Greetings,

On behalf of FPInnovations, I congratulate you on the quality and depth of the intentions paper. Upon review, my colleagues and I found your priorities to be well conceived and important – we support your focus areas.

In addition to what you have assembled, please find below a few suggestions/points for your consideration:

1) Codes/Standards
   a. FPI agrees that stronger codes and standards is an effective way for government to advance clean, efficient buildings.
   b. With the recent BC Energy Step Code, it proves once again that British Columbia is leading Canada in reducing carbon emission from the built environment and to achieve net-zero energy in the near future. We understand that the BC Energy Step Code and the national model energy code treat the various construction materials equally, which would allow the different industries to innovate.
   c. It should be noted that some programs and local policies tend to put more emphasis on single-family houses and on residential buildings up to six storeys for higher levels of energy performance.
   d. Builders and developers will generally meet the minimum code requirements, so continually pushing the envelope would help advance the move towards net-zero energy ready buildings.

2) Energy retrofits
   a. FPI agrees that a coordinated energy retrofit program would yield strong results to reduce energy consumption and carbon emission from the existing building stock. However, it will be challenging to develop a program with a success factor (like pay-back) that could be applied fairly across the different types and starting conditions of existing buildings.
   b. Technical support is available in the wood sector to help B.C. undertake demonstration projects. For example, a demonstration project for the “Energiesprong” approach from the Netherlands would require support provided to a local prefabricator to make wood-frame wall/roof panels.
   c. Let us be open to new products that provide strong value propositions and are made from renewable fibres. A good example is wood-fibre insulation board. Although we do not produce this material in B.C. yet, it presents a great value proposition for utilizing low-quality fibres from the forest that would otherwise be burned. Incorporating the use of this product will stimulate investment to produce this locally and provide double GHG benefits in the product application and the utilization of woody biomass.

3) Low Carbon Building Innovation Program
a. We suggest that “embodied carbon” be considered in the determination of carbon in buildings. The embodied carbon in the construction materials would become more relevant in the carbon calculation as buildings move towards net-zero energy ready which would have much improved operational carbon emissions.

b. We strongly suggest utilizing provincially funded buildings as demonstrations in pushing what is possible:
   i. Building net-zero energy ready schools would educate the students – our next generation of responsible citizens
   ii. Providing opportunities to monitor the performances so to demonstrate with real values and to continue to improve design and construction
   iii. Reducing financial risks by partially covering the contingencies applied to the construction costs so to initiate projects that would eventually lead to lowering the risks and contingencies in future projects

FPI looks forward to supporting the implementation of Clean, Efficient Building with our depth and breadth of technical expertise in this area.

Best regards, Tim

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A Green Transportation Roadmap: Reducing Greenhouse Gas Emissions from Transportation and Infrastructure

Technical report no. 32 - March 2017

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FPInnovations is a not-for-profit world-leading R&D institute that specializes in the creation of scientific solutions in support of the Canadian forest sector’s global competitiveness and responds to the priority needs of its industry members and government partners. It is ideally positioned to perform research, innovate, and deliver state-of-the-art solutions for every area of the sector’s value chain, from forest operations to consumer and industrial products. FPInnovations’ staff numbers more than 525. Its R&D laboratories are located in Québec City, Montréal and Vancouver, and it has technology transfer offices across Canada. For more information about FPInnovations, visit: www.fpinnovations.ca.

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301011095: A green transportation roadmap – Technical report no. 32

ABSTRACT

This roadmap highlights past and present efforts to lower greenhouse gas (GHG) emissions in Canada and the United States. The magnitude and potential GHG reduction opportunities by equipment sector, province, and road classification are examined. The roadmap explores technologies and business practices that can lower GHG emissions for off-road fleets engaged in road work, road fleets, road users, and off-highway resource road and highway road improvements. It also presents policy and program opportunities.

ACKNOWLEDGEMENTS

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Disclosure for Commercial Application: If you require assistance to implement these research findings, please contact FPInnovations at info@fpinnovations.ca.
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1. INTRODUCTION

The Canadian transportation sector is estimated to be responsible for 23% of the total national greenhouse gas (GHG) emissions (Environment and Climate Change Canada, 2015), with the freight sector accounting for 30% of the transportation sector’s emissions. The freight sector is the fastest-growing source of transportation-related emissions. The forest sector, which represents 12% of Canada’s gross domestic product, is an important component of Canada’s freight transportation sector, and the Forest Products Association of Canada states that one of the greatest opportunities for the forest sector to reduce GHG emissions lies in the transportation of the forest sector’s goods (FPAC, 2016). The Canadian government has committed to aggressively reducing GHG emissions, and the forest sector has an important role to play.

Thousands of kilometres of resource roads are built and maintained yearly throughout Canada, and these roads must cater to traffic by heavy vehicles that often exceed traditional on-highway loads and configurations. The extent of resource roads in Canada is difficult to validate; however, in British Columbia alone, it is estimated that there are 400 000 to 550 000 km of forest service roads (Columbia Mountains Institute of Applied Ecology, 2012). GHG emissions are generated in the construction and maintenance of roads, and they are also generated by the vehicles using these roads. Both of these activities are interdependent and generate their share of GHG emissions that must be evaluated and targeted for potential reduction. How roads are constructed and used, whether it be initial construction or maintenance work, or how trucks that use the roads are configured and driven, will require a comprehensive strategy to reduce GHG emissions. Only a comprehensive look at the roads, the machines that build and maintain them and the heavy-duty trucks that use them to drive our economy will allow for a green transportation strategy.

A holistic approach is needed to maximize the possible benefits and to address the challenges that Canada’s resource road network will face in the coming decades. The roadmap presented in this document highlights opportunities that can be adopted in the development of public policy and product and technology advancements, and suggests how road work and the use of roads can be improved to better the environment and reduce GHGs.

2. OBJECTIVES

The objective of this report is to guide government policy and efforts toward the reduction of GHG emissions from the construction, maintenance, and use of road infrastructure in the resource sector. This objective will be accomplished by exploring the following elements:

- Summarizing the potential of GHG reduction opportunities by equipment sector, province, and road classification;
- Highlighting past and present efforts made by the Canadian and U.S. federal governments and non-governmental organizations to reduce GHG and criteria air contaminant (CAC) contributions attributable to on- and off-road fleets;
• Outlining business and operational practices and technological approaches for the reduction of GHG and CAC contributions attributable to road construction, maintenance, and use; and

• Suggesting future policy and program opportunities for off-road fleets engaged in road work, road fleets, road users, off-highway resource road improvements, and highway road improvements.

Innovative practices and new technologies are required to spur on reduced GHG emissions for on- and off-road fleets, and to better manage the manner in which forest roads are used in Canada. The practices and technologies identified through this green transportation roadmap can reduce fuel consumption and operating costs for industrial operations; they can also lead to more competitive on- and off-road fleets.

3. DISCUSSION

Past and present efforts to reduce fleet GHG emissions

On-road efforts in Canada

On-road fleets have enjoyed intense focus on their performance, which has allowed for fleets to compare their performance among each other and take advantage of new technologies and driver training that can lower GHG emissions. The most notable efforts include the following:

**SmartDriver for Forestry Trucks**

FPInnovations developed *SmartDriver for Forestry Trucks*\(^1\) two decades ago. The course has received several updates over the years to provide a training tool that is still relevant today. Student drivers learn how to specify a truck for maximum energy efficiency, they learn the factors affecting fuel efficiency and how to work with them, and, most importantly, they learn the driving techniques that cut fuel consumption, reduce harmful emissions, and save money. Given that the fuel consumption difference between the best and worst drivers can be as high as 35%; this training is one of the first steps a fleet can take toward reducing fuel consumption and GHG emissions.

**Fuel Management 101 for Forestry**

*Fuel Management 101 for Forestry* is another training program developed and offered by FPInnovations. In this full-day workshop, participants receive hands-on training with sample worksheets for evaluating baseline measures and fuel consumption, fuel reduction opportunities, and actual savings. Guidance is also provided on how to put together a clear and actionable fuel management plan. A well-conceived energy efficiency action plan with strong follow-up can reduce a fleet’s fuel consumption by 10%.

**SmartWay Transport Partnership**

The SmartWay Transport Partnership\(^2\) is a federal government program that helps transport companies benchmark their operations, track fuel consumption, and improve environmental performance.

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SmartWay Partners seek to: reduce their carbon emissions and fuel consumption, and thus, reduce operating costs as well. This approach differentiates SmartWay Partners from their competitors and attracts SmartWay shippers to their business.

**Go with Natural Gas Program**
This partnership between the federal government and industry is not a grant program, but instead offers educational and outreach opportunities. Most notably, workshops were hosted that brought together technical experts, suppliers, and truck industry, as well as early adopters of natural gas heavy-duty vehicles (original equipment manufacturer [OEM] offerings only).

Some of the larger provinces have also offered provincial grant programs.

**FortisBC Natural Gas for Vehicles Program**
FortisBC provided partial funding for vehicles, fuelling infrastructure, and maintenance facility upgrades to the end of March 2017. The program was successful in bringing early adopters of natural gas trucks to highway transport in the produce and dairy sectors, as well as to wood chip container fleets. Fleet adoption stalled after Westport Innovations withdrew their 15 L high-pressure direct injection engine from the market.

**Province of Ontario Climate Change Action Plan**
The Province of Ontario committed to providing incentive funding for natural gas refuelling stations. Given the state of technology for natural gas vehicles, the funding will likely be directed to light-duty vehicles, transit, and refuse haulers.

**Province of Quebec Écocamionnage Grant Program**
The objective of the Écocamionnage program was to promote the use of equipment and technologies to improve energy efficiency while reducing GHG emissions in freight transportation. The program specifically targeted the freight and heavy vehicle industry. As well, the implementation of this program provided financial support to companies that reduced their GHG emissions and, in most cases, their fuel consumption. The program was to end on March 31, 2017, but has recently been extended to 2020.

The program was divided into four smaller programs:

- **Technology acquisition:** Financial support for applicants to acquire an eligible and evaluated fuel-saving technology. The list of eligible technologies was prepared by FPInnovations.
- **Technology certification:** Financial support for manufacturers or distributors to successfully get a technology approved for inclusion in the list of technologies eligible for funding. Approval was intended for marketable or already commercially available technologies.

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3 [http://www.gowithnaturalgas.ca/](http://www.gowithnaturalgas.ca/)

4 [https://www.fortisbc.com/NaturalGas/Business/NaturalGasVehicles/Pages/default.aspx](https://www.fortisbc.com/NaturalGas/Business/NaturalGasVehicles/Pages/default.aspx)

• Technology demonstration: Support for the implementation of various trucking projects that demonstrate potential for reducing GHG emissions. This component focused on technologies that were under development or that required demonstration or testing. Financial assistance was available to transport companies, manufacturers, or distributors that wished to demonstrate the potential reduction of GHGs and improvement in fuel efficiency that could be attributed to unproven technology.

• Logistics: Support for the implementation of projects that improved the logistics of road haulage companies, with a view to reducing GHG emissions.

Similar tools exist in other governmental jurisdictions throughout the world, and for good reason, as such tools for fleets have a proven track record. Off-road fleets, however, have been underserved, with there being few comprehensive government policies for reducing off-road fleet emissions, apart from limited adoption of low-carbon fuels in some provinces. Off-road fleets are further underserved by OEMs, who see developing alternative fuel technologies as risky, particularly when fuelling infrastructure can be a bigger barrier to adoption than the machine or vehicle that consumes the fuel itself.

Efforts in the United States

There are many efforts to reduce fleet emissions in the United States, many of which at the individual state level fall under the U.S. federal government’s Congestion Mitigation and Air Quality Improvement funding program. The programs presented below are primarily focused on CAC emissions, but they could be modified and adopted in an effort to lower GHG emissions as well.

Carl Moyer Grant Program

The Carl Moyer Memorial Air Quality Standards Attainment Program (Carl Moyer Program) provides grant funding for the incremental cost of cleaner-than-required engines and equipment for both on- and off-road machines. Grants are administered by local air districts in the State of California. The program is currently active.

Clean Diesel Program

The Clean Diesel Program (from the Diesel Emission Reduction Act) offers funding in the form of grants and rebates, as well as other support for projects that protect human health and improve air quality by reducing harmful emissions from diesel engines in the United States. The program expired at the end of 2016 and had also focused on such sectors as construction and agriculture.

Congestion Mitigation and Air Quality Improvement Program

Jointly administered by the U.S. Federal Highway Administration and the Federal Transit Administration, the CMAQ program has been renewed several times, most recently under the Moving Ahead for Progress in the 21st Century Act in July 2012. The Act provided just over $2.2 billion in CMAQ funding for each year of the authorization, 2013 and 2014.

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6 [http://www.arb.ca.gov/msprog/moyer/guidelines/current.htm](http://www.arb.ca.gov/msprog/moyer/guidelines/current.htm)

7 [https://www.epa.gov/cleandiesel/clean-diesel-rebates#2013co](https://www.epa.gov/cleandiesel/clean-diesel-rebates#2013co)
While currently expired, the project placed considerable emphasis on diesel engine retrofits and other efforts that underscored the priority of reducing fine particle pollution.

**Texas Emissions Reduction Plan**

The Texas Emissions Reduction Plan provides financial incentives to eligible individuals, businesses, and local governments to reduce emissions from polluting vehicles and equipment through retrofits and replacements. The State of Texas is currently reviewing the program, which offers several different kinds of grants for on- and off-road fleets, as well as for stationary power.  

**Ohio Diesel Emissions Reduction Grant Program**

This currently active State of Ohio grant program is intended to reduce diesel exhaust emissions and help improve air quality in counties and areas of the state that are not currently meeting national standards.

**California Air Resources Board**

Hundreds of millions of dollars in grants are available for reducing emissions from on- and off-road vehicles and equipment. Vehicle and equipment owners typically must apply for the funds. While the California Air Resources Board (CARB) is responsible for program oversight, some programs (such as the Carl Moyer Program) are implemented as a partnership with local air districts. Some of the CARB programs that are applicable to the resource sector in Canada include a loan incentive program and the Enhanced Fleet Modernization Program. The latter is aimed at getting older and more polluting cars off the road. With this program, a dollar from every vehicle registration is collected to provide incentive funding to scrap older cars and provide a rebate toward the purchase of an eligible car. Similar methods could be employed for off-road fleets.

**Other programs**

Other programs exist and are similar in execution to the ones listed above, particularly U.S. state programs that draw funds from the CMAQ program. Programs that are specifically targeted at reducing off-road fleets' major GHG contribution (i.e., liquid fossil fuels) are surprisingly rare, but they have primarily focused on low-carbon intensity fuels.

**Methods of reducing GHG emissions from resource road use**

**Changing off-road fleet and operator behaviour**

**Training**

Relative to documented success stories for improving truck driver performance, such as SmartDriver for Forestry, off-road operator skill development and tracking for improving energy intensity and reducing GHG emissions is unsophisticated. The full benefits of proper training and coaching of operators and the impact that better practices can have on fuel use and emissions should be studied.

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8 [http://www.tceq.texas.gov/airquality/terp](http://www.tceq.texas.gov/airquality/terp)


10 [https://www.arb.ca.gov/ba/fininfo.htm](https://www.arb.ca.gov/ba/fininfo.htm)
With better knowledge, measurable key performance indicators can be developed and educational course offerings created. Similar to on-road fleet efforts, such as *SmartDriver*, that have proven to lower fleet fuel consumption from 5–10% (Forest Engineering Research Institute of Canada, 2001), an off-road fleet training module could be developed to achieve similar benefits.

The development of such a course for off-road fleets would involve the following work:

- Benchmarking fleets’ energy intensity performance;
- Evaluating operator practices that impact energy intensity;
- Evaluating how equipment selection impacts energy intensity;
- Developing key performance indicators for the various off-road activities; and
- Developing training targeted to the various off-road sectors.

*Improving business practices*

Currently, off-road fleets generally do a poor job of tracking fuel use and machine productivity on an individual basis. Using new technologies, both of these can be accomplished to better understand GHG emissions and put better practices in place to reduce emissions. The approach would be based on the existing *Fuel Management 101 for Forestry* course developed by FPInnovations and could be incorporated into the concept of a SmartOperator course. The potential benefit is conservatively estimated at 5%, but it could be higher for poor performers.

In addition, energy use in off-road fleets can be used to evaluate fuel-saving technologies and record successful measures that reduce fuel consumption and GHG emissions. Full implementation could have a potential benefit of 5–10% (Natural Resources Canada, 2011).

FPInnovations has developed a fuel management course for on-road forestry fleets, incorporating some elements addressing off-road forestry fleets, but in a limited fashion. There is a need to further develop the off-road forestry fuel management offering and to develop similar educational offerings for other road-building (and maintaining) sectors. The development of this offering would involve the following work:

- Surveying fleets to better understand the logistics of distributing fuels;
- Surveying fleet managers to understand the range of business practice expertise associate with tracking fuel use;
- Surveying fleets operators and managers to highlight barriers to adopting new business practices; and
- Developing training targeted to the sectors. The sectors have a lot in common, but adaptation is needed to meet the specific needs of each sector.

*Improving trucks*

The following presents technologies that FPInnovations believes have potential for increased industry focus, with the more easily implemented measures listed first.
**Advanced Vehicle Configurations**

New higher gross vehicle weight vehicle configurations, which can be operated safely at higher allowable weights than current configurations, can significantly decrease transportation costs, energy intensity, fuel consumption, and GHG emissions. These configurations currently under development can reduce emissions by over 18% (per unit of delivered cargo). A number of configuration initiatives are currently underway in B.C., Nova Scotia, Québec, and Alberta, and they are being coordinated with industry, ministries, and departments responsible for transportation, and the ministries responsible for forests and natural resources. The configurations include:

- 9-axle B-train log trucks;
- 10-axle B-train chip trucks;
- Configurations to haul two 40-foot ocean containers directly to port;
- 9-axle B-train mining trucks (some of which are already in operation in B.C., with additional applications currently being evaluated).

British Columbia’s Ministry of Transportation and Ministry of Forests, Lands and Natural Resource Operations are currently working with industry and FPInnovations toward trial vehicles for the first three configurations listed above. In addition, they are looking to develop streamlined processes and policies to assist with future potential configurations and with the expanded use of these configurations once they are approved. The initiatives in the other provinces are either in development or just getting underway. There are opportunities for implementing other, new types of configurations in all Canadian jurisdictions.

All of these configurations, when employed in higher-capacity off-highway roles, will require additional stability and road and bridge capacity analyses.

**Anti-idling Technologies**

Idling a large industrial engine, whether to heat the machine to operating temperature from cold or to keep the operator warm or cool as needed, or simply from gross negligence, can use up to four litres of fuel per hour, depending on the engine size. Most modern engines can be programmed to shut down after a predetermined time to minimize the time spent running the engine. For older engines, several technologies are available that can shut engines down. Additional technologies exist that can heat the machine’s engine using a timer or thermostat, and ones that can engage the heater (or cooler) on an automated basis to ensure operator comfort, which can be up to 78% more efficient than idling the machine’s engine (Surcel, 2009). These technologies have the potential benefit of reducing GHG emissions up to 3%.

**Replacing Old Trucks with New**

New trucks can be very expensive purchases and, thus, some fleets try to extend the life of their machines for as long as possible. This means that a good portion of the national fleet is old and does not use the latest emission control systems, nor are these vehicles the most fuel efficient. By replacing older trucks with trucks that were produced according to the U.S. Environmental Protection Agency (EPA) 2014 or later standard (those with the selective catalytic reduction [SCR] emissions package), it is possible to achieve up to 5% lower fuel consumption than with previous emissions packages.
Moreover, with newer emissions systems, there are clear improvements to CAC emissions. The potential benefit is a reduction of 5–10% in GHG emissions.

**Lightweight Vehicle Components**
Trucks can benefit from reduced tare and, thus, improved payload capacity. New materials have allowed for the development of lightweight components, which can increase the amount of payload that can be carried per trip (decreasing energy intensity and emissions). Typical off-highway fleets could see 10% improvement in payload capacity and 10% reduction in fuel use (Surcel, 2010). The potential benefit is a reduction of up to 10% in GHG emissions.

**Aerodynamic Trucks and Devices**
Trucks that travel for sustained distances and at highway speeds can benefit greatly from having improved aerodynamic features. This can be achieved by redesigning the vehicle or using retrofit devices. The possible improvement in fuel consumption, and hence GHG, can be as high as 15% (Surcel, 2013) and highly depends on the vehicle configuration. This approach, which has been thoroughly examined for highway box-container trailers, has seen little attention for trucks in the resource sectors and trucks configured for more specialized roles (e.g., bulk fluid haulers or stake-sided cargo trailers). The potential benefit is a reduction of up to 15% in GHG emissions.

**Single wide-base Tires**
Single wide-base tires can replace conventional dual tires in many applications and can improve fuel efficiency by 6% (Surcel, 2010). In some provinces, trucks equipped with single wide-base tires have weight parity with trucks that use dual tires. Consistency in regulations between provinces and expanded applications for the use of these tires deserves further examination. The potential benefit is a reduction of up to 6% in GHG emissions.

**Long Combination Vehicles**
Conventional 5-axle semi-trailer truck configurations are employed throughout Canada to haul freight. These trucks fit current infrastructure at their terminals, or loading docks, and at storage facilities. To further the use of long combination vehicles, not only would the truck need change, but the infrastructure that handles bulk containers and trailers would also need change. A long combination vehicle can double the cargo capacity and lower energy intensity by up to 31% (Surcel, 2007). Consideration should be given to overcoming logistic, infrastructure, and technical challenges to better aid their adoption. The potential benefit is a reduction of up to 30% in GHG emissions.

**Electrified Highway**
Using electric trucks or trolleys, powered by suspended powerlines, in high-capacity truck corridors can dramatically reduce GHG emissions. Combining such technology with compact internal combustion powertrains for a small transit from an electrified highway to the distribution terminal could provide the benefit of reducing up to 90% of GHG emissions.

**Alternative Fuels: Renewable diesel and natural gas**
There are a variety of sources of biodiesel, and these can be blended with petroleum diesel to yield modest GHG emissions reductions commensurate with the percentage of biodiesel that is blended. However, the blend ratio must be lower in colder climatic conditions, and OEMs impose a limit to higher blend ratios to preserve engine warranty coverage and operability.
One bio-sourced fuel that does not suffer such limitations is renewable diesel from the Neste Corporation. Their renewable diesel product, which is not a fatty acid methyl ester fuel, can operate in cold environments and can lower GHG emissions by 40–60%.11 Renewable diesel as developed by Neste is chemically identical to ultra-low-sulphur diesel (ULSD) and is considered a “drop-in fuel.” However, to provide sufficient quantities, a production plant would be needed, and the price of fuel would need to be incentivized to bring price parity to ULSD. Similar drop-in fuels could be used to increase low-carbon fuel content, and they can be developed from renewable, Canadian-sourced feedstocks.

The increased use of natural gas could lower GHG emissions by 20–25%. Incentives that drive increased interest in natural gas applications and product development could bring this fuel into the mainstream for highway trucks. Currently, the lack of higher-horsepower offerings limits this fuel’s role in heavy-haul applications.

**Hybrid Technology**
Series electric hybrid drive uses an internal combustion engine paired with a generator, which in turn electrically powers electric-drive motors at the machine’s hubs. Parallel hybrid systems, in which the internal combustion power plant as well as the electric motor(s) can propel the vehicle, have been popular in the automotive realm, but have yet to be implemented on a commercial scale for freight. More development at the OEM stage and lighter-weight batteries with better power density will be needed before these technologies can be considered for the majority of the Canadian freight sector.

**Electrohydraulic Power Steering**
Electrohydraulic power steering (EPHS) is an electrically assisted steering mechanism that uses electronically controlled on-demand steering with hydraulic actuation. The system uses a motor pump unit and conventional rack-and-pinion power steering gear; it can be used in light-duty vehicles and in smaller off-road equipment. The system as developed by ZF TRW can save up to 0.3 L/100 km and reduce carbon dioxide emissions by approximately 7 g/km12. While the magnitude of the fuel savings is small, it is a good reminder that incremental performance improvements are made each year in the heavy equipment product sector.

**Improving off-road equipment**
The following presents technologies that FPInnovations believes have the potential for increased industry focus. The technologies are listed in the order of GHG-reducing potential, with the more easily implemented measures listed first.

**Replacing Old Equipment with New**
Off-road equipment is extremely expensive in any industry. Thus, off-road fleet owners try to extend the life of their machines for as long as possible. This means that much of the fleet is very old (more than eight years) and is equipped with little or no emissions controls. By replacing older off-road heavy machinery with new US EPA Tier 4 Final (SCR emissions package) equipped machines, it is possible to reduce fuel consumption up to 5% than with the Tier 2 or 3 emissions packages.


Potentially more advantageous are the newer, sophisticated hydraulic control systems that also make a machine more productive. The potential benefit is a reduction of 5–10% in GHG emissions.

**Alternative Fuels: Renewable diesel and natural gas**
There are a variety of sources of biodiesel, and these can be blended with petroleum diesel to yield modest GHG emissions reductions commensurate with the percentage of biodiesel that is blended. However, the blend ratio must be lower in colder climatic conditions, and OEMs impose a limit to higher blend ratios to preserve engine warranty coverage and operability. One bio-sourced fuel that does not suffer such limitations is renewable diesel from the Neste Corporation. Their renewable diesel product, which is not a fatty acid methyl ester fuel, can operate in cold environments and can lower emissions by 40–60%. Renewable diesel as developed by Neste is chemically identical to ULSD and is considered a “drop-in fuel.” However, to provide sufficient quantities, a production plant would be needed, and the price of fuel would need to be incentivized to bring price parity to ULSD. Similar drop-in fuels could be used to increase low-carbon fuel content and can be developed from renewable, Canadian-sourced feedstocks.

Increased use of natural gas could lower GHG emissions by 20–25%. Incentives that drive increased interest in natural gas applications and product development could bring this fuel to the off-road sector. However, there are important infrastructure issues and needs for off-road equipment and for remote resource-oriented fleets that need to be better understood.

**Anti-idling Technologies**
Idling a large industrial engine, whether to heat a machine to operating temperature from cold or to keep the operator warm or cool as needed, can use up to five litres of fuel per hour, depending on the engine size. Several technologies exist that can shut down an engine after a predetermined time to minimize the time spent running the engine. Additional technologies exist that can heat the machine’s engine using a timer or thermostat, and ones that can engage the heater (or cooler) on an automated basis to ensure operator comfort, which can be up to 78% more efficient than idling the machine’s engine (Surcel, 2009). The potential benefit is a reduction of up to 3% in GHG emissions.

**Hydrostatic Drive and Hybrid Technology**
Hydrostatic drive uses an internal combustion engine that drives a hydraulic pump connected through hydraulic valves to final drive pumps to propel a machine. This allows for smooth power delivery and rapid directional changes free of mechanical wear. Series electric hybrid drive uses an internal combustion engine paired to a generator, which in turn electrically powers electric-drive motors at the machine’s hubs. These two systems allow for optimized engine efficiency and can reduce fuel consumption by up to 28% (Schinck, 2014). The advantages of these two technologies need to be emphasized to off-road fleets, to which the technology is applicable.

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Hydromechanical Variable Transmission
The hydromechanical variable transmission combines mechanical and hydrostatic travel drive and could be employed in wheel loaders, graders, reach stackers, forestry skidders, heavy forklifts, and other mobile wheeled machines. The device from Dana Rexroth is scheduled to be available commercially in 2017 and promises to reduce fuel use by up to 25%.\textsuperscript{14}

Electrohydraulic Power Steering
EPHS is an electrically assisted steering solution mechanism that uses electronically controlled on-demand steering with hydraulic actuation. The system uses a motor pump unit and conventional rack-and-pinion power steering gear; it can be used in light-duty vehicles and in smaller off-road equipment. The system as developed by ZF TRW can save up to 0.3 L/100 km and can reduce carbon dioxide emissions by approximately 7 g/km.\textsuperscript{15} While the magnitude of the fuel savings is small, it is a good reminder that incremental performance improvements are made each year in the heavy equipment product sector.

TorqStor
TorqStor is an energy storage device developed by Ricardo that utilizes a flywheel to store energy, which is currently at a pre-production demonstration phase awaiting OEM product integration. Its’ construction uses a carbon-fibre composite flywheel with a magnetic coupling connected to a gear system that provides for a scalable range of energy storage capacities, that can be incorporated into many different equipment applications.\textsuperscript{16}

Methods of reducing GHG emissions from resource road management
The planning, construction, and maintenance of resource roads are essential activities to ensure effective resource management, transportation of goods, public access to communities, and for recreational activities. Resource roads must be built to provide for cost-effective and safe forest operations and transportation, but it must also be ensured that environmental values and concerns are integrated into their management. The goal of reducing GHG emissions as a response to climate change mitigation is a recent objective that must be integrated into resource road management. FPInnovations is well positioned between governments and industry and can help identify barriers for adoption, be they policy or practical matters. FPInnovations also excels at quantifying the benefits of proposed reduction measures and how to best convey these to industry on a regional basis. A partnership between government, industry, and FPInnovations will be needed to achieve the stated goals.

The Forest Products Association of Canada states that one of the key recommendations to allow the forest sector to achieve reductions in GHG emissions is for governments to “approve higher-capacity trucks to lower net GHG emissions per tonne of product moved” (Forest Products Association of Canada, 2016).

\textsuperscript{14} http://articles.sae.org/13940/
\textsuperscript{15} https://www.trwaftermarket.com/en/news/trw-aftermarket-examines-the-power-of-steering
In order for the goal of reduced GHG emissions in forest transportation to be achieved, such as through the implementation of high-capacity trucks, road infrastructure must be maintained and managed to support this initiative. Resource road infrastructure must be built and maintained in such a manner that allows opportunities for advanced and modernized transportation equipment and methods to be fully realized.

**Managing roads to support new truck and trailer configurations**

New truck and trailer configurations that provide heavier payloads, thereby reducing the number of vehicle trips, are a critical component of the forest sector in reducing GHG emissions. The recent approval of 9-axle truck configurations in B.C. highlights the current and potential need for resource roads to be designed and upgraded to support new configurations (Bradley & Forrester, 2016). Longer trucks will require changes to resource road design, as these trucks negotiate turns and intersections. Current bridges need to be evaluated to determine whether the increased payloads can be supported by the existing bridge infrastructure or whether it will need to be upgraded. The cost to upgrade or replace bridges can be expensive and can be a potential barrier to the implementation of increased truck payloads. The construction of new roads should take into consideration the revised road and infrastructure designs (geometric and structural) that may be required for future potential truck and trailer configurations. The development of national resource road design guidelines could provide guidance to resource road managers on required and efficient road design.

The management of Canada’s public highway infrastructure can also provide opportunities for the reduction of GHGs in the forest sector. The implementation of policies that optimize spring load restrictions can ensure that periods of reduced vehicle payloads are not implemented for periods longer than necessary, while protecting public infrastructure. Winter weight premiums, which are implemented when the underlying road material has achieved a sufficient frost depth, can allow for increased payloads, which reduce the number of vehicle trips required to transport the same amount of freight (Bradley 2015).

**Optimizing resource road designs to provide for implementation of GHG reduction initiatives**

Many efforts to reduce the GHG emissions of forest sector transportation rely on the ability and initiatives that reduce the consumption of fossil fuels. Improvements to fuel consumption are typically focused on the driving style of the operator and on the vehicle and engine technologies. In addition to driver style and vehicle technologies, the design of the road also influences fuel consumption. A road that has gradual changes in elevation (vertical alignment), is straight with gradual turns (horizontal alignment), and has few intersections where complete stops are required will offer the opportunity for lower vehicle fuel consumption. Designing a road to consider the vehicle engine load and its ideal fuel efficiency conditions can offer opportunities for reducing the GHG emissions of the transportation of forest products.

In the construction of high-volume public highways, the GHG emissions associated with a road’s construction are estimated to be 10–20% of the total GHG emissions emitted by all the vehicles that use the road through its lifetime (Hanson & Noland, 2015). Public highways, through the use of energy-intensive products, such as asphalt and concrete, can be expected to emit much higher levels of GHGs through their construction than resource roads as a result of the low-energy intensive practices typical of resource road construction (Egis International, 2010).
With the low levels of GHGs emitted from the construction of resource roads, there is less opportunity to reduce emissions that result from their construction compared to the emissions associated with the heavy and light vehicles that use the roads.

**Reducing the Amount of Material**

Resource roads are typically built with on-site material or aggregate that has been crushed or screened. Reducing the amount of off-site material that is used in the construction of a road can minimize equipment use for material production and can reduce the number of vehicle trips to transport the material. Reducing the amount of material needed to construct the road can be achieved through various practices, such as by building roads before their use is required so that the road can settle and compact and reducing the gravel requirements through greater use of geosynthetics.

**Reducing the Amount of Constructed Road**

The primary method of reducing GHG emissions for resource roads is ensuring that the smallest possible amount of road is built to support the operational, economic, and safety needs of the operation. Implementing best management practices at the planning stage, such as reusing old roads and minimizing loops, can reduce the GHGs that are emitted through the road’s construction and subsequent maintenance. In addition, minimizing road area ensures that the maximum amount of forested area is maintained, which in turn optimizes the area that is available for forest carbon sequestration.

**Minimizing Soil Disturbance**

Resource roads often need to be constructed through wetlands. Wetlands (bogs, fens, and swamps) are common throughout the forested regions of Canada and are a significant sink for the sequestration of carbon (Carlson, Wells, & Roberts, 2009; Tarnocai, 2006). The accumulation of peat in bogs and fens, which occurs in environments with high moisture levels, is particularly important for the sequestration of carbon. The disturbance of these peatlands through the construction of a resource road or through the reduction of soil moisture levels, which may occur by roads disrupting wetland hydrology, can release the stored peatland carbon. Releasing the stored carbon at the time of construction or by disrupting and reducing peatland soil moisture levels can amount to significant levels of GHG emissions. Resource roads can be constructed and maintained in ways that minimize the impacts on wetlands, by avoiding wetlands, using low-impact construction methods, and implementing practices that maintain wetland hydrology.

**GHG reduction opportunities**

Off-road fleets engaged in road maintenance and construction, whether they occur on paved highways or unsurfaced resource roads, emitted approximately 29 Mt\(^\text{17}\) of GHGs in 2014, according to Environment and Climate Change Canada’s *National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada*. It is estimated that the forest resource sector emits 2.5 Mt annually to transport raw fibre from the stump to the mill.

\(^{17}\) GHGs attributed to off-road diesel use by mobile machinery used in construction, mining, and logging, excluding diesel use by heavy-duty trucks and stationary mining equipment.
There are approximately half a million off-road machines engaged in all aspects of resource sector use, and they contribute to a considerable quantity of GHG emissions, which could most likely benefit from the GHG reduction methods highlighted in this report. One area where significant environmental improvements could be made is replacing older (10 years or more), greater polluting machines, some with no emissions control systems whatsoever; with new equipment that uses the latest emissions control technologies. The size of this opportunity is immense, as shown in Figure 1 (Environment Canada, 2011). This distribution is based on 130–223 kW engines and would vary slightly for engine power levels above and below this power range, as implementation was phased in over time, based on power levels. Clearly the majority of off-road engines are heavy polluters (Tiers 0 to 2) and efforts to modernize the fleet would be highly beneficial.

![Figure 1. EPA emissions Tier distribution for 130–223 kW off-road engines and by year of implementation.](image)

Older machines, with the Tier 1 or 2 emissions package, emit high levels of CACs and more GHGs, given the reduced efficiency from engine wear and poor sealing of hydraulic pumps and cylinders. Often, newer machines employ more sophisticated control systems that improve productivity and reduce GHGs per unit of production. In addition, machine uptime, or utilization level, is higher for new machines.

Heavy-duty diesel trucks (greater than 15 000 kg gross vehicle weight) emit 48 Mt of GHGs per year, which is 7% of all GHG emissions in Canada. The emissions equipment of these trucks is described as being EPA-compliant, with EPA 2010 emissions being approximately equivalent to Tier 4 off-road standards (the EPA Tier designation applies only to off-road engines, while EPA emissions standards for trucks are designated by the year in which the emissions standard came into force). However, truck fleet turnover is far greater than that of off-road fleets, and, thus, reducing GHG emissions through the renewal of truck fleets would have less impact than the renewal of off-road machine fleets.
Given the highly competitive nature of the OEM heavy-duty diesel truck market, the recent and coming regulations that mandate the reduction of GHG emissions (the EPA classified carbon dioxide a dangerous pollutant in 2009), and the recent innovations in transportation services, much improvement is anticipated in this sector’s GHG emissions. However, care must be taken to realize these gains in Canada, as much of the marketplace drivers originate in the U.S., where smaller-capacity trucks are more common.

**Policy and program opportunities for GHG emissions reductions**

**Off-road equipment**

Off-road equipment is highly specialized, so improving basic machine functioning to lower GHG emissions can be highly problematic from a technical standpoint. Instead, an approach to lowering GHG emissions that can be applied to all machines would be more successful. Key approaches with high probability of success or with proven success records that achieve this are:

- Switching to lower-carbon fuels, either natural gas or higher renewable fuel content;
- Implementing engine idling shutdown timers and heaters and coolers to limit engine idling;
- Replacing older machines with new and more efficient machines; and
- Improving business and machine operator practices to lower fuel consumption.

To improve the uptake and use of these technologies, incentive programs should be considered for device retrofits in the case of fitting engine anti-idling technologies as part of a “clean idle” initiative. Past efforts by provincial and federal governments that funded knowledge exchange activities from industry experts and truck fleet operators and managers (i.e., *SmartDriver*) have proven highly successful and could be expanded to include new educational offerings to the off-road sector. Another component of the SmartOperator concept could be a thorough presentation of the cost of operating older machines and a discussion about determining when an older machine has reached the end of its economic life and is best replaced.

To better utilize domestically produced natural gas in off-road fleets, and, thus, achieve significant GHG reduction, investments in clean technology need to be made. Relying on foreign suppliers to produce off-road machines that consume natural gas and meet domestic needs may be futile. Domestic research and development for natural gas combustion technology needs to be created for Canadian customers by Canadian suppliers.

**Trucks**

Many of the approaches developed for forestry fleets have been adopted from programs developed for large, over-the-road fleets using mature technology and business practices. However, smaller fleets and fleets in smaller communities have yet to realize these benefits. Therefore, renewed effort should be made in knowledge-exchange activities, such as the *SmartDriver* courses for forestry and highway trucks, *Fuel Management 101* with its’ discussion of modern fleet management tools, as well as in more basic messages, such as clean idling campaigns.
The potential benefits of some proven technologies are yet to be fully realized by industry, as a result of either technical or regulatory limitations. For example, taking full advantage of aerodynamic devices may require amendments to overall truck dimension regulations and weight parity for single wide-base tires across all provinces would likewise result in greater fleet adoption. Regulatory requirements for inclusion of these products and other energy-conserving devices in new truck or trailer sales could further their adoption. Higher-capacity vehicles, long combination vehicles, and lightweight technologies need further research and development investments, which should be focused to benefit the realities of the Canadian environment and marketplace. Electrified highways could provide even larger GHG reductions, but they would need to be situated in key locations and built through a partnership between private companies and governments.

Resource roads
The planning, construction, and maintenance of resource roads are essential activities to ensure effective resource management, transportation of goods, public access to communities, and for recreational activities. The most significant opportunities for the reduction of GHGs are embedded in the reductions available through enhanced technologies and operator practices of the equipment that is used to construct and maintain resource roads. In addition, to achieve the GHG emissions reductions in forest transportation through initiatives such as the implementation of high-capacity trucks, road infrastructure must be maintained and managed to support these initiatives. Resource road infrastructure must be built and maintained in such a manner that allows opportunities for advanced and modernized transportation equipment and methods to be fully realized. The development of nationally recognized resource road standards could aid in the implementation of road designs and specifications that provide the opportunity for the effective implementation of advanced truck and trailer configurations.

Public highways
The management of Canada’s public highway infrastructure can provide significant opportunities for the reduction of GHGs in the forest sector. The implementation of methods that ensure the effective use of spring load-restriction periods can ensure that periods of reduced vehicle payloads are not implemented for longer than necessary, while protecting public infrastructure. Provincial policies that support winter weight premiums have been shown to allow for an increase in payload by 15% and represent a savings of greater than $1.5 million per year for the forest sector in Alberta (Bradley 2015). These savings are primarily achieved through fuel reduction costs, with a reduced number of vehicle trips required to transport forest goods. Ensuring the application of enhanced spring load-restriction periods and winter weight premiums throughout Canada would support the reduction of GHG emissions. Another opportunity is the implementation of route-restricted trucking, whereby trucks are allowed to carry higher-capacity payloads than those prescribed in the general provincial weights and dimension regulations. Higher payloads lead to reduced energy intensities and the “funneling” of trucks into a specific route can allow provincial governments to target their infrastructure dollars to these routes, which could lead to overall efficiencies.
4. CONCLUSIONS

Trucks have been the object of much study in efforts to reduce GHG emissions, but off-road machines and specialized trucks in the resource sectors have been underserved by past research and development efforts. Enhanced fleet management skills are needed for off-road fleets, which would be best accomplished by developing an educational offering, tentatively called SmartOperator. The benefits of such training are tangible and they not only have the ability to reduce GHG emissions, they also enhance businesses’ profitability. The SmartOperator training concept is currently under development in the forest sector and could be transferred to other sectors with additional and complementary efforts.

Newer machines are often seen as a necessary evil replacement for older machines that have surpassed their useful life. Identifying when an off-road machine should be replaced, and the benefits of such replacement, is poorly understood in many fleets. Newer off-road machines often do not come with fuel consumption ratings, and if they do, their ratings, as supplied by the OEMs, relate poorly to the fleets' needs and uses. Of far greater concern is the improved productivity and uptime that the newer machine would bring. It is on this basis, or litre of fuel consumed per litre of production, that new machines should be properly judged and their benefit to the environment and machine operator profitability explained to fleets. As shown graphically in Figure 1, the vast majority of machines have little to no effective pollution control systems compared with modern machine power plants. Efforts should be made to make the continued ownership and operation of these old machines more economically undesirable than it already is.

Alternative fuels, such as bio- or renewable diesel and natural gas, can play an important role in reducing Canada’s GHG emissions. However, the operating conditions in Canada and the remote location of Canadian resource road work will require Canadian investments to develop technologies that meet the country’s needs. Waiting for foreign technology suppliers, who are more focused on the needs of Canada’s larger business competitors, is futile and will ultimately delay, or prohibit entirely, the availability of advanced technologies that meet the needs of Canada’s off-road fleets.

A good example of Canadian successes in developing advanced transportation technology is that of higher-capacity trucks, wholly developed by organizations like FPInnovations in concert with OEMs and equipment manufacturers. These higher-capacity trucks can be introduced into the general weights and dimensions regulations or can be limited to specific routes or corridors. Further partnering of Canadian industry and governments will be needed to design and build advanced road infrastructure, such as roads capable of supporting long combination vehicles or electrified highways, to name two concepts explored in this roadmap.

Planning for future road investments or upgrades to road capacity will also require multi-sector co-operation in partnership with governments to ensure the needs of all are met in the long term. FPInnovations can serve as the hub for these efforts and can be a trusted evaluator of new and emerging technologies.
5. REFERENCES


Forest Products Association of Canada. (2016). *Canada’s forest products industry is part of the solution to the climate change challenge*. Ottawa, Ontario: Forest Products Association of Canada.


