arizona, Maryland, Michigan, Oregon, Pennsylvania, and Texas in July and August 2013.

4. TRUCK TECHNOLOGY AND POLICY SURVEY

Between December 2020 and February 2021, we conducted online surveys and telephone interviews of fleet owners and manufacturers in the trucking industry, and we also had several conservations with CARB staff with direct knowledge of the policies and programs that have targeted commercial truck fuel-efficiency and electrification. We received responses from 11 trucking fleets of various types, sizes, and areas of geographic focus. Altogether, these fleets own and operate roughly 90,000 tractor trucks and 230,000 trailers. In addition to the trucking fleets, we had participation from a major truck OEM and an aerodynamic device supplier, both of whom have a significant footprint in the North American market. For the sake of honoring the confidentiality of the industry participants, we will not divulge any details about the companies or individuals that provided information for this study.

Given the relatively small number of participants, the findings from this survey should be seen as illustrative of the range of opinions and experiences across the trucking industry. Rather than having statistical relevance, the results are intended to provide a qualitative snapshot of perspectives. As such, we caution against making conclusions for the entire sector based on the information presented in this section.

The surveys for both the fleets and manufacturers consisted of several questions related to technologies and policies in the trucking industry in California, the United States, and Canada. For reference, the fleet and manufacturer survey templates are included in Appendix A and Appendix B, respectively.

The initial question asked respondents to rank the cost-effectiveness of various technology areas on the tractor-trailer, and the subsequent question asked for a ranking of the same set of technologies, but as if it were 10 years ago. Figure 9 summarizes the results. For each of the eight technology areas, the ‘High’ and ‘Low’ marks represent the range of rankings given to that technology, with 1’ being the most cost-effective and ‘8’ the least cost-effective. The data points with the blue (2010 rankings) and orange (2020 rankings) borders are the average rankings for the 13 responses.

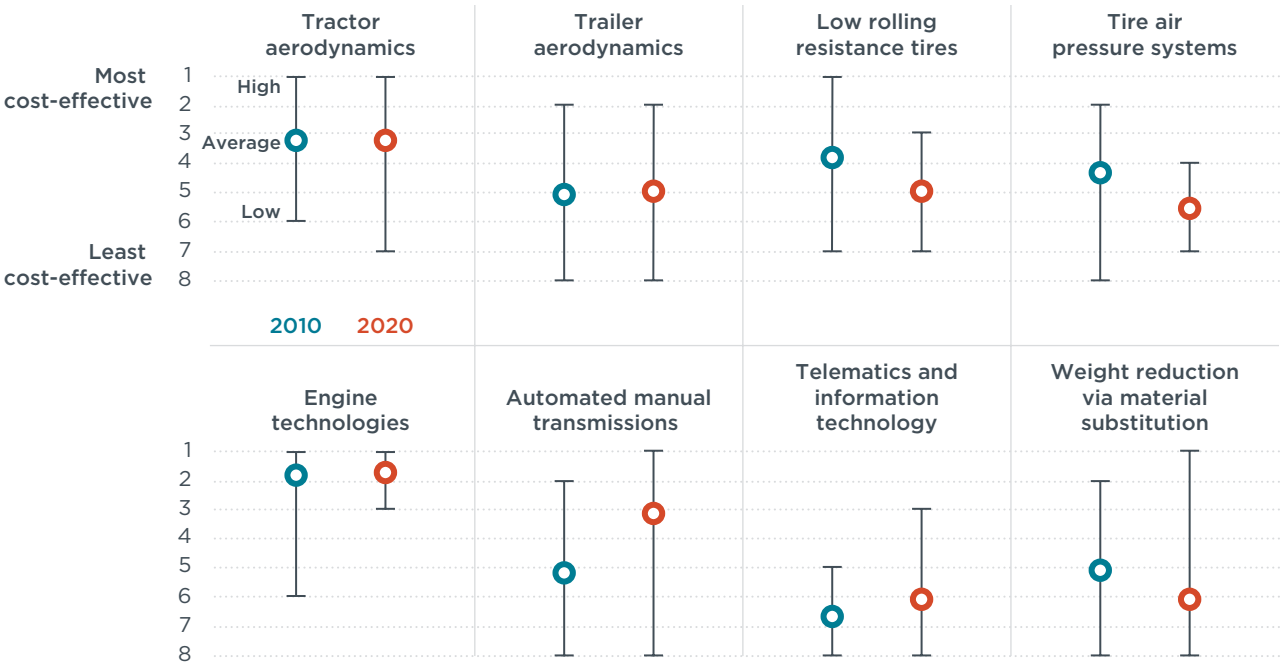

Figure 9. Survey responses: value of tractor-trailer fuel-saving technologies in 2010 and 2020.

Findings

- There was near consensus that engines technologies are very cost-effective, and that has generally held steady over time.
- On average, tractor aerodynamics are seen as more cost-effective than trailer aerodynamics. This may be due to the fact that, typically, fleets own and/or operate more trailers than tractor trucks. Since there are larger numbers of trailers than tractors, activity levels are lower per trailer than per tractor. For example, for a fleet with 3 times as many trailers as tractors, trailers will only travel one-third as much, on average, as a tractor. The lower average annual kilometers for trailers can make it more challenging for trailer fuel-saving devices to payback as quickly as with tractor technologies.
- Respondents reported that the two tire technology areas—lower rolling resistance and air pressure management systems—have grown less cost-effective since 2010.
- The technology with the largest increase in cost-effectiveness ranking between 2010 and 2020 is automated manual transmissions (AMTs). As discussed in Section 3, AMTs have seen a significant increase in adoption in Canada and the United States over the past 10 years.
- While the survey respondents scored telematics relatively low in terms of cost-effective fuel savings, this technology is increasingly seen as a valuable asset for several aspects of fleet operations based on a previous study and a swell in market adoption in recent years.
- On average, reducing vehicle weight using alternative materials ranked relatively low compared to the other technology areas.

The next question in the survey focused on what factors are most significant during the decision-making process on whether to adopt a new fuel-saving technology. We

asked the participants to rank the following six factors: cost-effectiveness, reliability and durability, competitive advantage over other fleets, impacts to operations (e.g., driver retention), environmental goals, and regulatory compliance. The results are shown in Figure 10. As with Figure 9, the range of rankings across the 13 respondents is shown with the 'High' and 'Low' bars, and the colored points represent the averages.

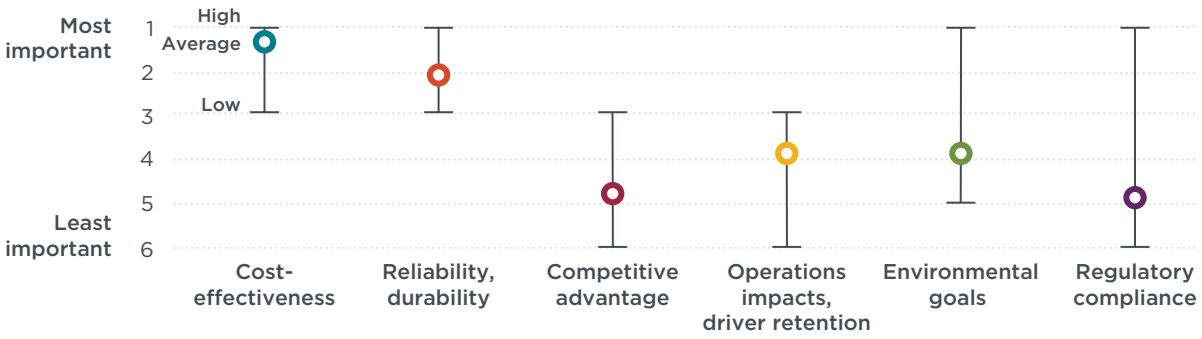

Figure 10. Survey responses: importance of various factors when evaluating potentially acquiring new a fuel-saving technology.

Findings

- On average, cost-effectiveness scored highest, and 9 out of the 13 respondents ranked this as the most important factor in deciding whether to adopt a new fuel-saving technology.
- Reliability and durability followed cost-effectiveness in the decision factor rankings.
- The remaining four factors—competitive advantage, operations impact, environmental goals, and regulatory compliance—ranked much lower, on average, than cost-effectiveness, reliability, and durability.

The subsequent set of three questions asked the participants for their opinions about the impact of California's tractor-trailer regulation on technology uptake as well as the value of the Phase 1 and 2 regulations in pushing cost-effective technologies into the market. Answers ranged from 'strongly disagree' (1) to 'strongly agree' (7) and are summarized in Figure 11. Even more so than in previous questions, there was a large disparity in the responses, with scores spanning the full range from 1 to 7 for all three questions.

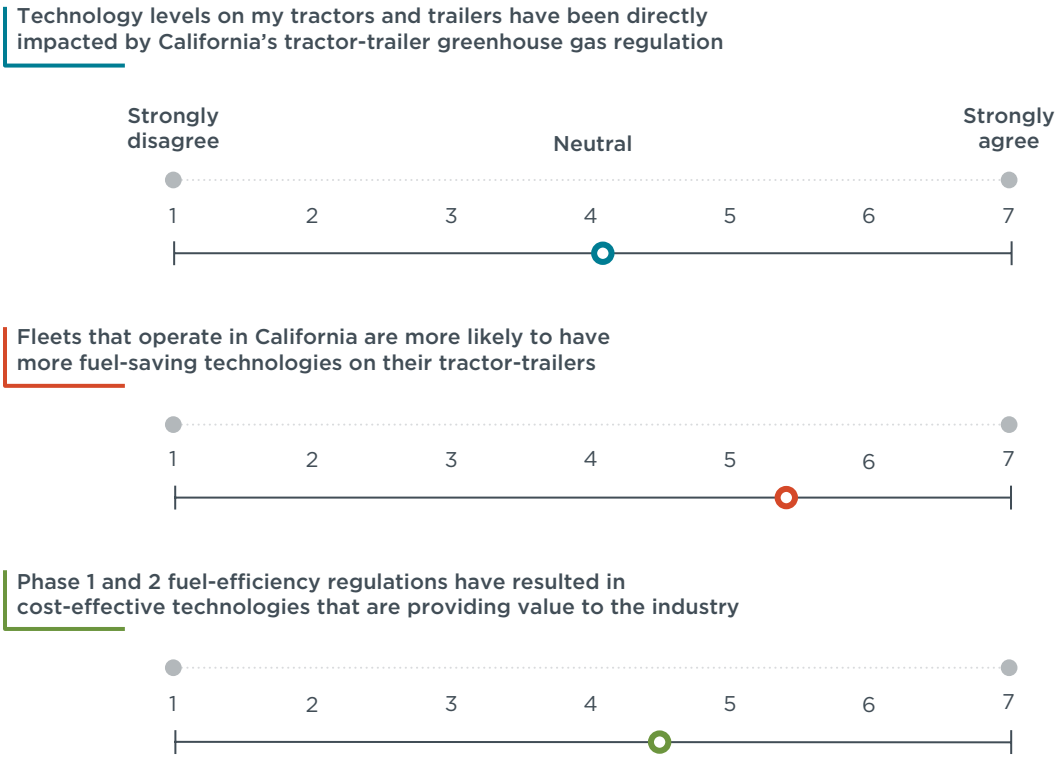

Figure 11. Survey responses: impact of regulation on the technology levels of tractor-trailers.

Findings

- Only fleets that operate in California are subject to the state's tractor-trailer GHG regulation. Since not all of the respondents' fleets have been directly impacted by the rule, we see a wide range of responses.
- On average, the respondents agree that fleets that operate in California are more likely to use trailer aerodynamic devices.
- Opinions were roughly split on the value of the Phase 1 and 2 regulations for delivering cost-effective technologies to the U.S. and Canadian trucking industry.

The final question was devoted to COVID-19 impacts and instructed the participants to rate how various aspects of their business have been affected by the pandemic and its associated effects on the economy. For five areas—equipment acquisitions, freight volumes, routes or trip lengths, employee availability, and technology deployment—we asked the respondents to give a rating from '1' (significant impact) to '5' (little impact). The results are shown in Figure 12.

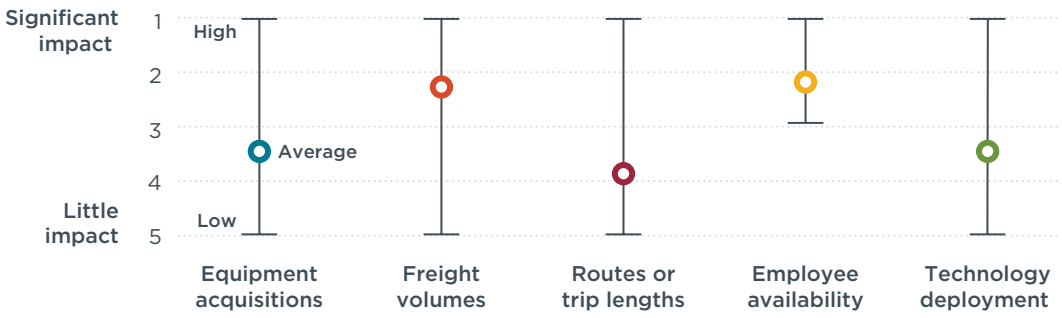

Figure 12. Survey responses: impacts of COVID-19 on various aspects of fleet operations

Findings

- On average, respondents reported that freight volumes and employee availability have been most impacted over the past year. These sentiments are further supported by findings from the American Trucking Research Institute that found substantial volatility in freight markets and major disruptions to the labor market.
- While some of the respondents had significant detriment to their ability to acquire equipment and deploy new technology, these were relatively modest impact areas, on average, across the 11 fleet responses.
- Most of the fleets reported relatively low impacts to their routes or the average length of trips.

5. SUMMARY

In this study, we analyzed the policies that California, the United States, and Canada have enacted to promote reduced GHG emissions from heavy-duty trucks, how these policies have impacted technology deployment, and lessons that Canada can take as it evaluates policy options to accelerate the deployment of fuel- and GHG-reduction technologies in its trucking fleet. Table 1 summarizes the key findings of the study.

Table 1: Key findings

TOPIC	KEY FINDINGS
Differences in technology uptake between trucks in California and Canada	• California's requirement for tractor-trailer fleets that operate in the state to use aerodynamic devices and low rolling-resistance tires is the most significant policy difference compared to the United States and Canada. Our real-world survey of aerodynamic devices revealed 85% of box-type trailers in California had at least one device, versus 63% for trailers in Oregon. This survey of major trucking routes in the two states suggests that California's GHG regulation for fleets has resulted in a quantifiable increased rate of adoption of trailer aerodynamic technologies. • Comparing real-world trailer aerodynamic assessments from 2013 to data from this study suggests that adoption rates of side skirts and other aerodynamic devices has more than doubled over this timeframe. • For other conventional (i.e., non-zero-emission) technologies, there is no strong evidence to suggest that medium- and heavy-duty trucks in California have higher levels of efficiency technologies than trucks in other states or Canada. • More-severe winter conditions and more-relaxed maximum weight limits in Canada are the most significant factors that lead Canadian-based fleets to have a preference for larger engines, more transmission gears, and heavier-duty axles. • With several ZEV-supportive incentive programs and regulatory measures at the state, regional, and local level in California, the state holds a considerable share of the early market for zero-emission commercial vehicles. Through 2020, 42% of all zero-emission buses and trucks in the United States and Canada have been sold in California (EV-Volumes 2021).[8]
Industry attitudes and experiences with fuel-saving technologies and policies	• Attitudes about the value of various technology areas have remained fairly stable between 2010 and 2020 for engines, as well as tractor and trailer aerodynamics. Improved tire rolling-resistance, tire pressure regulation, and weight reduction via material substitution are seen as slightly less cost-effective over the 10-year period. Respondents favor telematics systems slightly more in 2020 versus. 2010 and assigned automated manual transmissions as having the biggest increase in value. • When evaluating a new technology, cost-effectiveness was the clear choice for the most important factor, followed by reliability and durability. There was a wide range of opinions on the importance of the other four factors. • While a good portion of the fleet respondents do not have operations in California (and thus are not affected by its fleet regulation), most of the respondents acknowledge that fleets operating in California have higher uptake of trailer aerodynamic devices, on average. • Fleets reported a wide range of impacts to various aspects of their operations resulting from COVID-19. On average, employee availability and freight volumes had the most significant effect on the survey respondents.
Policy opportunities and challenges for Canada	• Imposing technology requirements on trucking companies similar to California's tractor-trailer GHG regulation presents an important opportunity to reduce fuel use and emissions in Canada. This type of in-use fleet regulation would require a sustained commitment to fleet outreach and to small businesses and owner-operators in particular. • Regulating the thousands of trucking fleets that operate across a vast network of roadways throughout Canada's provinces and territories would require considerable cooperation across various government entities and robust coordination from Canada's federal government.

8 For context, California is estimated to represent about 6% of HDV sales in the U.S. and 5% of the combined U.S. and Canada market. Canada's HDV annual sales are roughly 13% of U.S. sales.

Amongst the three jurisdictions, California stands apart in three key policy areas: 1) regulation for trucking fleets that requires the use of tractor-trailer efficiency technologies, 2) regulations that will require the sales and purchase of zero-emission commercial trucks, and 3) a suite of incentive and financing programs to support the adoption of a range of fuel-saving and electrification technologies. As a result of these policies, the analysis from this study suggests that:

- **Trailers operating in California have higher adoption rates of aerodynamic devices**. We performed counts in November 2020 of roughly 1,000 tractor-trailers operating on a major trucking corridor in California and found that 85% of 53 ft. box-type trailers have at least one aerodynamic device, compared to 68% in Oregon.
- **California is the early leader in the zero-emission commercial vehicle sales.** In the nascent zero-emission heavy-duty vehicle market, California represents 42% of zero-emission buses and trucks sold in the United States and Canada.

As we've found in previous studies, there is considerable diversity across the trucking industry in Canada and the United States with regard to fuel-saving technologies. Results from our survey of 11 trucking fleets and 2 manufacturers highlight the wide range of opinions, experiences, and expectations with regard to efficiency and electrification technologies. While the attitudes about the value of various technology areas on the tractor and trailer have evolved over time, engine technologies had the highest average score on cost-effectiveness in both 2010 and 2020. Respondents identified cost-effectiveness, reliability, and durability as the most important factors when considering a new technology. On policy, nearly all of the survey participants acknowledged that California's tractor-trailer GHG regulation has resulted in trucking fleets having higher uptake of fuel-saving technologies—in particular, trailer aerodynamic devices. With respect to electrification, most of the fleets seemed willing to start deploying zero-emission trucks once the technology has been vetted by other trucking companies in real-world operations.

California has provided a comprehensive policy blueprint for Canada and other governments that are interested in accelerating the development and deployment of fuel-saving and zero-emission technologies for HDTs. This study suggests that a regulatory program aimed at increasing the uptake of tractor-trailer efficiency technologies in Canada could provide significant fuel use and GHG emissions benefits while yielding attractive return on investment for trucking fleets. To best realize these environmental and economic benefits, the federal government can continue its engagement across of diversity of public and private stakeholder groups with the aim of crafting a regulatory program that is designed to take into account the unique aspects of Canada's trucking industry, geography, and climate. The ongoing outreach to support the development of an in-use fleet regulation also presents opportunities to solicit feedback about some of other critical issues facing the sector, including electrification, vehicle automation, driver shortages, and the evolving freight and logistics landscape resulting from COVID-19 impacts.

Canada's ambitious climate goals for the transportation sector and the imperative to significantly reduce GHGs from HDTs require that federal, provincial, and local governments expand the suite of regulatory, incentive, and market-based measures for both new and in-use vehicles. This growing set of policies can better position Canada on the path to zero-emission technology while helping ensure that efforts are being taken to use conventional fuels as efficiently as possible during the transition out to mid-century.

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APPENDIX A: TRUCKING FLEET SURVEY TEMPLATE

THE VALUE OF FUEL-SAVING TECHNOLOGIES IN YOUR FLEET

1. **For the following technology areas, please rank from 1 (most cost-effective fuel savings) to 8 (least cost-effective fuel savings).**

   Tractor aerodynamics ___
   Trailer aerodynamics ___
   Tires (low rolling resistance tires) ___
   Tires (air pressure control systems) ___
   Engine ___
   Transmission (AMT) ___
   Telematics and information technology ___
   Weight reduction (alternative materials) ___

2. **Imagine answering question (1) 10 years ago. Please rank the technology areas as if it were 2010.**

   Tractor aerodynamics ___
   Trailer aerodynamics ___
   Tires (low rolling resistance tires) ___
   Tires (air pressure control systems) ___
   Engine ___
   Transmission (AMT) ___
   Telematics and information technology ___
   Weight reduction (alternative materials) ___

3. **Please rank the following factors in your fleet's decision-making on new fuel-saving technologies with 1 being the most important, and 6 the least important.**

Cost-effectiveness, payback time ___

Reliability, durability ___

Competitive advantage over other fleets ___

Impact to operations, driver retention ___

Company's environmental or fuel efficiency goals ___

Regulatory compliance (e.g., California's requirements for trucks and trailers) ___

4. **Which of the below best describes your fleet in terms of rolling out new fuel-saving technologies or operational practices? The values represent roughly the percentages of the total market in each segment. Pick one.**

Innovator (5%) ___

Early adopter (15%) ___

Early majority (30%) ___

Late majority (30%) ___

Late adopter (20%) ___

5. **My fleet will seriously consider acquiring a battery electric or hydrogen fuel cell truck. Pick one.**

We already have; or as soon as possible ___

Only once the technology has been vetted in real-world operations by other fleets ___

If we're required to do so because of regulation ___

Under no circumstances in the foreseeable future ___

6. What is the trade cycle (lifetime in your fleet) for your trucks? _____ years

7. What is the ROI time period that is your threshold for buying new features? __ months

POLICY AND ECONOMIC IMPACTS ON TECHNOLOGY DECISION-MAKING

8. Fuel-saving technologies on our tractors and/or trailers have been directly impacted by California's tractor-trailer greenhouse gas regulation, which has required fleets to adopt aerodynamic devices such as side skirts, as well as use low rolling resistance tires.

Strongly disagree			Neutral			Strongly agree
1	2	3	4	5	6	7

9. Fleets that operate in California for all or part of their business are more likely to have higher levels of fuel-saving technologies on their tractor-trailers than fleets that never operate in California.

Strongly disagree			Neutral			Strongly agree
1	2	3	4	5	6	7

10. **The U.S. Environmental Protection Agency and the Department of Transportation's Phase 1 (model years 2014 – 2018) and Phase 2 (model years 2021 – 2027) fuel efficiency regulations for heavy-duty vehicles have resulted in additional technologies that provide attractive return on investment for my fleet.**

Strongly disagree			**Neutral**			**Strongly agree**
1	2	3	4	5	6	7

11. **COVID-19 has impacted the following areas of my fleet's business. '1' is very little impact; '5' is a significant impact**

Equipment (tractor and trailer) acquisitions	1	2	3	4	5
Freight volumes	1	2	3	4	5
Routes or length of trips	1	2	3	4	5
Employee availability	1	2	3	4	5
Plans for new technology deployment	1	2	3	4	5

APPENDIX B: MANUFACTURER SURVEY TEMPLATE

THE VALUE OF FUEL-SAVING TECHNOLOGIES

For questions 1 through 3, try to take the perspective of a trucking fleet. For example, imagine that you are the fleet manager at the company of one of your most important customers.

12. **For the following technology areas, please rank from 1 (most cost-effective fuel savings) to 8 (least cost-effective fuel savings).**

    Tractor aerodynamics ____

    Trailer aerodynamics ____

    Tires (low rolling resistance tires) ____

    Tires (air pressure control systems) ____

    Engine ____

    Transmission (AMT) ____

    Telematics and information technology ____

    Weight reduction (alternative materials) ____

13. **Imagine answering question (1) 10 years ago. Please rank these as if it were 2010.**

    Tractor aerodynamics ____

    Trailer aerodynamics ____

    Tires and wheels ____

    Engine ____

    Transmission and axles ____

    Telematics and information technology ____

    Weight reduction (alternative materials) ____

14. **Please rank the following factors in your decision-making on new fuel-saving technologies with 1 being the most important, and 6 the least important.**

Cost-effectiveness, payback time ___

Reliability, durability ___

Competitive advantage over other fleets ___

Impact to operations, driver retention ___

Company's environmental or fuel efficiency goals ___

Regulatory compliance (e.g., California's requirements for trucks and trailers) ___

15. **Which factors are most important in your company's development of new fuel-saving technologies or features? Please rank, with 1 being the most important, and 4 the least important.**

Customer demand ___

Competitive advantage over other manufacturers ___

Corporate sustainability goals ___

Regulatory compliance (e.g., US/Canada Phase 1 and 2 regulations) ___

16. **Please estimate what year zero-emission trucks will reach the following market share for new Class 7 and 8 tractor trucks in the US and Canada (e.g., "2035"). Write "Never" if you think that market share level will never be reached.**

1% of new truck sales _____

5% of new truck sales _____

50% of new truck sales _____

100% of new truck sales _____

17. Over the next 5 years, what do you expect to be the most important development in your industry? Will government policy have important impacts on this development?

18. When developing or marketing fuel-saving technologies to customers, what is the ROI time period that is your maximum threshold? _____

POLICY AND ECONOMIC IMPACTS ON TECHNOLOGY DECISION-MAKING

19. Fuel-saving technologies on tractors and/or trailers have been directly impacted by California's tractor-trailer greenhouse gas regulation, which has required fleets to adopt aerodynamic devices such as side skirts, as well as use low rolling resistance tires.

Strongly disagree			Neutral			Strongly agree
1	2	3	4	5	6	7

20. Fleets that operate in California for all or part of their business are more likely to have higher levels of fuel-saving technologies on their tractor-trailers than fleets that never operate in California.

Strongly disagree			Neutral			Strongly agree
1	2	3	4	5	6	7

21. **The U.S. Environmental Protection Agency and the Department of Transportation's Phase 1 (model years 2014 – 2018) and Phase 2 (model years 2021 – 2027) fuel efficiency regulations for heavy-duty vehicles have resulted in additional technologies that provide attractive return on investment for the trucking industry. (Canada has harmonized its Phase 1 and 2 regulations with the U.S.)**

Strongly disagree			**Neutral**			**Strongly agree**
1	2	3	4	5	6	7

22. **COVID-19 has impacted the following areas of my company's business. '1' is very little impact; '5' is a significant impact**

Sales volumes	1	2	3	4	5
Target sales markets	1	2	3	4	5
Research and development budget	1	2	3	4	5
Plans for new technology deployment	1	2	3	4	5
Employee availability	1	2	3	4	5


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