Truck Efficiency and GHG Reduction Opportunities in the Canadian Truck Fleet

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Executive Summary

Fuel-efficiency devices such as retrofittable aerodynamic technologies, fuel-efficient tires, and auxiliary power units can effectively offset engine-efficiency losses resulting from the 2002 and 2007 Environment Canada and U.S. EPA emissions regulations, while reducing greenhouse-gas (GHG) emissions significantly. To identify which fuel-saving devices are most effective, consistent, clear involvement from government is critical. If the industry is to quickly and effectively improve its GHG emissions, government must play a leadership role, a technical role, and a financial role.

This report discusses how truck operators can reduce the fuel use and GHG emissions of their vehicles. Beginning with an explanation of end-use efficiency, we outline the major end-use opportunities on highway trucks and then discuss the financial and environmental benefits of the efficiencies. Estimates show that if the entire Canadian fleet of 294,000 Class-8 trucks were to adopt a full package of energy-efficiency technologies, Canadian truck owners and operators would save 4.1 billion litres of fuel and reduce emissions by 11,500,000 tonnes of GHG each year. This is equivalent to taking 64,000 Class-8 trucks off the road or taking 2.6 million cars off the road.

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Industry Obstacles and Government Leadership

For years, tractor-trailer operators have been the target of energy-saving initiatives that pushed ideas ranging from more aerodynamic vehicle shapes to a myriad of fuel and oil treatments, all of which claim significant savings. The industry's challenge is to determine which of the advertised savings are real and applicable to a given fleet's operation. While some large fleets have shown initiative and have undertaken significant testing efforts to validate fuel-savings claims, the majority of fleets and most owner-operators do not have the time or expertise to carry out rigorous engineering tests. In an industry with small margins, it's common for truck operators to continue with "business as usual" and avoid the risk of losing time and money on trial-and-error testing.

The concepts underlying the efficiency devices discussed in this report are not new. NASA studies from the 1970s[1] show notable savings from certain technologies, proof that the technologies we present here are no surprise to the scientific community. As can be seen by the age of these projects, studies that differentiate winning technologies from "snake oil" are important but not enough on their own to spark industry adoption.

Consistent, clear involvement from government in identifying proven fuel-saving devices is critical. If the industry is to quickly and effectively improve its GHG emissions, government must play a leadership role, a technical role, and a financial role. To address a lack of clear guidance in the U.S. truck market, the U.S. Environmental Protection Agency (EPA) created a program called EPA SmartWay. This program applies engineering methods to test prototypes, publishes peer-reviewed Society of Automotive Engineering scientific papers, funds early market introduction of certain fuel-saving devices, and also manages a "certification program," in which manufactures can have their new models EPA SmartWay Certified if they have a certain number of fuel-savings options installed.

The basic specifications for a U.S. EPA Certified SmartWay tractor are: model year 2007 or later engine, integrated cab-high roof fairing, tractor-mounted side-fairing gap reducers, tractor fuel tank side fairings, aerodynamic bumper and mirrors, optional equipment that reduces the amount of engine idling (auxiliary power units, generator sets, direct-fired heaters, battery-powered HVAC systems, and automatic engine start/stop systems) and optional low-rolling resistance tires (single wide or dual).

Achieving U.S. EPA Certified SmartWay trailer certification can be done several ways. New long-haul van trailers can be ordered, and existing trailers can be upgraded to qualify provided that they are equipped with: side skirts, weight-saving technologies, gap reducers on the front or trailer tails (either extenders or boat tails), and options for low-rolling resistance tires (single wide or dual).

It is important to note that the industry will not change quickly on its own. EPA SmartWay is a significant government–industry partnership that is informing the truck industry about proven energy efficiency and GHG-reducing technologies. Canada, which has no similar coordinated effort, has taken an initial step in providing incentives for APUs. From 2004 to 2006, Natural Resources Canada ran the "Commercial Transportation Energy Efficiency Rebate" program, which encouraged the purchase of idling-reduction technologies. APUs and modified RV generators have been installed on the trucks of fuel-conscious drivers for years. Recently fuel prices have caused a renewed interest in such devices,

[1] Montoya, Lawrence C. and Louis L. Steers, *Aerodynamic Drag Reduction Tests on a Full-Scale Tractor-Trailer Combination With Several Add-On Devices*, NASA TM-X-56028, 1974.
[1] Steers, Louis L. and Edwin J. Saltzman, "Reduced Truck Fuel Consumption through Aerodynamic Design," *Journal of Energy*, vol. 1, no. 5, Sept.–Oct. 1977, pp. 312–318.
[1] Muirhead, V. U. and E. J. Saltzman, "Reduction of Aerodynamic Drag and Fuel Consumption for Tractor-Trailer Vehicles," *Journal of Energy*, vol. 3, no. 5, Sept.–Oct. 1979, pp. 279–284.

but not until NRC's rebate did the industry begin to significantly adopt this economically and environmentally beneficial technology en-masse. Canada's rebate of up to 19% of retail cost led to the purchase of 13,280 idling-reduction devices and resulted in an estimated annual savings of 186,000 tonnes of GHG. Showing the importance of government involvement, sales of APU units in Canada jumped in Aug 2003 when the program started. Compared to 2002 annual sales when no rebate was available, sales in 2004 were significantly higher. In the case of one APU manufacturer, sales during 2004 were 810% higher. During this program, C$6.2 million of government funds were spent on the rebate which spurred truck industry investment totaling over C$31 million, a 5-1 leveraging of taxpayer dollars to deliver GHG savings.[2]

Truck-Efficiency Introduction

New emissions regulations have resulted in changes to engine architecture and after-treatment to control certain pollutants. These changes improve emissions (up to 95% cleaner than previous regulations required) but can cause a 3–8% decrease in fuel economy and similar increases in GHG emissions, depending on operational conditions. A major reason for the decrease in fuel economy is that engines are now equipped with a cooled exhaust gas recirculation system (Cooled EGR), which has a negative impact on engine efficiency. Because these systems require higher pressure in the exhaust system than in the intake system to move gas through the control valve, the engines incur greater gas-pumping losses. The Cooled EGR system also demands more work by engine turbomachinery (higher boost) and more heat dissipation through the radiator. Greater heat rejection requires bigger cooling fans with more on-time and also more truck frontal area, which has a negative effect on aerodynamics. To meet 2010 emissions engine makers are considering various strategies including carrying liquid urea on-board and, separately, "next generation cooled EGR" which may also result in fuel economy reductions.

There are opportunities to increase overall truck efficiency to offset the decreases resulting from emission regulations. In 2005 RMI helped Wal-Mart improve the fuel economy of its truck fleet. Focusing on retrofit solutions for maximum near-term impact, testing showed that fuel savings of 25%[3] were possible on Wal-Mart's long-haul fleet. It is important to note that there is no silver bullet. Rather, these savings are the result of several energy-efficiency technologies combined. It is important to approach long-haul trucks from a "whole-system" perspective, where attention is given not only to the tractor but to the trailer and to overnight driver comfort. In the following pages we will explore the practical fuel-efficiency opportunities that are applicable to truck fleets with a focus on the type of technology best suited for fleets to make immediate reductions in fuel use and greenhouse-gas emissions.

End-Use Efficiency

We will start with a simple engineering example. A typical industrial pumping loop includes numerous energy conversion steps, each of which is not entirely efficient and wastes energy. These inefficient steps add to the total amount of energy lost throughout the process (called "compounding losses"). Figure 1 below is an illustration of these conversion steps showing the flow of energy from beginning to end in a typical industrial pumping application. It takes one hundred units of fossil-based energy at the power plant to produce about ten units of energy (embodied in the flow of water) out of the pipe—a loss factor of about ten. When seeking ways to improve the efficiency and the emissions of such a system, it is tempting to focus on the power plant, where 70% of the energy is lost to inefficiency and where 100% of the emissions are generated. However, turning those ten-to-one

[2] Source: Natural Resources Canada
[3] www.walmartstores.com/GlobalWMStoresWeb/navigate.do?catg=349.

compounding losses around backward yields compounding savings. Saving one unit of energy farthest down the chain, at the point of use, by reducing pipe friction or water flow, avoids enough of the upstream compounding losses to save ten units of energy and an equal (percentage) emissions reduction at the power plant.

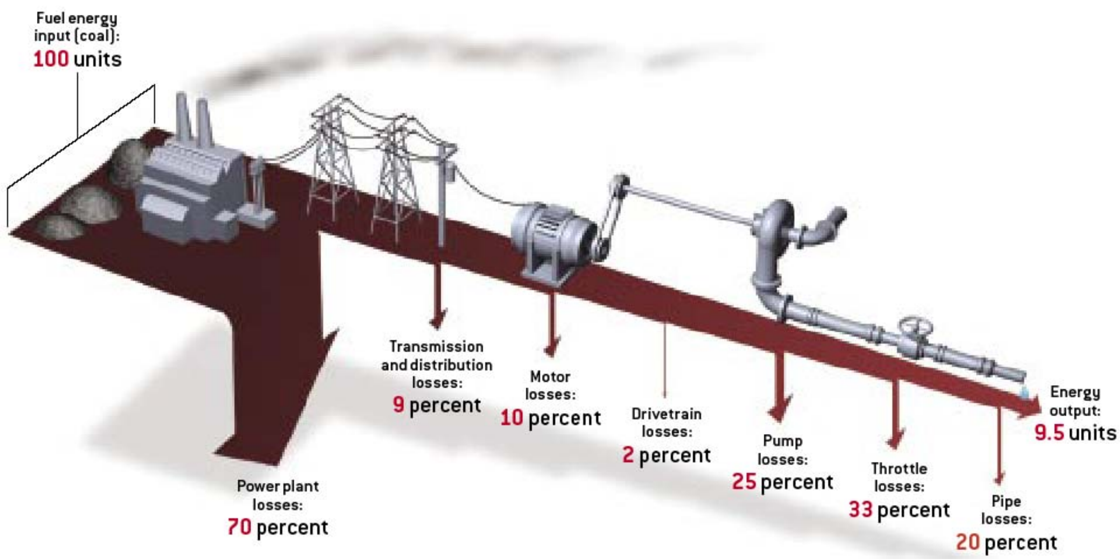


Figure 1: Industrial Pumping Example

Those compounding savings represent significant economic, emissions-reducing, and energy-saving leverage. And, they are the same principles that efficient tractor-trailers use to multiply reduced aerodynamic drag, rolling resistance, and idle-time use into big fuel savings:

> "In a chain of successive improvements, all the savings will multiply, so they appear all to have equal *arithmetic* importance. However, the *economic* importance of an energy-saving measure will depend on its position in the chain. Savings furthest downstream will have the greatest leverage in making the upstream *equipment* smaller, and this saves not just energy but also capital cost. Downstream savings should therefore be done first in order to save the most money. Downstream-to-upstream thinking is thus a special case of a more general rule: Do the right things *in the right order*.[4]

End-Use Opportunity on Tractor-Trailers

When looking for ways to improve the fuel efficiency and GHG emissions of modern tractor-trailers, one can take the same end-use approach that is discussed in the industrial pumping example above. In the average long-haul trucking operation, only about 6.5% of the energy in each litre of diesel fuel is used to move the cargo and only 4.5% is used to move the tractor-trailer. The remaining 89% is lost along the way: 56% to thermodynamic effects in the engine, 12% due to idling, 2% to driveline and transmission drag, 19% to overcome aerodynamic forces, and 11% to tire rolling resistance. Rather than focus on the diesel engine—a tempting target since more than half of the total fuel energy used by a truck is lost in thermodynamics in the engine—we will focus on the end of the chain, where we

[4] Hawken, Paul, Lovins, Amory and Hunter. *Natural Capitalism: Creating the Next Industrial Revolution*. Little, Brown. 1999.

have the opportunity for compounding savings. These downstream savings let us leverage the principle of end-use efficiency to maximize the benefits of our investments.

Aerodynamics

Basic physics tells us that the majority of energy used to move a typical highway truck down the road is used to counter aerodynamic resistance. At 105 km/h, two thirds of the horsepower created by the engine is used to overcome aerodynamic drag.[5] Of that two thirds, a large portion is caused by aerodynamic drag on the trailer and the tractor-trailer connection. By making changes to the aerodynamics of the trailer it is possible to reduce drag by approximately 20%, resulting in approximately 10% lower fuel consumption for a truck traveling at 105 km/h. It should also be noted that lower speeds result in less aerodynamic drag. By simply reducing a truck's speed from 115 km/h to 105 km/h, it is possible to reduce the fuel consumption of the average truck by approximately 7% with no changes to the truck itself.[6] Assuming trucks spend 75% of their time on highways, this speed reduction equates to a savings of 3100 liters/y and 8.5 tonnes of GHG emissions/y for each truck. If 50% of Canada's Class-8 fleet achieved this result, it would save 460 million liters of fuel and 1.2 million metric tones of GHG emissions each year.

For the purposes of this review we will adopt a "baseline" tractor-trailer design upon which all fuel savings will be based. Our baseline assumption will be a typical "aero cab" tractor pulling a 53-foot trailer (Figure 2). This commonly used configuration is 25–30% more fuel-efficient than the old-style "long-nose" cab with no roof fairings, exposed air cleaners, and exposed exhaust stacks.[7]

Tractor—Bumpers and Tank Fairings

Upon the purchase of a tractor, the dealer offers several different aerodynamic options that improve energy efficiency. Tractors that incorporate aerodynamic mirrors, full aerodynamic bumpers, and aerodynamic fairings on the fuel tanks (Figure 3), typically use 2% less fuel than trucks without these features.[8] Together, we call these devices "Tractor Aerodynamics."

Figure 2: Baseline Assumption: "Aero Cab" Tractor with Roof Fairing

[5] Technology Roadmap for the 21st Century Truck Program (DOE 2000).

[6] Wood, R. M. et. al, (2003), "Simple and Low-Cost Aerodynamic Drag Reduction Devices for Tractor-Trailer Trucks" SAE 2003-01-3377 (www.sae.org/technical/papers/2003-01-3377).

[7] www.kenworth.com.

[8] Leuschen, Jason and Cooper, Kevin R., (2006) "Full-Scale Wind Tunnel Tests of Production and Prototype, Second-Generation Aerodynamic Drag-Reducing Devices for Tractor-Trailers" SAE 06CV-222 (www.freightwing.com/test/NRC_Wind_Tunnel_Test_SAE_Paper.pdf).

Figure 3: Preferred Tractor: Baseline plus Aero Bumper and Tank Fairings

Trailer—Gap fairing, Base Flaps, and Skirts
RMI's analysis shows that an untapped energy-efficiency opportunity exists through additional attention to trailers as part of the tractor-trailer system. RMI's calculations, based on leading published research, show that approximately half of truck fuel consumption can be attributed to the forces acting on the trailer. In fact, more than 60% of total aerodynamic drag in a tractor-trailer unit is due to the trailer. Using currently available "bolt-on" solutions, the trailer could be reshaped to provide more than a 10% fuel economy improvement to the tractor-trailer system.[9]

Tractor/Trailer Gap
It is important that the air flow as smoothly as possible as it moves from the tractor to the trailer. "Gap fairings" or "nose cones" on the trailer can deliver a 1–2% fuel savings.[10]

Figure 4: Retrofitted Trailer with Base Flaps and Side Skirts. photo: Andrew Smith, ATDynamics

Base Flaps (aka "Boat Tails," "Rear Drag Devices")
Aerodynamic systems attached to the rear of a trailer (known in the automotive community as the trailer's "base") offer the greatest single aerodynamic efficiency opportunity.[11] When the truck moves, the amount of drag created at the trailer base is equal to the drag created when air is forced around the

[9] Bachman, J.L., Erb, A., and Bynum, C., (2005) "Effect of Single Wide Tires and Trailer Aerodynamics on Fuel Economy and NOx Emissions of Class 8 Line-Haul Tractor-Trailers" SAE 05CV-45

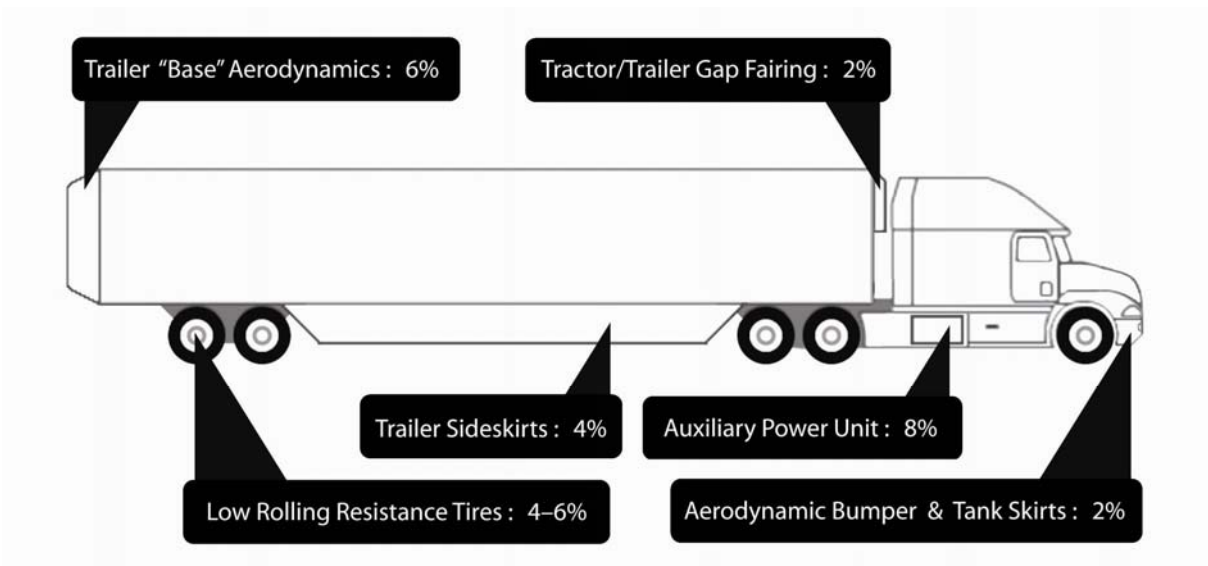
[10] Bachman, J. L. et al, (2006) "Fuel Economy Improvements and NOx Reduction By Reduction of Parasitic Losses: Effect of Engine Design," SAE 2006-01-3474

[11] Ortega, J. M. et. al, (2004), "An Experimental Study of Drag Reduction Devices for a Trailer Underbody and Base" AIAA Fluid Dynamics Conference UCRL-CONF-204489

front of the truck. Base flap aerodynamic systems such as "TrailerTail™" (Figure 4) have the potential to reduce the fuel consumption of long-haul fleets by 6%[10] and enhance vehicle safety without interfering with trucking operations.

Side Skirts
Side skirts, now in production by several manufacturers, are available for a variety of trailer styles—including trailers with movable rear axles, spread-axles (see Figure 4), flat-beds, and pin-chassis—for container hauling. These devices offer a 4% fuel savings.[10]

Combined, the aerodynamic improvements from these three trailer solutions, Gap Fairings, Side Skirts, and Rear Drag Devices deliver a potential fuel savings of approximately 12% during highway operation.



<u>Low Rolling-Resistance Tires</u>
To move a truck at 105 km/h along a level highway, the average truck engine produces 220 hp (167 kW). Roughly 70 hp (52 kW) is required to overcome the drag caused by rolling resistance in the tires.[12] By choosing tires with a strong emphasis on fuel economy instead of solely on wear characteristics, significant fuel savings are possible. New versions of common "dual tires" that have been designed for reduced rolling resistance can save up to 4% over standard tires. For greater savings, choosing "wide-base tires," sometimes called "super-singles," can save 4–6% over typical dual tires. Because they need only one rim and have only two sidewalls (compared to the four in a dual-tire configuration), wide-base tires offer the additional benefit of weight savings. When fitted with aluminum rims and wide-base tires, trucks can save 200 lb per axle, or 800 lbs (363 kg) per truck, allowing the truck to carry more.

<u>Engine-Idle Reduction</u>
Technologies that reduce idling time can help achieve significant fuel savings for fleets whose drivers spend their rest periods inside the truck. Traditionally, in trucks without APUs, the primary engine must be running in order to provide electricity and hot or cool air for comfort during resting periods. "Anti-idle" systems now available provide all the comfort a driver expects without having to idle the

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[12] Technology Roadmap for the 21st Century Truck Program (DOE 2000) (http://roadmap.itap.purdue.edu/ctr/documents/21stcenturytruck.pdf).

primary engine. A typical primary engine, usually rated for 350–550 hp, consumes approximately 1 gallon (3.76 litres) of fuel for each hour of idle time. In contrast, an auxiliary power unit (APU) burns 0.2 US gallons per hour (0.76 lph) or less. Battery-electric APU systems can provide electricity and cooling services while using zero fuel and are typically quipped with a diesel fired heater to provide warmth with extremely low fuel consumption rates (0.15 lph). These systems can improve a truck's overall fuel use by 8% or more depending on the amount of idling. APUs also reduce the amount of wear and tear caused by primary engine idling, potentially reducing the amount of maintenance needed over the life of the vehicle. In the US, there is a federal provision to grant vehicles equipped with APUs a 400 lb weight allowance, permitting a maximum vehicle weight of 80,400 lb.

There are three types of APU systems that can provide full comfort to drivers.

1) Diesel APU: Simplest of the three designs, a diesel APU includes a small diesel engine that powers belt-driven automotive-style accessories. Designs vary, but typically an alternator provides 12-V power, an R134a compressor provides air conditioning, and hot coolant from the small diesel warms the cab and the primary engine.

2) Diesel-Electric APU: A diesel-electric APU uses a small diesel engine that runs a 120-V generator mounted outside the cab. Electricity generated by the small engine is then used in-cab to operate accessories and heating systems, and to condition air. This type of APU is often capable of plugging in to 120-V "shore power" (from a nearby building, a gas station, etc.) to provide comfort without running the engine.

3) Battery-Electric APU: This "zero-idle" APU is the cleanest and most energy-efficient type of APU available. Energy is stored in deep-cycle batteries, which provide electricity to operate an electric air conditioner, a diesel-fired heater, and an inverter that provides 120-V accessory power. These systems are recharged by the primary engine during normal operation or can operate using 120-V shore power. For trucks hauling refrigerated freight, there are systems that can recharge via optional connections to reefer units.

California created rules that limit the idling of heavy vehicles and take effect in 2008. Emissions regulations in California, widely recognized as a leader in emissions reduction strategies, often become de-facto standards. Because of growing concern over diesel pollution at local and national levels in the United States, it is likely that other states will adopt similar regulations. This type of regulation may cause the battery-electric APU to become the industry standard, as no diesel APU "retrofit kits," which bring existing APUs up to the new California standard, have been certified by California Air Resources Board (CARB).

Title 13, California Code of Regulations (including Section 2485 - Airborne Toxic Control Measure to Limit Diesel-Fueled Commercial Motor Vehicle Idling) states:

> The new engine requirements require 2008 and newer model year heavy duty diesel engines to be equipped with a non-programmable engine shutdown system that automatically shuts down the engine after five minutes of idling or optionally meet a stringent oxides of nitrogen idling emission standard. The in-use truck requirements require operators of both in-state and out-of-state registered sleeper berth equipped trucks to manually shut down their engine when idling more than five minutes at any location within California beginning in 2008.
>
> Emission producing alternative technologies such as diesel fueled auxiliary power systems (APUs) and fuel fired heaters are also required to meet emission performance

requirements that ensure emissions are not exceeding the emissions of a truck engine operating at idle. Specifically, the regulation requires diesel APUs installed on 2007 and newer truck engines to control particulate matter (PM) emissions by either routing the APU exhaust through the PM trap of the truck engine or by retrofitting the diesel APU with a verified level 3 PM control device that reduces PM emissions by at least 85 percent. Fuel fired heaters installed on 2007 and newer truck engines are also required to meet the Ultra Low Emission Vehicle requirements specified in the Low Emission Vehicle regulations. These requirements are effective beginning in 2008.[13]

Other Improvements

Systems that can improve fuel economy but which are not included in our analysis include a tag axle, which can improve fuel economy roughly 1% and reduce truck weight by 200–500 lbs; automated manual transmissions, which can improve fuel economy and help reduce driver variability; low-viscosity synthetic lubricants, which can improve fuel economy; and diesel-electric refrigeration units, which use less fuel to keep refrigerated loads cool and are equipped to use shore power for "zero-emissions" cooling when the truck is parked at terminal facilities.

Data Analysis

Several assumptions were made in evaluation of fuel and GHG savings. These assumptions included a fuel cost of C$0.97/litre, a fleet size of 294,000 trucks, an average of 1400 hours/year of overnight idle time, and an average driving distance of 160,000 km/year. When discussing the energy efficiency of each device, it is important to note that energy savings are specific to the way trucks are operated. Tires designed to improve fuel efficiency do so while the truck is being driven. An APU, in contrast, improves fuel efficiency when a truck is parked. The technologies described in the following paragraphs are organized according to the mode of operation in which they are used—driving or idling.

While the devices discussed here are additive in their effects, not all of the fuel-saving devices on the market achieve their advertised savings. As shown in NRC full-scale wind-tunnel tests[8],certain aerodynamic devices meant to improve fuel economy actually increase the fuel use of a truck. Fundamentally, these vortex-generating devices can have benefits and can be found on the wings of many aircraft. However, improper application without careful attention can turn these benefits into detriments. In addition, driver and load variability can introduce uncertainty.

Driving

Energy efficiency in driving mode can be improved by changing aerodynamic characteristics and rolling resistance. The specific devices and their corresponding fuel savings are listed in Table 1.

Aerodynamic devices can alone result in a 14% fuel savings and save 17 tonnes of GHG per year if a truck has all of the aero devices discussed in Table 1 installed. These benefits are realized at speeds over 105 km/h. In our calculations we will assume that the average truck spends 75% of its time at speeds near 105 km/h, thus enjoying 75% of the aero fuel savings shown in Table 1. Canadian manufacturer Laydon Composites Ltd. sells several aerodynamic devices for tractors and trailers, including trailer side skirts. Base flaps, which fit to the rear of the trailer and can fold flat to the trailer door for easy cargo access, are being commercialized by Advanced Transit Dynamics. They are being brought to market with select fleets in 2007 and are expected to be commercially available in 2008. Gap fairings and side skirts can be purchased from companies such as Freight Wing.

[13] www.arb.ca.gov/msprog/truck-idling/truck-idling.htm

Table 1: Driving Add-on Technologies and Associated Savings

		Fuel Savings %	Incremental Cost (C$/truck)	GHG Savings Per Truck (tonnesCO_2eq/y)
Driving	*Aerodynamic Add-ons*			
	Tractor Aero	2%	$ 1,050	2.49
	Side Skirts	4%	$ 1,679	4.98
	Base Flaps	6%	$ 3,150	7.47
	Gap Fairing	2%	$ 891	2.49
	Rolling Resistance (Choose 1)			
	Efficient Dual Tires	4%	$ 55	6.64
	Wide Base Tires	5%	$ 5,913	8.30

Several tire manufacturers offer models with less rolling resistance than standard tires. There are two common configurations: a dual-tire configuration that includes two narrow tires or a single-tire configuration that uses a wide-base tire. Results vary depending on the baselines used, but it is reasonable to expect a 4% increase in fuel efficiency when switching to dual tires and a 5% fuel savings and a 200-lb/axle weight savings when switching to wide-base tires.[14] In calculations of tire costs, we estimated the difference between the fuel-efficient tire configurations and a standard configuration. Wide-base tires have a dramatically longer payback period because of a one-time cost of new aluminum wheels, which adds C$5,880 to the cost. It should be emphasized that this is a one-time initial installation cost that would not be required with subsequent tire replacements. In addition, the use of wide-base tires typically means a weight reduction of approximately 800 lb (363 kg) per truck, which translates to an increase in payload capacity.

Idling

Two types of APU units are considered: diesel-electric and battery-electric. Table 2 lists the fuel-savings and greenhouse-gas-emissions reductions as a result of using these devices on a percentage basis in comparison to the fuel that is required to idle the main engine.[15] Although maintenance cost reductions are not included here, generally less idling of the primary engine means less wear and tear, meaning, in turn, longer maintenance intervals and engine life.

A battery-electric APU runs on energy stored in deep-cycle batteries, which can be recharged during driving via the vehicle's alternator. RMI has accounted for this alternator energy in the form of additional diesel fuel used by the primary engine to recharge the APU's batteries. A standard system with a battery capacity of 220 amp hours that will operate for up to 8 hours is a $3,900 investment. Its fuel savings is greater than the diesel-electric APU at 92%. Battery-electric APUs are available aftermarket as a complete system from several manufacturers including Sun Power Technologies and Bergstrom, Inc., which manufactures the NITE System.

Table 2: Idling Add-on Technologies and Associated Savings

[14] The specific dual configuration discussed here is based on the Goodyear steer, drive, and trailer model tires G395 LHS, G305LHD Fuel Max, and G316LHT Fuel Max. The wide-base configuration is based on the X One wide-base tires from Michelin. The models used in the steer, drive, and trailer positions are the XZA3, the X One XDA, and the X One XTA.

[15] Fuel savings percentages represent the amount of fuel saved when using APUs over the amount of fuel used when idling the primary engine. The baseline used is 1,400 h/y at 3.79 L/h.

		Fuel Savings %	Incremental Cost (C$/truck)	GHG Savings Per Truck (tonnesCO_2eq/y)
Idling	*Idle Solutions (Choose 1)*			
	APU (diesel-electric)	80%	$ 7,429	11.70
	APU(battery-electric)*	92%	$ 3,932	13.46

(* battery electric APUs are zero emissions—here, "fuel savings" is based on RMI's estimate of the amount of fuel energy used by the primary engine to recharge the battery while driving.)

In the "simple" package discussed below, a diesel-electric APU was chosen because of its availability and acceptance within the trucking community. For a C$7,400, one can save 80% of the fuel that would normally be required for idling (as shown in Table 2). Two Canadian manufacturers of diesel-electric APUs are Mechron Power Systems and Rigmaster.[16]

Fuel, Dollar, and GHG Savings: Two Implementation Scenarios

In this section we have compiled data from those technologies discussed above and evaluated two packages for fuel efficiency and greenhouse-gas-emissions-saving benefits. The first is a "full" package, which assumes implementation of all the technologies discussed above, including all aerodynamic devices, wide-base tires, and a battery-electric APU. The second "simple" package only uses side skirts, and substitutes fuel-efficient dual tires for regular tires and a diesel-electric APU. We picked these two scenarios to demonstrate both the maximum achievable savings and to show the result if only a portion of the Canadian class-8 fleet incorporated these features. This Simple Package, modeled to include installation on only 50% of trucks, is based on the assumption that not all trucks would be suitable for the specific devices discussed here, and that some trucks would utilize only a portion of the full package. For instance, day-cab trucks would not benefit from the installation of an APU due to a lack of overnight idling, and a tanker truck would not be able to utilize the rear drag devices discussed here which are meant for a box-shaped trailer.

Full Package:

- Wide-Base Tires
- Battery-Electric APU
- Tractor Aerodynamics
- Trailer Side Skirts
- Trailer Base Flaps
- Trailer Gap Fairings

Simple Package:

- Side Skirts
- Fuel-Efficient Duals
- Diesel-Electric APU

In calculating potential fuel savings and reductions in greenhouse-gas emissions, RMI considered two scenarios. In the first scenario we assumed that 100% of the Canadian truck fleet installed a "full package" consisting of 100% of the efficiency opportunities discussed above. A second, more conservative, scenario was also considered in which 50% of the Canadian truck fleet adopted a "simple package" of just three fuel-saving technologies. In each scenario, the total amount of fuel consumed in both driving and idling modes offered an overall picture of the potential fuel savings, possible greenhouse-gas emissions reductions, and payback periods. Table 3 summarizes the overall energy savings and emissions reductions under each implementation scenario.

[16] For more a more complete list of APU systems available on the market today see: www.epa.gov/smartway/idlingtechnologies.htm.

According to Canadian Trucking Alliance data, the average truck fleet owns 3 trailers for every 1 tractor in operation. To achieve full fuel savings both the truck and the trailer must be equipped with fuel saving devices. This means that a fleet must retrofit all 3 trailers to ensure that each truck-trailer combination will be fully equipped for efficiency, To account for this, Table 3 incorporates the larger investment required to purchase additional tires, wheels (in the case of Wide Base Tires), and aero devices to equip all 3 trailers.

Table 3: Summary of Savings for Two Recommended Packages

ASSUMES: 3 trailers per tractor (To represent industry-average trailer-to-tractor ratio)						
Package	**Includes**	**Fuel Economy Improvement (%)**	**Cost (C$/truck)**	**GHG Savings (tonnesCO_2eq /truck-y)**	**10 Year GHG Savings per Truck (tonnesCO_2eq/truck)**	**10 Year Cost per GHG Tonne Saved (C$/tonne$CO_2$eq)**
Simple, on 50% of trucks	Side Skirts, Fuel-Efficient Duals, Diesel-Electric APU	13%	$ 12,546	23.3	233	53.80
Full, on 100% of trucks	Tractor Aero, All Trailer Aero, Wide-Base Tires, Battery-Electric APU	22%	$ 33,589	39.2	392	85.73

The "full package" of fuel-saving devices applied to an "average" Canadian truck driving 160,000 km/y and idling 1400 hours/y delivers an estimated 22% fuel savings and a greenhouse-gas emissions reduction of 39 tonnes per year. Assuming that the improvements to the truck will last ten years and that greenhouse-gas emissions reductions each year are maintained, investment cost per tonne of GHG "saved" is 86 C$/tonne of GHG. If the entire Canadian fleet of 294,000 trucks were to adopt these energy-efficiency technologies, Canadian truck owners and operators would save 4.1 billion litres of fuel and reduce emissions by 11,500,000 tonnes of GHG each year. This is equivalent to taking 64,000 Class-8 trucks or 2.6 million cars off the road.

RMI also analyzed a simple package of modifications—modifications deemed available, affordable, and achievable in the very short term. These modifications have the potential to reduce greenhouse-gas emissions at a cost of C$54/tonne of GHG. Fuel savings produced by this simple efficiency package are estimated to be 13% and each truck would avoid emissions of 23 tonnes of GHG/y. Assuming this simple package of energy-efficiency technologies were adopted by just 50% of the Canadian Fleet (147,000 trucks), Canadian truck owners and operators would save 1.2 billion litres of diesel fuel and reduce greenhouse-gas emissions by 3,400,000 tonnes of GHG per year. This is equivalent to taking 19,000 Class-8 trucks or 800,000 cars off the road.

Conclusions

Fuel efficiency devices such as retrofittable aerodynamic technologies, low rolling resistance tires, and auxiliary power units can effectively offset efficiency losses from the 2002 Environment Canada and U.S. EPA emissions regulations. Furthermore, the fuel savings from these technologies will result in a significant reduction in greenhouse emissions. The devices recommended are easily adoptable as retrofits and have been chosen because they provide the highest percentage fuel savings with the most consistent test results. While the payback periods for the fuel-saving devices range from 1 to 3 years, the investment costs are significant for truck operators. Providing and developing innovative financing options to mitigate the financial burden on truck operators is one role for government, however there are several others that can aid in implementing this technology wide scale.

History shows that when government takes on a technical, financial, and leadership role in implementing these technologies it stimulates the market and helps to change old myths within the trucking industry, as demonstrated by EPA SmartWay and Natural Resources Canada truck efficiency program results. Concrete action by government provides the temporary assistance and consistent direction needed to jumpstart industry action and to create the desired result when industry obstacles are preventing change. Government can and should act as a catalyst to speed adoption of these technologies on a wide scale.

The "full" and "simple" packages which we have described in this paper with 100% and 50% fleetwide implementation scenarios can result in dramatic savings, especially when implemented on a nationwide scale.

If the entire Canadian fleet of 294,000 Class-8 trucks were to adopt the full package, we estimate that Canadian truck owners and operators would save 4.1 billion litres of fuel and reduce emissions by 11,500,000 tonnes of GHG each year, equivalent to taking 64,000 trucks or 2.6 million cars off the road. Adopting the simple package on just 50% of the Canadian Fleet (147,000 Class-8 trucks), Canadian truck owners and operators would save 1.2 billion litres of diesel fuel and reduce greenhouse-gas emissions by 3,400,000 tonnes of GHG per year. This is equivalent to taking 19,000 trucks or 800,000 cars off the road. These packages demonstrate the benefits that can result from wide-scale implementation of energy-efficient technologies on trucks.