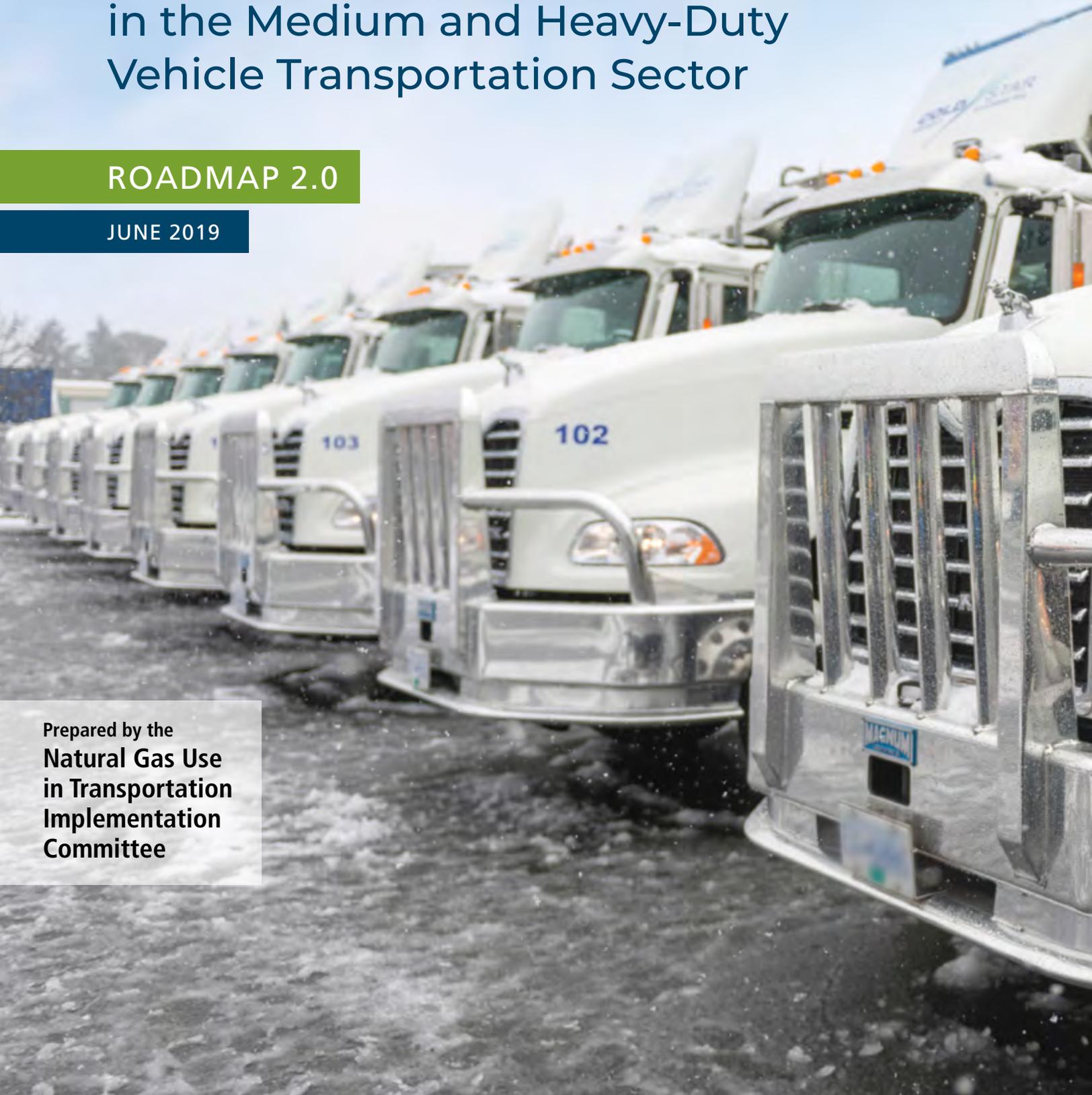


# Natural Gas Use in the Medium and Heavy-Duty Vehicle Transportation Sector

ROADMAP 2.0

JUNE 2019

Prepared by the  
**Natural Gas Use  
in Transportation  
Implementation  
Committee**



#### Disclaimer

This Roadmap provides the perspective of numerous stakeholders and was prepared under the direction of the Natural Gas Roadmap Implementation Committee members. The contents, conclusions, and recommendations are not necessarily endorsed by all participating organizations and their employees or by the Government of Canada.

Cat. No. M134-58/2019E-PDF

ISSN 978-0-660-29589-3

For more information or to receive additional copies of this publication, write to:

Canadian Natural Gas Vehicle Alliance

350 Albert Street, Suite 1220

Ottawa, ON K1R 1A4

Telephone: (613) 564-0181

Email: [bruce.winchester@cngva.org](mailto:bruce.winchester@cngva.org)

[www.cngva.org](http://www.cngva.org)

“With the permission of Canadian Standards Association, (operating as “CSA Group”), 178 Rexdale Blvd., Toronto, ON, M9W 1R3, material is reproduced from CSA Group’s Compressed Natural Gas and Liquefied Natural Gas Placemats. © 2019 Canadian Standards Association. For more information or to purchase standard(s) from CSA Group, please visit [store.csagroup.org](http://store.csagroup.org) or call 1-800-463-6727.”

# Foreword

## Roadmap Exercise Revisited

In 2010, Natural Resources Canada (NRCan) brought together stakeholders from governments at all levels, industry, academia and non-government organizations to identify the optimal use of natural gas in the Canadian transportation sector. Together, they published the *Natural Gas Use in the Canadian Transportation Sector: Deployment Roadmap* (Roadmap 1.0). The Roadmap identified the medium- and heavy-duty vehicle (MHDV) sector as the optimal use of Canada's abundant natural gas supplies, and recommendations stemming from this Roadmap were put in motion.

Much has been done by both industry and government in addressing the Roadmap recommendations, however, there is still work to do. Many of the barriers that were identified in the first Roadmap, such as the upfront capital cost vehicle premium and the need to continue to develop and harmonize codes and standards, still exist today. However, new challenges have come to light such as how to integrate renewable natural gas (RNG) into the market in a meaningful way. Furthermore, the changing dynamics in the market such as carbon pricing, the Clean Fuel Standard and technology advances will influence the use of natural gas as a transportation fuel. Key industry stakeholders have expressed the need for an updated Natural Gas Roadmap that reflects the current reality of the Canadian market place. The work of almost a decade ago is now being revisited in the current policy and business environment.

We recognize the work of all involved in this process and appreciate their dedication in contributing to the delivery of the updated Roadmap 2.0.

# Roadmap Participants

Alberta Department of Energy

ATCO Gas

Canadian Gas Association

Canadian Natural Gas Vehicle Alliance

Canadian Trucking Alliance

Change Energy Services

Cummins Westport Inc.

Enbridge Gas Distribution

Énergir

Ferus Natural Gas Fuels

FortisBC

Kauling Solutions

Ministère de l'Énergie et des Ressources naturelles du Québec

Ministry of Energy, Mines and Petroleum Resources (B.C.)

Murray Thomson (Consultant)

Natural Resources Canada

Paul Blomerus (Consultant)

Standards Council of Canada

Step Change Communications

Transport Canada

Union Gas Ltd.

Westport Fuel Systems

# Glossary

## Terms of Reference and Acronyms

**Biogas:** Biogas is a renewable source of methane gas, created when organic matter breaks down in an oxygen-free environment. It is produced from the organic wastes generated by farms, forests, landfills, municipal solid waste and water treatment plants. Biogas often contains water vapour, carbon dioxide and other elements such as sulphur, which can be removed through processing.

**Biomethane:** Biogas that is upgraded to pipeline quality-standard and can be used interchangeably with geologic natural gas.

**Clean Fuels Standard (CFS):** A non-prescriptive, performance-based standard to reduce the carbon intensity of fuels used across the transportation, industry and buildings sectors. The overall objective is to achieve 30 megatonnes of annual reductions in GHG emissions by 2030.

**Diesel litre equivalent (DLE):** The amount of natural gas it takes to have the same energy content as a litre of diesel.

**Compressed natural gas (CNG):** Natural gas that is compressed to a high pressure of 3,000 to 3,600 pounds per square inch (psi), reducing the volumes by a factor of at least 300 compared with gas at normal temperature and pressure.

**End-user:** The person or organization that is the actual user of a product. For the purposes of this document, an end-user is typically an owner/operator of a vehicle or a fleet of vehicles.

**Fuel Value Index (FVI):** A measure (used in business case modelling) that allows all costs associated with natural gas use to be consolidated and reflected as a cost-per-diesel-litre equivalent. FVI values greater than 1 indicate a value proposition for natural gas that is equivalent to or better than that for a comparable diesel fleet.

**Heavy-duty vehicle:** Class 7–8 vehicles with a gross vehicle weight of 15 tonnes or greater.

**Internal rate of return (IRR):** The rate of return used to measure and compare the profitability of investments.

**Lifecycle greenhouse gas (GHG) emissions:** The total amount of GHG emissions created throughout the full fuel lifecycle, including stages of fuel and feedstock production, distribution, delivery, and use.

**Light-duty vehicle:** Class 1–2 vehicles with a gross vehicle weight of up to 4.5 tonnes.

**Liquefied natural gas (LNG):** A form of natural gas made by cooling the gas temperature to -162°C, reducing the volume by a factor of 600 compared with gas at normal temperature and pressure.

**Medium-duty vehicle:** Class 3–6 vehicles with a gross vehicle weight between 4.5 and 14.9 tonnes.

**Natural gas vehicle (NGV):** An alternative fuel vehicle that uses CNG, LNG or RNG as a clean alternative to conventional liquid fuels.

**Original equipment manufacturer (OEM):** The company that originally manufactures products, in this case, vehicles or powertrain components.

**Paris Climate Accord:** Legally binding global climate deal signed in 2015 by Canada and 194 other countries to set out a global action plan putting the world on track to avoid dangerous climate change.

**Renewable natural gas (RNG):** Also known as biomethane, this is biogas that is upgraded to pipeline quality-standard and can be used interchangeably with geologic natural gas.

**Return-to-base (RTB):** Refers to a type of fleet operations where all vehicles return to a central facility at the end of a day's operation.

**Roadmap 1.0:** The initial roadmap exercise, undertaken in 2010, through NRCan's facilitation of a Roundtable of individuals from government at all levels, industry, academia and non-government organizations that produced the *Natural Gas Use in the Canadian Transportation Sector: Deployment Roadmap*.

**Tight gas:** Natural gas produced from reservoir rocks with such low permeability that hydraulic fracturing is necessary to produce the well at economic rates.

**Value proposition:** The collective set of benefits that a purchaser or adopter can justifiably expect to receive, based on the specific attributes of a product.

# Table of Contents

|     |                      |
|-----|----------------------|
| i   | Foreword             |
| ii  | Roadmap Participants |
| iii | Glossary             |
| vii | Executive Summary    |

## BACKGROUND

|    |   |
|----|---|
| 1  | Chapter 1: Introduction                           |
| 7  | Chapter 2: Policy Landscape and Drivers of Change |
| 13 | Chapter 3: State of Play                          |
| 19 | Chapter 4: Natural Gas Supply                     |

## MARKET NEEDS AND INNOVATION

|    |  |
|----|--|
| 29 | Chapter 5: Validating the Business Case for NGV Adoption                         |
| 37 | Chapter 6: End-User Needs  |
| 39 | Chapter 7: Cross-Canada Case Studies Show the Way                                |
| 43 | Chapter 8: Research and Development – Addressing User Needs Helps to Deploy NGVs |

## ROADMAP – PATH FORWARD FOR TRANSFORMING THE NGV MARK

|    |  |
|----|--|
| 49 | Chapter 9: Education and Outreach          |
| 53 | Chapter 10: Recommendations and Next Steps |

## APPENDICES

|    |   |
|----|---|
| 63 | Appendix A: Inputs, Considerations and Reviews by Various Industry Stakeholders |
| 67 | Appendix B: Priority Research and Development Areas                             |
| 71 | Appendix C: Natural Gas Standards   |

# EXECUTIVE SUMMARY



CNG  
FUEL  
EMERGENCY  
SHUT-OFF



Dispenser instructions

1. Prepare your vehicle for refueling.
2. Insert your card.
3. Press the button to start refueling.
4. Press the button to stop refueling.
5. Lift the nozzle to stop refueling.
6. Press the button to stop refueling.
7. Remove nozzle to stop refueling.

Price per kg

3600 PSI

FOR NON-EMERGENCIES

Energy at work FORTIS BC





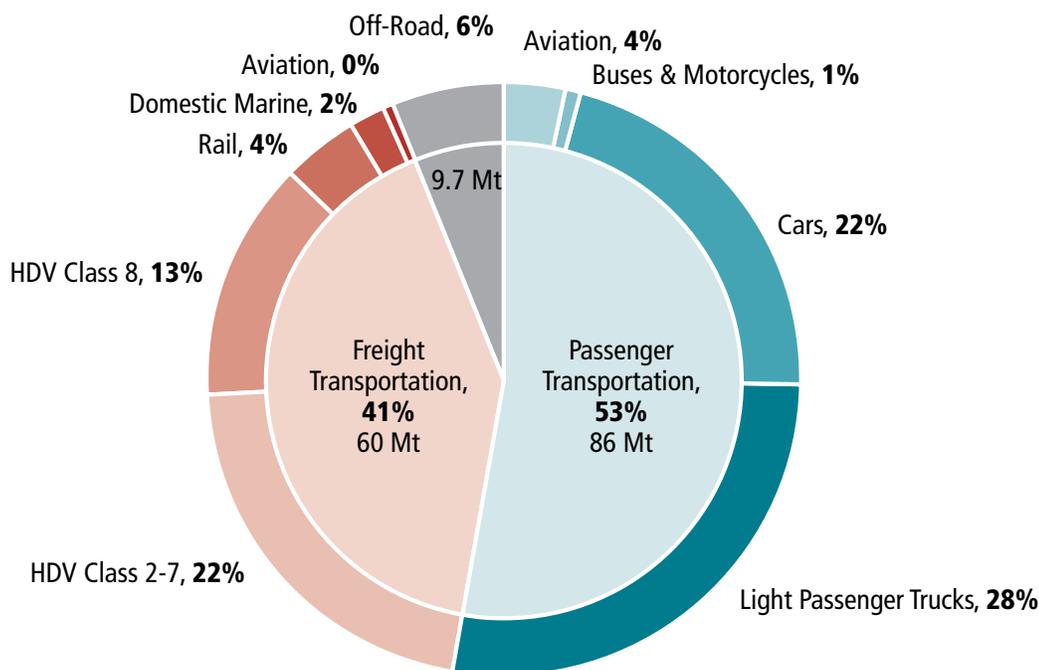
# Executive Summary

## Roadmap Exercise Revisited

In 2010, Natural Resources Canada (NRCan) brought together stakeholders from governments at all levels, industry, academia and non-government organizations to identify the optimal use of natural gas in the Canadian transportation sector. Together, they published the *Natural Gas Use in the Canadian Transportation Sector: Deployment Roadmap* (Roadmap 1.0). The roadmap identified the medium- and heavy-duty vehicle (MHDV) sector as the optimal use of Canada's abundant natural gas supplies in the transportation sector and recommendations stemming from this roadmap were put in motion. The work of almost a decade ago is now being revisited in the current policy and business environment.

## The Transportation Sector and Greenhouse Gas Emissions

The transportation sector is the second-largest source of greenhouse gas (GHG) emissions in Canada, after the oil and gas industry. Domestic transportation emissions were 173 Mt CO<sub>2</sub>e in 2016, accounting for 25% of Canada's total domestic emissions. Light-duty passenger vehicles account for about half of Canada's transportation emissions. Although the emissions from the light-duty passenger vehicles continue to decrease, emissions from on-road heavy-duty freight vehicles (35% of the sector) are triple what they were in the mid-90s, in part due to an increase in trucks on the road and in the volume of goods being moved.



**Figure 1:** 2016 Greenhouse Gas Emissions by Vehicle Type in Canada

Other transportation modes accounted for just 10% of transportation emissions in 2016, with 6.8 Mt of emissions coming from railways, primarily freight rail, 7.1 Mt from domestic aviation, and 3.9 Mt from domestic marine.

Emissions from passenger transportation continue to decrease as a result of improvements in fuel efficiency and the rising penetration of zero-emission vehicles (ZEVs). However, emissions from freight transportation have risen since 2005 and will decrease only slightly by 2030. Increases in fuel efficiency could be largely offset by the projected increased volume of goods being moved and consumers' preference for "just-in-time" delivery.

### Current Policy Environment

In 2016, the Government of Canada signed the Paris Climate Agreement and developed the Pan-Canadian Framework on Clean Growth and Climate Change (PCF) with the provinces and territories, and in consultation with Indigenous peoples, to meet its emissions reductions targets, grow the economy, and build resilience to a changing climate. The plan includes a pan-Canadian approach to pricing carbon pollution and measures

to achieve reductions across all sectors of the economy. It aims to drive innovation and growth by increasing technology development and adoption to ensure Canadian businesses are competitive in the global low-carbon economy. It also includes actions to advance climate change adaptation and build resilience to climate impacts across the country.

Key measures on transportation in the PCF include (1) setting and updating vehicle emissions standards and improving the efficiency of vehicles and transportation systems; (2) expanding the number of zero-emission vehicles on Canadian roads; (3) supporting the shift to lower-emitting types of transportation, including through investments in infrastructure; and (4) using cleaner fuels.

Pricing carbon pollution is widely recognized as an efficient way to reduce GHG emissions and helps achieve our objectives to protect the environment, stimulate investments in low-carbon innovation and create a sustainable clean-growth economy. Carbon pricing sends an important signal to markets and provides incentives to reduce energy use through conservation and efficiency measures, while also serving to drive fuel switching and technology advances. Applying carbon pricing to a broad set



Union Energy Solutions – Trucks from the CAT Transport and Express Mondor CNG fleets, fueling at the Enbridge Gas Inc. Clean Energy-Shell Flying J station in London, Ont.

The Government of Canada is also already taking action on multiple fronts to progress towards a low carbon transportation sector. Through initiatives such as the Electric Vehicle and Alternative Fuel Infrastructure Initiative, the government is enabling the adoption of alternative-fuelled transportation options by supporting the deployment of zero-emission vehicle infrastructure by creating a coast-to-coast network of recharging infrastructure for electric vehicles; refuelling infrastructure for natural gas across freight corridors; hydrogen refuelling in major metropolitan areas, supporting the demonstration of next-generation charging technologies, and developing the necessary codes and standards to support their deployment. Through its numerous vehicle regulations, it is working towards reducing the amount of fuel used by the Canadian transportation sector.

of emission sources across Canada, with increases in stringency over time, will help to reduce GHG emissions at the lowest cost to businesses and consumers, while supporting clean growth.

To further reduce emissions across the transportation, industry and buildings sectors, the Government of Canada is developing a Clean Fuel Standard to reduce Canada's greenhouse gas emissions through the increased use of lower-carbon fuels, energy sources and technologies. The objective of the Clean Fuel Standard is to achieve 30 million tonnes of annual reductions in GHG emissions by 2030. The Clean Fuel Standard will complement carbon pollution pricing by reducing GHG emissions throughout the lifecycle of fuels and by driving investments in cleaner fuels and in clean technology in Canada.

Shortly after the PCF was released, NRCan, through Generation Energy, initiated a national dialogue on Canada's energy future. The Generation Energy Council report provided a framework with four pathways to get to a low-carbon future: (1) reducing energy consumption; (2) switching to cleaner power; (3) using more renewable fuels; and (4) producing cleaner oil and gas.

The Government of Canada announced it would appoint an Advisory Council on Climate Action to identify opportunities for the Government of Canada to build on the commitments in the transportation and buildings sectors in the PCF, including existing federal government actions and those of provinces and territories.

Provincially, Quebec, Ontario and British Columbia have all recently announced plans that include actions to support carbon reductions across their respective transportation sectors. All three plans mention increased production of renewable energy, such as RNG, as a means to achieving GHG emissions reductions. Provincial plans will further be reinforced by strong policies, such as the Clean Fuel Standard, at the federal level.

Internationally, Canada is a member of the Clean Energy Ministerial, a high-level global forum to promote policies and programs that advance clean energy technology, to share lessons learned and best practices, and to encourage the transition to a global clean energy economy. Canada is

hosting the 10th annual Clean Energy Ministerial, bringing together Energy Ministers from 25 member countries and the European Commission, which account for about 90% of global clean energy investments and 75% of global GHGs. Transportation-related actions will figure prominently in the CEM10 agenda.

## **Business Climate**

Over the last decade, the natural gas vehicle (NGV) industry has experienced substantive shifts in market demand for natural gas products, services and applications. While market uptake of natural gas in Canada's transportation sector has increased, it still requires a focussed effort from industry, governments and end-users to reach its full potential as a clean technology solution for transportation.

Many market forces and factors, including fuel prices and responses to climate change, have influenced the uptake of natural gas in the MHDV sector. As a global average, natural gas today represents a 3.2% share of the energy used to fuel transportation. However, in North America, this share is much lower at 0.5% of total transportation energy use, which presents an opportunity to grow the market in Canada given its abundant supply of low-cost domestic natural gas resources.

In 2010, there were many unknowns regarding NGVs, including performance and availability of NGVs, access to refuelling infrastructure and environmental benefits. Although some fleets are not yet fully aware of the costs and benefits of fuel switching, early adopters have demonstrated that NGV can provide a strong return on investment while lowering operating costs in the long run. More work is still required to ensure that fleets are aware of NGV benefits.

More broadly, ongoing investments in NGV applications, infrastructure and support for the expanding renewable natural gas (RNG) market are required alongside engagement to ensure that natural gas is understood and recognized as a solution for reducing emissions from the transportation sector while providing economic benefits to Canadians.

## Moving forward with NG Roadmap 2.0

As with Roadmap 1.0, NRCan partnered with a comprehensive cross-section of industry experts and leaders to research key discussion areas to finalize recommendations contained in Roadmap 2.0.

- Drivers and opportunities
- Current state-of-play of the NGV industry
- Business case for NGV applications including growth modelling
- End-user needs for decision-making
- Case studies of leading Canadian fleets
- Renewable natural gas opportunity
- Research and development priorities
- Barriers for stakeholders
- Education and outreach priorities
- Roadmap recommendations

### The Business Case

The business case modelling in Roadmap 2.0 demonstrates that, true to Roadmap 1.0 findings, the use of CNG by MHDV applications provides substantial economic and environmental benefits. The expanded modelling underpinning these findings provides more details on which applications (e.g. trucks, buses and refuse haulers) are best suited for fuel switching to natural gas, the reductions in GHG emissions and improvements to local air quality, and cost savings that can be achieved over the long run. Case study profiles, such as those included in this report, exemplify fleets that are experiencing these benefits.

### RNG Can Further Improve the Carbon Footprint

The research in this report demonstrates how RNG can further improve GHG emissions reductions from MHDVs, offering an important pathway to meeting Canada's Paris Climate Accord commitments. Modelling indicates that substituting 5% of natural gas used in Canada with RNG can eliminate 14 MT of GHGs by 2030<sup>1</sup>. To achieve these anticipated

GHG reductions, an RNG supply chain is required, beginning with its production from the further processing of biogas or from converting biomass through a process such as anaerobic digestion, then blending it into the natural gas delivery system from where it can be delivered to the end-user. Use of RNG can reduce or eliminate methane emissions from waste facilities and can yield a carbon-neutral outcome or net reduction in GHG from a lifecycle perspective in addition to converting waste into energy.

### Other Competing Technologies

In 2010, the only competitive technology in the MHDV sector was the diesel engine, whereas today, emerging technologies such as electric vehicles and fuel cell vehicles are being deployed across North America. At the time of Roadmap 1.0, these types of technologies were not part of the market-ready landscape. While electric vehicles have gained market share among passenger vehicles and growing interest among transit fleets, natural gas vehicles retain a larger market share in the majority of the MHDV segment due to the power and range offered by existing natural gas applications.

Given these emerging technologies, operators are making more complex decisions for their fleets, and policymakers and investors need to rationalize a growing diversity of investments in low-carbon transportation. Recognizing that the MHDV market may soon be divided along different technology lines, the NGV industry is called upon to assess and validate where NGVs continue to provide a long-term solution for operational cost savings and GHG reductions. There is not one single pathway that is necessarily optimal for all fleets to follow. Instead, a multitude of technologies, practices and policies need to work together to accelerate the transition to decarbonize the transportation sector while stakeholders need to be well-informed to support and choose optimal solutions.

---

<sup>1</sup> CGA, 2016 <http://www.cga.ca/publication/the-canadian-natural-gas-opportunity-ghg-reduction-potential-to-2030/>

## Barriers to Advancement

For all stakeholders—fleet operators, supply chain, OEMs, investors, R&D developers, and governments—various barriers to optimal natural gas uptake remain. These include additional up-front capital and operational costs associated with deploying NGVs, low prevalence of infrastructure relative to diesel, and residual uncertainty regarding the applicability and performance of NGVs in meeting fleet needs.

Workshops were held in eastern and western Canada to gather the views of fleet operators and other natural gas industry representatives. From the fleet operator perspective, certain prominent barriers have persisted since 2010. Most notably, these include:

- **Exposure to risk because of the higher up-front cost of NGVs and their operational requirements** – Workshop participants spoke strongly to the need for fiscal measures at the adoption stage to help reduce the higher up-front costs of NGVs relative to diesel. Concerns about lower anticipated resale value of NGVs can also extend calculation of the return on investment period.
- **Access to fuelling** – Access to public infrastructure is sparse and uneven across the country. The high cost of infrastructure installation presents a ‘chicken and egg’ situation that is common to the deployment of new fuels and technologies wherein infrastructure developers are reluctant to invest ahead of significant demand (and vehicle deployment).
- **Uncertainty that switching to natural gas fuel is a viable business decision for their operation from either a cost savings or emissions reductions perspective** – In addition to knowing about NGVs and their benefits in general terms, operators require the ability to evaluate if and when they should integrate NGVs into their operations.
- **Technology suitability and performance** – Uncertainty about how technology will work for specific enduse applications and stack up against conventionally fuelled vehicles.

- **Availability of high-horsepower engine** – In Canada, between 100,000 and 400,000 vehicles carry heavy loads over mountainous terrain. This is an existing market that is now without a suitable natural gas-fuelled +400 hp engine, requiring a multi-stakeholder initiative to seek a solution.

## Research and Development (R&D)

R&D efforts, including collaborative partnerships with all levels of government, other countries and many research institutions, continue to enable NGVs to be seen as a viable cleaner alternative to diesel vehicles. Taking a full lifecycle view, current R&D is prioritized to reducing barriers to adoption, particularly the reduction of methane emissions from multiple lifecycle stages including fuelling, engine design, after-treatment, and overall system operation. Reducing the purchase price of NGVs to be competitive with diesel vehicles is an equally high R&D priority that primarily focuses on developing a cost-effective fuel storage technology that operates at greater energy density and with minimized energy and material costs.



Hiller Truck Tech CNG-electric hybrid truck

## Updated Recommendations and Responsibilities

The following recommendations stem from the work undertaken to develop Roadmap 2.0. In many cases, they indicate the need to continue action in

similar areas and in other cases, the recommended actions are new. Either way, stakeholders will continue to need to work together on closing the gap between the potential of the technology and where it stands today in terms of deployment levels in the future.

**Table 1: Recommendations**

| De-Risk Investment  |
|---|
| 1. <b>Vehicle Premium</b> – Need for financial support to offset price premium and de-risk decision-making for end-users. (Chapter 3: State of Play)  |
| 2. <b>Vehicle Maintenance Facility Costs</b> – Provide financial support to partially offset costs to operate/build/retrofit maintenance facilities. (Chapter 3: State of Play)   |
| 3. <b>Corridor and Return-to-Base Infrastructure</b> – Continue to deploy fuelling infrastructure involving public/private partnerships to expand use of infrastructure to other modes (i.e. off-road, ports and rail) and multiple users (trucking, transit, fleets and municipalities). (Chapter 6: End-User Needs) |
| 4. <b>RNG infrastructure</b> – Enable capital investment for production, processing, blending and connecting RNG supply to existing pipeline with a goal of increasing availability of RNG for transportation use. (Chapter 4: Natural Gas Supply)  |
| 5. <b>RNG Market</b> – Engage stakeholders to raise awareness of RNG opportunities with a goal of growing the RNG market. (Chapter 4: Natural Gas Supply)   |
| 6. <b>Demonstration</b> – Create new opportunities to demonstrate the use of natural gas to raise awareness and experience with new applications. Conduct feasibility studies and assessments for specific fleets to address technical barriers. (Chapter 6: End-User Needs)  |
| Address Information Gaps and Engage   |
| 7. <b>Education and Outreach Strategy</b> – Develop a more targeted strategy to engage and educate key stakeholders on NG/RNG with practical, modern outreach tools. (Chapter 9: Education and Outreach)  |
| Grow and Sustain Markets  |
| 8. <b>Codes and Standards and Regulations</b> – Continue to develop, update and integrate codes and standards, and expand working groups' membership to address ongoing and emerging regulatory issues across jurisdictions to ensure greater implementation. (Chapter 8: Research and Development)                   |
| 9. <b>Implementation Committee</b> – Expand membership to include other jurisdictions and additional industry sectors, and evolve role of Implementation Committee (IC) to prioritize, plan and lead engagement initiatives. (Chapter 2: Policy Landscape and Drivers of Change)                                      |
| Ensure Ongoing Competitiveness and Advancements   |
| 10. <b>R&amp;D</b> – Further investment in R&D with a focus on eliminating the cost differential and maximizing NGVs operational and environmental benefits. (Chapter 8: Research and Development)  |
| 11. <b>Use of Natural Gas in Other Applications</b> – Continue to explore use of NG in other transportation applications to expand market (e.g. rail and mine haul). (Chapter 8: Research and Development)  |

These recommendations have been developed in consultation with the Implementation Committee and are supported by all members, which include representatives from federal and provincial

government departments, natural gas industry associations, natural gas companies including utilities, and transportation equipment providers.



Calgary, Alta., Fleet: Calgary Transit, Design/build: ComTech Energy

# BACKGROUND





## Chapter 1: Introduction

This chapter provides an overview of the original impetus for Roadmap 1.0 and a description of how the market for NGV in Canada's transportation sector has evolved over the last decades.

### Roadmap 1.0 – Identifying the Optimal Use

In 2010, NRCan gathered a roundtable of individuals from government, industry, academia and nongovernmental organizations to identify the optimal use of natural gas in Canada's transportation sector. These efforts produced the first Roadmap, entitled *Natural Gas Use in the Transportation Sector: Deployment Roadmap*.

As a starting point, the 2010 report identified that specific segments of the MHDV market would be well suited for the adoption of natural gas. This included a combination of tractor trailers used in long-haul trucking and return-to-base (RTB) applications.

To better integrate NGV use into Canada's fleet, Roadmap 1.0 outlined ten recommendations in the following four areas:

- De-risking investment and early adoption;
- Addressing information gaps;
- Increasing capacity to sustain markets; and,
- Ensuring ongoing competitiveness.

It further recommended the establishment of an industry and government-led implementation committee to guide and support natural gas vehicle deployment. Following the establishment of the implementation committee, three additional working groups were formed to support deployment. These included:

- Education and outreach working group to support consumer-awareness-related activities;

- A technical advisory group to support the development and harmonization of codes and standards across Canada and with the U.S.; and,
- An emerging markets working group.

Over the span of the last decade or so, these groups have come together with government support to build the NGV network of vehicles and infrastructure that exists today. The section below speaks to these achievements.

### Reaction to Roadmap 1.0 Recommendations

In 2011, the Government of Canada launched the ecoENERGY for Alternative Fuels Program. This program, with funding of \$2M, was a response to the recommendations made in Roadmap 1.0. The objectives of this program were to address the non-financial barriers to the greater deployment of medium- and heavy-duty NGVs identified in the Roadmap. The program encompassed two pillars of action:

1. Education and outreach – To deliver reliable information, education materials and outreach activities to stakeholders (e.g. end-users) to increase their knowledge, awareness and access to information on the benefits of alternative fuel option such as natural gas.
2. Codes and standards – To engage with stakeholders to update and develop codes and standards related to natural gas (both compressed–CNG and liquefied–LNG) vehicles, refuelling stations, technology, etc.; and harmonize/align codes and standards with those of the U.S.

Key results stemming from this program included the following:

Education and outreach:

- Go with Natural Gas Website – A web portal containing consistent fact-based information to guide investments in and the adoption of alternative fuels (particularly natural gas) in medium- and heavy-duty vehicles;
- Local support networks established (i.e. hubs) to provide on-the-ground resources for end-users (i.e. fleet managers) and other key stakeholders (e.g. vehicle manufacturers). In total there were 25 workshops held throughout the country, reaching over 700 attendees.

Codes and standards:

- Development of new bi-national LNG vehicle component standards;
- Updates to codes related to CNG refuelling station installation and NGV installation codes;
- Development of a national training strategy as well as education and outreach tools (e.g. fact sheets, guides) and station-permitting guides; and
- Development of a guideline for Transport Canada’s National Safety Mark (NSM) compliance.

Upon completion of the ecoENERGY for Alternative Fuels program, NRCan continued to contribute to codes and standards development.

Through the 2016 and 2017 federal budgets, the Government of Canada provided funding for the Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative (EVAFIDI).

- Phase 1 (Budget 2016) of EVAFIDI contributed to establishing a coast-to-coast charging network of over 100 new publicly accessible electric vehicle fast chargers, 7 natural gas stations, 3 hydrogen refuelling stations, and 6 real-world demonstration projects.
- Phase 2 (Budget 2017) of EVAFIDI has notional targets of 900 new electric vehicle fast chargers, 15 additional natural gas stations and 12 hydrogen refuelling stations. Phase 2 will also support technology demonstration projects and further development of codes and standards.

From 2017 to 2018, NRCan contributed to the development of seven new and draft codes and standards, one guideline and a new eLearning Training module.



**Figure 2:** Map Illustrating the NGV Public Refuelling Infrastructure that Now Exists Across the Country (41 CNG and 5 LNG stations) <https://www.nrcan.gc.ca/energy/transportation/personal/20487#/find/nearest>

## Emerging Markets

The emerging markets group, created in 2016, was the last of the three working groups established under the Natural Gas Roadmap Implementation Committee. The group is chaired by NRCan, Transport Canada and the Canadian Natural Gas Vehicle Alliance. Gas utilities and other fuel providers have also turned their attention to emerging markets for natural gas such as marine, remote power, rail and mining. These markets are complementary to the on-road market on the basis that they increase the availability of fuel, specifically LNG.

## Marine

The marine market is developing faster than almost any predictions with BC Ferries, Seaspans Ferries and the *Société des traversiers du Québec* all growing their NG ferry fleets. Canada now has the second-largest LNG ferry fleet in the world behind Norway. The total ferry fleet size is now eight and is expected to continue to grow. In 2016, Groupe Desgagnés launched a new class of asphalt carriers, its very first vessel fuelled by LNG, and has further ships on order. Larger vessels stand to offer additional opportunities in the future.

## Remote Power

Remote power for off-grid mining, industry and communities also provides a complementary demand for LNG and increases its availability for over-the-road vehicles in remote locations. There are already several customers in British Columbia and Quebec in this market.

## Rail

There are positive trends in rail transportation with major OEMs like General Electric and Caterpillar releasing natural gas products. Uptake has been faster in the U.S. and it remains to be seen if Canadian railroads will launch significant pilot programs beyond the small-scale demonstrations conducted by CN thus far.

## Mining

Lastly, natural gas mine haul trucks are emerging with Caterpillar developing an OEM-supported conversion product. A pilot project at Teck Coal in B.C. demonstrated both the viability of natural gas fuelling for these large consumers of fuel and the importance of an OEM-supported conversion product. As one of the largest markets globally for mine haul trucks, Canada is positioned to validate the extent to which GHGs can be mitigated in this high-fuel-consumption application.



Ore-hauling vehicle in service at a Canadian coal mine enters a maintenance facility equipped to service natural gas vehicles



Kenworth T680, Cummins engine ISX12N, Eaton autoshift transmission, Agility tank with 210 DGE capacity, painted for the Quebec Breast Cancer Foundation

## Provincial Programming

The following programming was put in place at the provincial level to support NGV deployment. Many of these provincial programs provided support to bridge the incremental cost of purchasing an NGV.

### British Columbia

- Natural Gas for Transportation Vehicle Incentive Program (2012-2022), enabled through the Greenhouse Gas Reduction (Clean Energy) Regulation (GRR), where FortisBC Energy Inc. reimburses **up to 70%** (in 2019) of the price differential between an NGV and a diesel-powered vehicle up to \$224M for on-road and marine market segments. Additionally, the GRR enables FortisBC to invest up to \$107.5M in station and natural gas fuelling infrastructure to enable the network to build out to support the adoption of NGVs. Funding came from utility investment costs recovered through utility rates. Payback for utility customers is through load-building benefits on natural gas distribution systems.
- British Columbia's CleanBC plan was developed as a pathway to achieve the province's legislated climate targets of reducing greenhouse gas emissions by 40% by the year 2030. Achieving this target will require heavy reliance on renewable gas for use in many sectors of the economy, including:
  - Increasing the low-carbon fuel standard to 20% by 2030 and increasing the production of renewable transportation fuels;
  - Supporting the production of 650 million litres of renewable fuels per year for the transportation sector; and
  - Making residential and industrial natural gas consumption cleaner by putting in place a minimum requirement of 15% to come from renewable gas.
- British Columbia has also committed to renewing its Bioenergy Strategy, which will explore opportunities to turn organic waste into products and energy. A key component will be expanding production of renewable natural gas from landfills, organic waste matter and eventually woody biomass.

## Quebec

- Established the Program for Improving Energy Efficiency in Road, Rail and Marine Transportation, which funded up to \$15K per truck for alternative fuels ended March 31, 2013.
- In 2017, the *Écocamionnage* program was established and provided funding for 30% of the incremental cost of vehicles and measures to support fuelling infrastructure build-out.
- In 2018, Quebec released an energy policy document that aimed to guide the province's energy transition to 2030. The document outlines the government's plans to establish a cohesive governance structure to manage the transition, promote a low-carbon economy, diversify Quebec's energy supply, and take a new approach to fossil fuel energy. It also sets out targets to be achieved by 2030 for improving energy efficiency, reducing petroleum consumption and increasing renewable energy production.

## Ontario

- In June 2016, the Ontario government released its Climate Change Action Plan. The five-year plan introduced key actions Ontario would take towards meeting its emissions reductions targets. It also defines how revenues from the province's cap-and-trade program would be spent.
- The plan included up to \$170M in incentives for adopting electric and natural gas commercial vehicles, aerodynamic devices, anti-idling devices, and electric trailer refrigeration.
- Another \$75-\$100M would be used to build a province-wide natural gas fuelling network, which would be developed with input from the Ontario Trucking Association, Union Gas, Enbridge Gas and others.
- This programming was supported from revenue from the cap-and-trade program and was cancelled in 2018 when the cap-and-trade system was cancelled. During the five-month life of the program, 24 new CNG vehicles were funded.

- In November 2018, the Ontario government released its Environmental Plan, which supports the use of natural gas in transportation and increases development of RNG in Ontario. Ontario will maintain the existing tax exemption on natural gas as a transportation fuel and aims to improve rules and remove regulatory barriers that block private investors from deploying low-carbon refuelling infrastructure.

## Roadmap 2.0 – Updating the Roadmap

Initially, the economic benefits of natural gas were the salient feature driving market development for the use of natural gas use in transportation; however, growing concern for accelerating the transition to lower-carbon transportation is further expanding interest in natural gas as a readily available lower-carbon fuel. Overall, the price of natural gas has remained relatively stable since 2010, while the supply in Canada continues to expand.

The conditions that led to MHDV fleets being identified as well-positioned to adopt natural gas remain. However, much has changed in the sector within which they operate, ranging from fluctuating diesel prices, emerging technologies, increased commitment to curb climate change, and deployment of new natural gas infrastructure. Recognizing that experience-to-date with NGV deployment has been encouraging, there is also an opportunity to take a step back, analyze and reassess what is working, what could be done differently and what more is needed. This assessment has given rise to NG Roadmap 2.0.

In keeping with the first process used to develop Roadmap 1.0, working groups were tasked with assessing developments in key areas including business case analysis, R&D, and the identification of barriers and opportunities. Technical experts conducted research to inform recommendations for accelerating the uptake of natural gas and to better articulate the environmental benefits. Results of this work are contained in the following chapters.

## Continued Commitment to Support Deployment

One of the foundational and ongoing drivers since Roadmap 1.0 is the level of collaboration undertaken by government and industry to identify and further explore natural gas opportunities in Canada, as embodied by the Implementation Committee. This collaboration has encouraged innovations to be disseminated across sectors from energy to transportation, across modes that include marine and mining, and has attracted joint investment in infrastructure and established new partnership models. For example, natural gas refuelling stations established initially for LDVs have been servicing HDVs. The distribution infrastructure created for natural gas electricity is also serving HDV refuelling stations.

In developing Roadmap 2.0., industry has demonstrated continued commitment to the objectives of Roadmap 1.0 to lead and support investments and policies that would foster greater use of natural gas in transportation.

While the expectation is for a strong focus to remain with on-road vehicles, many of the principles, challenges and solutions outlined in Roadmap 2.0 will also be applicable in supporting new applications in the off-road, rail and marine sectors. Representatives from industry and government which collaborated on Roadmap 1.0 will continue to work together to support this next round of recommendations.



Xebec HRB-type high pressure natural gas dryer for midstream application



## Chapter 2: Policy Landscape and Drivers of Change

This chapter highlights the current context of operating NGVs in Canada, from policies that foster adoption and deployment to investments in innovation and the emerging use of renewable natural gas (RNG), which can reduce lifecycle emissions even further. The landscape has changed considerably and favourably since 2010.

### Broader Energy Story

Shortly after the PCF was released, NRCan, through Generation Energy, initiated a national dialogue on Canada's energy future. The Generation Energy Council report provided a framework with four pathways to get to a low-carbon future: (1) reducing energy consumption; (2) switching to cleaner power; (3) using more renewable fuels; and (4) producing cleaner oil and gas.

### Natural Gas Opportunity – The Big Picture

Natural gas has been used across the Canadian economy for well over 100 years.

In addition to Canada's abundant supply, the following benefits, identified in Roadmap 1.0, remain drivers for NGV adoption for MHDV applications:

- Diversification of energy sources serving the transportation sector, while strengthening markets for Canada's established energy resources and industry;
- Potential for significant operational cost savings (on a per kilometre basis) due to stable low-commodity pricing of natural gas;
- Increased Canadian competitiveness in the transportation sector, leading to overall economic growth and jobs; and,
- Reduction of GHG/carbon emissions compared to those from incumbent petroleum fuel.

Going forward, additional factors are at play:

- Canadian leadership on climate change and emerging regulations in this regard;
- Clean technology investments; and,
- Integration of RNG into energy systems and fuel distribution.

The factors and benefits match well. The following sections expand on how the benefits NGV has to offer, with key policy drivers, investments in innovation and the integration of RNG into the supply chain.

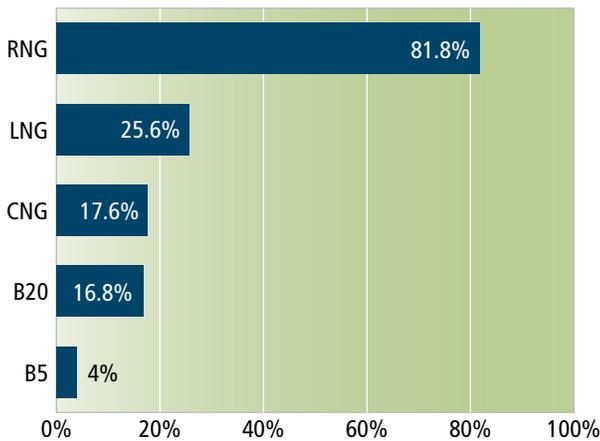
### Environmental Performance of NGVs

The use of an NGV compared to a diesel equivalent is estimated to reduce GHG emissions by up to 25% depending on the vehicle and fuelling system being used. In addition to GHG reductions, NG use can also reduce black carbon emissions. Approximately 75% of the particulates emitted by heavy-duty diesel vehicles and engines are black carbon. Like methane, black carbon has a global warming potential more powerful than that of carbon dioxide.

It is fair to say that the GHG reduction potential of NGVs continues to be subject to ongoing discussions. While some studies show benefits of up to 25%, this aspect of NGV system operation could benefit from the real-world testing of the various vehicle fuelling system configurations in which it is used. Increased emissions reductions could be

possible as technologies evolve and different aspects of the vehicle-fuel system improve in terms of their efficiency and overall performance.

Figure 3 provides a comparison of the different options available for reducing emissions across MHDV applications today when compared to diesel.



**Figure 3:** GHGenius Version 5.0d – Percentage Reductions in GHG Emissions by Using Biodiesel (5% and 20%), CNG LNG, and RNG in Comparison to Using Diesel

While engine suppliers continue to reduce their tailpipe emissions to comply with tightening emissions standards, the fuel economy of spark-ignited natural gas engines underperforms compared to the equivalent diesel engine by about 10%. This serves to reduce the economic and environmental case for NGVs and is a priority area for R&D.

## The Policy Landscape – Canadian Leadership on Climate Change

In late 2016, the Government of Canada ratified the Paris Climate Accord, signalling its commitment to reduce GHG emissions by 30% from 2005 levels by 2030. Since then, the federal government has worked with the provinces and territories to develop and implement the PCF, which outlines measures that support Canada’s efforts to reduce GHGs while growing the economy. These include an approach to pricing carbon pollution and measures to achieve reductions across all sectors.

Key measures on transportation in the PCF include: (1) setting and updating vehicle emissions standards and improving the efficiency of vehicles and transportation systems; (2) expanding the number of zero-emission vehicles on Canadian roads; (3) supporting the shift to lower-emitting types of transportation, including through investments in infrastructure; and (4) using cleaner fuels.

In 2018, Canada assumed presidency of the G7 and reiterated Canadian leadership on climate change by identifying ‘climate change, clean energy, and oceans’ as one of five key themes to set the agenda for the year. Canada’s commitment to fighting climate change was reiterated by Minister McKenna in late 2018 when she attended COP24 in Poland. “By bringing together not only governments, but also stakeholders, organizations, businesses, Indigenous partners, and civil society, COP24 demonstrated the world’s shared commitment to fight climate change. As we move toward a more sustainable economy in our common fight against climate change, we can ensure good jobs and healthy, resilient communities for our people.”

The following sections provide an overview of key commitments in the PCF which could influence NGV uptake.

### 1) Carbon Pricing – Federal Approach

The PCF includes a pan-Canadian approach to pricing carbon pollution and measures to achieve reductions across all sectors of the economy. Pricing carbon pollution is widely recognized as an efficient way to reduce GHG emissions and help achieve Canada’s objectives to protect the environment, stimulate investments in low-carbon innovation and create a sustainable clean-growth economy. Carbon pricing sends an important signal to markets and provides incentives to reduce energy use through conservation and efficiency measures, while also serving to drive fuel switching and technology advances. Applying carbon pricing to a broad set of emission sources across Canada, with increases in stringency over time, will help to reduce GHG emissions at the lowest cost to businesses and consumers, while supporting clean growth.

All elements of the backstop will apply in a jurisdiction that does not have a carbon pricing system in place. The backstop will also supplement (or “top-up”) systems that do not fully meet the benchmark. For example, the backstop could expand the sources covered by provincial carbon pollution pricing or it could increase the stringency of the provincial carbon price.

The federal option will be composed of two elements:

**i. A levy on fossil fuels** that will increase annually (**carbon tax**) – goes into effect on April 1, 2019.

Fossil fuels that will be subject to the levy include liquid fuels (e.g. gasoline, diesel fuel and aviation fuel), gaseous fuels (e.g. natural gas) and solid fuels (e.g. coal and coke).

In most cases, the levy will be applied early in the supply chain of each fuel used in a backstop jurisdiction and will be payable by the producer or distributor. The final user of a fuel will not generally have any special rights or obligations in respect of the levy, as the user will purchase levy-paid fuel in most cases.

Fuel producers and certain distributors will be able to acquire and hold fuel without the levy being payable until the fuel is subsequently used by the producer or distributor, or, as discussed later, delivered to a final retailer or end-user.

Table 2 below contains the carbon levy that will be applied to gasoline, diesel and natural gas as examples.

The difference between the carbon levy on diesel and natural gas will enhance the case for NGVs.

**ii. Measures to price pollution from industry.**

This sets limits on pollution and will ensure that the more an industrial facility pollutes above its limit, the more it will pay. The more a facility reduces its emissions below the limit, the more it can earn by selling credits to less efficient competitors.

**The output-based pricing system (OBPS)** goes into effect on January 1, 2019 and will be published in Gazette II in Spring 2019.

## 2) Medium- and Heavy-Duty Vehicle Regulations

Canada’s heavy-duty vehicle emissions regulations reduce greenhouse gases from on-road heavy-duty vehicles, engines, and trailers. The regulations apply to both the manufacture and importation of heavy-duty vehicles, engines, and trailers, in Canada. The regulations also improve air quality in Canada and reduce health issues related to air pollution, such as asthma and cardiovascular diseases.

The regulations are maintaining a fuel-neutral approach to ensure that there is no direct regulatory incentive or obstacle for a given fuel, including biofuels and renewable natural gas.

Phase 1 of the regulations applies to model year 2014 through 2020 while Phase 2 of the regulations applies to model year 2021 through 2027.

Canada also introduced regulations to set air pollutant emission standards for new passenger cars, light-duty trucks, motorcycles, heavy-duty vehicles (such as highway tractors, buses and dump trucks) and their engines beginning with the 2004 model year. These On-Road Vehicle and Engine Emission Regulations align emission standards with the U.S. federal standards.

**Table 2: Carbon Levy**

|                                      | 2018<br>(\$10/tonne) | 2019<br>(\$10/tonne) | 2020<br>(\$10/tonne) | 2021<br>(\$10/tonne) | 2022<br>(\$10/tonne) |
|--------------------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| <b>Gasoline (c/L)</b>                | 2.33                 | 4.65                 | 6.98                 | 9.30                 | 11.63                |
| <b>Diesel (c/L)</b>                  | 2.74                 | 5.48                 | 8.21                 | 10.95                | 13.69                |
| <b>Natural gas (c/m<sup>3</sup>)</b> | 1.96                 | 3.91                 | 5.87                 | 7.83                 | 9.79                 |

### 3) Clean Fuel Standard

To further reduce emissions across the transportation, industry and buildings sectors, the Government of Canada is developing a Clean Fuel Standard to reduce Canada's GHG emissions through the increased use of lower-carbon fuels, energy sources and technologies. The objective of the Clean Fuel Standard is to achieve 30 million tonnes of annual reductions in GHG emissions by 2030. The Clean Fuel Standard will complement carbon pollution pricing by reducing GHG emissions throughout the lifecycle of fuels and by driving investments in cleaner fuels and in clean technology in Canada.

The Clean Fuel Standard regulations will set separate requirements for liquid, gaseous and solid fossil fuels. The regulations for the liquid stream will be developed first, with the draft regulations planned for publication in *Canada Gazette*, Part I in spring/summer 2019 and final regulations in 2020.

The Clean Fuel Standard will allow some end-use fuel switching to generate credits. End-use fuel switching occurs when an end-user of fuel changes or retrofits its combustion devices (e.g. an engine) to be powered by another fuel or energy source. End-use fuel switching does not reduce the carbon intensity of the fossil fuel. Instead, it reduces greenhouse gas emissions by displacing the fossil fuel with a fuel or energy with lower carbon intensity.

In the liquid stream, end-use fuel switching from a higher carbon intensity fossil fuel used for

transportation to the following lower carbon intensive fuels will be eligible for credit generation: natural gas, propane, electricity and hydrogen.

### 4) Methane Regulations for the Upstream Oil and Gas Sector

Natural gas is composed almost entirely of methane ( $\text{CH}_4$ ), a colourless, odourless and flammable gas. Methane is considered toxic under the *Canadian Environmental Protection Act, 1999 (CEPA)*. As a greenhouse gas (GHG), it has a global warming potential more than 70 times greater than carbon dioxide ( $\text{CO}_2$ ) over a 20-year period.

When oil and gas are extracted and processed, natural gas can leak accidentally or be released intentionally into the environment. These emissions contribute significantly to global warming and climate change, and also cause smog and other negative impacts on air quality.

Oil and gas facilities are the largest industrial emitters of methane in Canada. They release 44% of total methane emissions. Upstream activities such as exploration, drilling, production and field processing contribute close to 90% of methane emissions and account for 26% of Canada's total GHG emissions.

There are many cost-effective opportunities such as gas capture, clean combustion and fixing leaks that can help to reduce this loss and promote sound industry practices.

The federal regulations that apply to methane in the upstream oil and gas sector aim to control methane emissions and also reduce the amount of volatile organic compounds (VOCs) released into the air. VOCs are found with methane and are known to have adverse health effects and contribute to smog formation.

These regulations apply generally to facilities that handle significant volumes of gas. They cover key fugitive and venting emission sources in the upstream oil and gas sector and will be implemented between January 1, 2020 and January 1, 2023. These regulations will reduce lifecycle emissions from natural gas production and therefore the lifecycle performance of natural gas when used as a transportation fuel.



Vedder B-Train at the British Columbia Legislature in Victoria, B.C., Peterbilt 386 with a high pressure, direct injection, LNG-modified, Cummins engine

## Path Forward for Further Identifying Opportunities

Through the Fall Economic Statement of 2018, the Government of Canada further announced it would appoint an Advisory Council on Climate Action to identify opportunities for the Government of Canada to build on the commitments in the transportation and buildings sectors in the PCF, including existing federal government actions and those of provinces and territories, specifically:

- Actions that can help achieve Canada's commitments under the Paris Agreement;
- Actions that can help Canada move towards a low-carbon economy by mid-century; and
- Actions that can help advance clean growth in Canada, including opportunities for Canadian businesses and workers, and sustainable finance.

Provincially, Quebec, Ontario and British Columbia have all announced their climate change plans, which include actions to support carbon reductions across their respective transportation sectors. All three plans mention increased production of renewables, such as RNG, as a means to achieving GHG emissions reductions. Provincial plans will further be reinforced by strong policies, such as energy efficiency and fuels-related regulations at the federal level.

## Clean Technology Investments

The pace of small- and large-scale investments in clean technology is accelerating. Over the last ten years, environmental and clean technology activities contributed approximately 3% per year to the Canadian gross domestic product, increasing to 3.1% or \$59.3B of GDP in 2016. Both private and public investment in clean technology is increasing substantially, with Canada ranked as fourth overall in the Global Cleantech Index in 2017, surpassing the U.S. and leading the G20. The federal government committed \$2.3B in 2017 to support the development of the clean technology sector in Canada. Chapter X provides greater detail on NGV-specific investments.

Internationally, Canada is a member of the Clean Energy Ministerial, a high-level global forum to promote policies and programs that advance clean energy technology, to share lessons learned and best practices, and to encourage the transition to a global clean energy economy. Canada is hosting the 10th annual Clean Energy Ministerial, bringing together Energy Ministers from 25 member countries and the European Commission, which account for about 90% of global clean energy investments and 75% of global GHGs.

## RNG as an Emerging Fuel

One of the most important drivers of market interest in natural gas applications since Roadmap 1.0 is the growing interest in bio-based natural gas and RNG. Canada's natural gas and biogas industries have taken a lead in exploring and outlining opportunities for RNG in Canada. The natural gas industry has outlined aspirational targets to blend 5 and 10% RNG content into their systems over the next two decades. While RNG was available in 2010, opportunities to use this in a transportation fuel were not as evident. There are now strong RNG markets in the U.S. coupled with new technologies and policies here in Canada. Roadmap 2.0 explores these opportunities in greater detail in Chapter 4.

Moving RNG applications to net-zero emissions will be a critical component to the long-term development of the RNG market. RNG is a significant addition to the emissions reductions toolbox.

## Competitiveness

Over time, it is expected that the roll-out of the regulations discussed in this chapter will help to improve the competitiveness of NGV as a low-carbon option in transportation. Ongoing investments in clean technology to service this sector and the transition from fossil-based natural gas to more renewable forms will make these benefits even more pronounced. Taken together, these factors will increase the competitive advantage of natural gas as a source of energy for moving goods and people across and around the country.

## Summary

The following table provides an overview of these major drivers and opportunities.

**Table 3: Driver, Opportunities and Benefits**

| Drivers  | Opportunities   | Benefits   |
|--|---|--|
| Abundance of domestic natural gas reserves                               | Cost-effective widespread adoption of natural gas; energy security through increased fuel choice  |       |
| Domestic and international climate change commitments                    | Coordinated transition to low-carbon transportation; increased use of RNG; public/private partnerships  |    |
| Emerging carbon credit markets   | Improved business case for switching to natural gas/RNG   |      |
| Competitive costing with other technologies                              | Shared infrastructure and business models; price of natural gas remains low   |       |
| Competitiveness in technology development and commercialization          | Targeted and collaborative Canadian technology investments; collaborative high-hp engine development; transfer of technology to broader markets |      |
| Diverse energy use needs across expansive geography                      | Shared infrastructure models; targeted regional development   |     |
| Job growth and transitioning, i.e. replacement of 'old-economy' jobs     | Natural gas infrastructure build-out; 'New-economy' workforce in manufacturing, installation and operation                                      |     |
| Urgency for practical, implementable low-carbon transportation solutions | Awareness raising/demonstration of natural gas as a technology that can be implemented today with long-lasting benefits                         |      |

Legend:  = savings;  = energy efficiency;  = greenhouse gas reductions;  = job creation;  = productivity improvements;  = research and development

## Conclusion

All levels of government in Canada and around the world have signalled a strong commitment to combatting climate change. Carbon pricing and other complementary measures such as more stringent regulations to reduce the carbon intensity of fuels and vehicles, and clean technology deployment, are at the forefront of policy development. Significant work and collaboration should continue to ensure that these multiple natural gas benefits of lower energy costs, energy

efficiency, job growth, Canadian-led R&D and the competitiveness of Canadian clean transportation technologies are widespread.

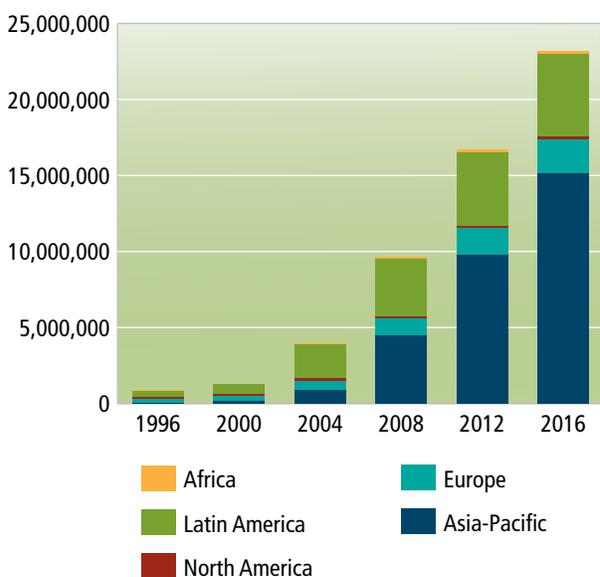
The Implementation Committee has provided an ongoing foundation for collaborative work across industry and government to implement the first Roadmap's recommendations. The following chapters outline what has worked to date and what more can be done to advance opportunities that integrate natural gas as a fuel for Canada's transportation system.

## Chapter 3: State of Play

This chapter provides a global and national overview of the current state of natural gas use in the transportation sector since 2010. Some of the external and internal factors impacting adoption are discussed along with some of the factors constraining deployment in Canada.

### Global Adoption of Natural Gas as a Transportation Fuel

Figure 4 shows the global NGV market has grown from under 10 million NGVs in 2008 to approximately 23 million in 2016, with the vast majority being LDVs. The prevalence of NGVs in the light-duty sector is partly due to the higher number of passenger vehicles relative to commercial vehicles worldwide. The higher rate of adoption of NGVs in Africa, Asia Pacific and Europe relative to the Americas is due to more favourable policy and regulatory frameworks and the abundance of a low-cost supply of natural gas in surrounding countries.



**Figure 4:** Total Global Numbers of Natural Gas Vehicles 1996-2016



U.S. Gain Fueling Station in Lanoraie, Que., for Express Mondor, constructed by ComTech Energy

As a global average, natural gas today represents a 3.2% share of the energy used to power transportation, which is a significant development. However, in North America, this share is much lower at 0.5% of total transportation energy use.

Figure 5 illustrates how U.S. sales of MHDVs increased to approximately 8,000 units per year between 2010 and 2016. Key points to note here include:

- Much of this uptake can be directly attributed to major municipalities taking advantage of grant funding to support the adoption of natural gas-fuelled transit buses; and
- Several high-profile fleets in the heavy-duty truck and refuse truck segments (e.g. UPS, FedEx, Waste Management) switched to NGVs.

NGVs now represent approximately 3% of all trucks and buses sold in the U.S. Class 7-8 HDV market; however, certain municipalities have converted a much higher proportion of their fleets and transit buses to natural gas.



**Figure 5:** Sales of NGVs in North America 2010-2016

### Canadian Context

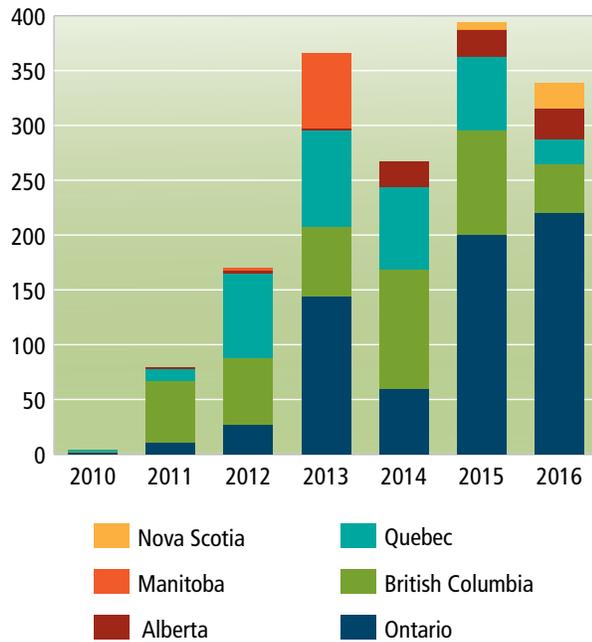
In Canada, MHDV sales increased markedly, with an incremental 1,600 natural gas-fuelled trucks and buses on the road by the end of 2016 compared with 2010. Certain municipalities have converted large portions of their transit buses, including Surrey, Whistler, Calgary and Hamilton.

The breakdown of MHDV sales by province is shown in Figure 6, which indicates strong initial growth in the heavy-duty LNG truck market from 2010 to 2013. Refuelling infrastructure development matched this growth with a total of seven new natural gas stations established in British Columbia, Alberta, Ontario, and Quebec. Uptake of LNG for on-road vehicles has not grown since 2014. However, available CNG options have increased to meet the needs of many regional and long-haul fleets. There is a preference in Canada for high-horsepower engines in long-haul and specialty trucking, and having available high-horsepower natural gas options would increase interest in more LNG-fuelled vehicles.

As a result, more recent progress in deployment has been almost exclusively based on CNG vehicles. Sales remain at approximately 300 vehicles per year, representing a market penetration of less than 1% of all Class 7-8 trucks and buses sold in Canada.

- Refuse and transit segments accounted for almost all the growth in British Columbia, Ontario, Alberta, Manitoba, and Nova Scotia.
- Overall, sales numbers for North America indicate that up to half of the new refuse vehicles sold during the last five years were equipped with natural gas engines.
- CNG refuelling infrastructure installed to support these new fleets is operated using different business models, including the 'do-it-yourself', 'the utility package,' and through a third-party service provider with most operating on a private basis.
- Two refuse fleets have opened their refuelling stations to third parties, with one partnering in the development of a new public refuelling station.

Overall, the total number of NGVs has remained relatively constant at approximately 12,500 in 2016 compared to 12,000 reported in 2010. This is due to a decline in LDVs, which has had the added downside that only 41 public CNG refuelling stations remain operational today, down from 72 in 2010.



**Figure 6:** Heavy-Duty NGV Registration by Province

## Market Forces and Factors: 2010-2017

From 2010 to the present, the impetus for achieving GHG reductions in Canada has increased. Specific factors that have influenced adoption are discussed below. When end-users are contemplating a different approach to their operations, many factors need to be taken into account. These range from more macro-level impacts such as fuel costs and exchange rates to more micro-level impacts such as the availability of public refuelling, engine options, maintenance facility upgrade and change management costs, and vehicle purchase incentives.

## Macro-level Forces and Factors

### Economic Factors

#### i) Expectations of where diesel prices could land

- Higher diesel prices compared to the price of natural gas favour the business case for NGVs, whereas lower prices make the decision a less compelling one.
- Fleets base their business decisions not only on prices today, but on the expectation of where prices might go in the future.
- Over the 2010-2018 period, the Canada average price for diesel fluctuated by over \$0.50/litre as indicated in Figure 7. These fluctuating prices have made investments in NGVs difficult for some fleets considering a fuel switch because the pay back period on the investment becomes unclear.
- On the flip side, natural gas prices (as indicated below) have remained fairly stable, which has helped the business case, but the overall impact has meant a longer payback period than may have been expected in some cases.



**Figure 7:** Gasoline and Diesel Prices

The price of natural gas as a commodity has remained close to historic lows between 2010 and the present day.

#### ii) Natural gas commodity prices

- The price of natural gas as a commodity has remained close to historic lows between 2010 and the present day. This is helpful because perceptions of payback potential are also influenced by commodity price expectations and projections—a psychology that can intensify when commodity and retail fuel prices rise rapidly.
- Natural gas is not subject to the excise tax on fuels (10 cents/litre on gasoline and 4 cents/litre on diesel), which continues to exert a positive impact on the price of natural gas as a fuel. The combination of exemptions from the excise tax and the provincial fuel taxes maintains an important price advantage for NGVs.
- In most provinces, the cost of delivered natural gas is subject to provincial energy regulators, which typically adjust prices on a quarterly basis. Fleets that have opted to use in-house refuelling, as opposed to public access refuelling, likely only experienced fuel price adjustments as a result of this process. Refer to Chapter 5 for more details on natural gas markets.

#### iii) Treatment under Carbon Pricing and the Clean Fuel Standard

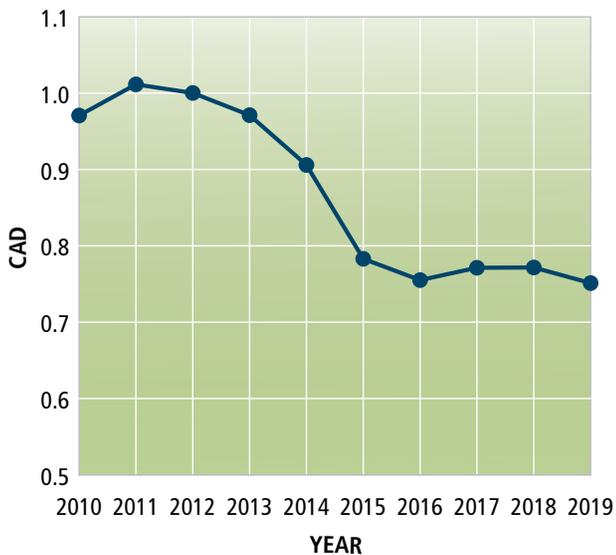
- A lower carbon price and the ability for credit generation under the Clean Fuel Standard will also help the business case.
- Refer to Chapter 2 for more details on these policies.



Waste Management’s Stony Creek, Ont., facility, constructed by ComTech Energy

#### iv) Lower value of the Canadian dollar

- While it can be argued that a lower value for the Canadian dollar is helpful for the manufacturing sector in Canada, it makes the purchasing power of goods sold in \$U.S., like NGVs, more expensive for Canadian firms.
- Many supply chain components are manufactured in Canada (e.g. gas clean up systems, fuel dispensers and cylinders), yet the available OEM engines most commonly used are sourced from factories in the U.S.
- Given the lower purchasing power of the Canadian dollar over the U.S., it means that engine purchases can be up to 30% higher for Canadian fleets.



**Figure 8:** Average Yearly CAD/USD Exchange Rates

#### v) Procurement strategies

- Some levels of government (e.g. municipalities) include GHG benefits within their procurement criteria when purchasing refuse and other service trucks.
- This has helped with the deployment of NGVs, especially when it comes to the refuse market.
- It would be helpful to ensure that officials and company representatives are well informed of the benefits that NGVs can provide in terms of overall environmental benefits (e.g. GHG and air quality), especially as the transition to a lower carbon is underway.

#### vi) Competition from other technologies

- EVs and hydrogen-powered fuel cell technologies are also emerging and are closer to being commercialized than they were back in 2010. This situation adds complexity to fleet owners’ purchasing decisions. The challenge for fleet owners is in determining which options and practices are best suited for their operations.
- There are several competing technologies on the horizon for NGVs in the lower carbon space.
- Environmental regulations, such as the Heavy-Duty Vehicle Regulations, are driving innovation in the incumbent technology (diesel engine), rendering these vehicles more efficient and harder to compete against.
- Retrofit technologies, such as aerodynamic devices, and operational practices (e.g. driving training) can also help to reduce the fuel consumption of both diesel and natural gas technologies.

## Micro-level Forces and Factors

Forces and factors identified to be ‘internal’ in the increased deployment of NGVs across the transportation sector in Canada include the factors below. In addition to these, R&D, codes and standards and education and outreach are treated in Chapters 8 and 9, respectively.

### Market Transformation Measures

#### i) Availability of incentives for vehicle and infrastructure purchases

- The cost differential of \$35,000 to \$75,000 relative to the diesel alternative. The premium to purchase an NGV was identified as a significant barrier to adoption across all market segments.
- British Columbia, Ontario and Quebec have had incentives in place that partially offset the incremental cost of NGVs to encourage adoption and growth in heavy-duty natural gas truck fleets in these provinces. (Further information on these incentives can be found in Chapter 2.)
- Access to refuelling infrastructure is equally important for potential adopters. However, high refuelling infrastructure installation costs remain a significant barrier to deployment. These infrastructure investments can be upwards of \$2M for a commercial station.

#### ii) Engine availability

- A combination of engine and vehicle energy efficiency improvements and emissions reductions innovations contributed to an increase in NGV adoption in this sector, particularly in the case of transit, school buses and marine applications.
- However, the Canadian heavy-haul trucking market is currently underserved.
- The largest engine remaining is Cummins Westport’s 11.9 ISX12N spark-ignited engine, which is limited to 36,300 kg (80,000 lb) gross vehicle weight. This engine is insufficient for hauling some heavy freight and inadequate for certain regional markets with significant mountainous terrain (Canadian Rocky Mountain region).

- An attempt by aftermarket dual fuel conversion kit manufacturers to fill the gap has yet to obtain any support from OEMs. Without OEM support or emissions certifications, aftermarket dual fuel kits will face considerable challenges in demonstrating the emissions performance necessary to generate emission credits or to access incentive funding.

#### iii) Maintenance facility change management

- In addition to purchasing the vehicle, facilities to maintain them need to either be built or converted from diesel operation and personnel need to be trained and certified to work on natural gas engines.
- This was not identified as a barrier in Roadmap 1.0 but was highlighted as feedback has been obtained from fleets undertaking this transition.

#### iv) Fuel storage

- The high cost of fuel storage systems represents the largest component of the incremental cost of NGVs.
- Advances in both LNG and CNG storage solutions have significantly reduced this cost.
- CNG storage systems are now 40% lighter, 30% cheaper, and provide 40% more range compared to the 2010 models.
- In the same timeframe, the price of LNG tank systems was halved, and innovations like the Westport ICE PACK LNG tank system substantially improved the range and performance of LNG trucks.
- Further cost reductions are needed to improve the value proposition and encourage growth in adoption.



FortisBC-Ledcor LNG tractor on display at BC Place in Vancouver, B.C.

## Conclusion

Various factors have contributed to the increased deployment of natural gas across the MHDV transportation sector in Canada. However, some economy-wide impacts have resulted in a somewhat dampened uptake. There were factors at the more micro-level which had an impact as well.

This analysis can be summarized by the identification of the following target recommendations to address the barriers identified:

- Reducing the vehicle premium as a significant barrier to adoption across all market segments.
- Reducing the added cost of building, converting and upgrading NGV maintenance facilities as well as costs to train and certify maintenance personnel, which have emerged as additional barriers to adoption for some fleets.

- Demonstrating and better articulating the environmental and economic benefits of NGVs to fleet owners.
- Continued investments in refuelling infrastructure.
- Continued and accelerated collaboration of R&D efforts that support ongoing improvements in environmental performance.
- Ensuring product choice and competition among OEMs to grow the market.
- Exploring market synergies with off-road vehicles and applications from other modes.

These targeted efforts need to be supported by accurate and up-to-date information that captures innovations, cost savings and environmental benefits. All stakeholders need to work together to create a solid foundation to support the market expansion of NGV use in Canada.



## Chapter 4: Natural Gas Supply

Natural gas is an energy solution that can help Canada meet its economic and environmental goals and commitments. To do so, natural gas must be accessed and ultimately made available to end-users through a robust market system. This chapter provides an overview of natural gas market fundamentals, including outlooks on supply, pricing, taxation and environmental implications. The initial focus is on existing sources of natural gas, leading to a discussion on the use of RNG.

### Natural Gas Supply Outlook

Canada's natural gas production is predominantly from the Western Canadian Sedimentary Basin in British Columbia, Alberta, and Saskatchewan, although other gas is produced from offshore Nova Scotia and smaller amounts are produced in Ontario, New Brunswick and the territories. Most notably, Roadmap 1.0 revealed a promising picture of a long-term, abundant supply of natural gas from now-accessible shale deposits. Since 2010, commercial development of these deposits continues to expand, mainly in the Horn River Basin and Montney formation in northeastern British Columbia.

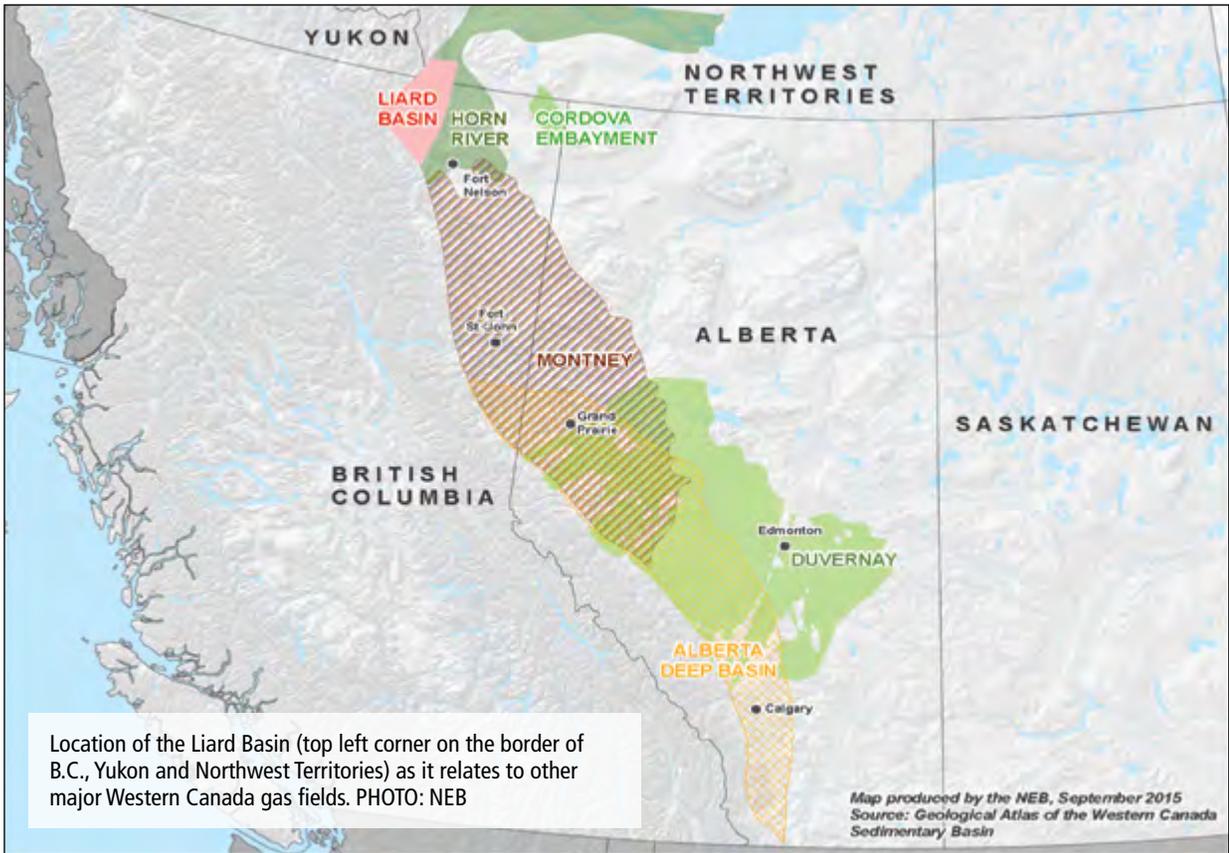
Figure 9 shows some of the shale gas deposits that are spread across the country. Each area has unique geological and geographical characteristics that affect extraction costs. These costs are increasingly reduced through incremental improvements in drilling techniques, bringing additional fields into a feasible economic range where the cost of extraction will pay off. There is a large supply of natural gas available in Canada and production will remain competitive, so long as natural gas prices remain relatively low.

Over the years, Canada's natural gas market has become heavily integrated with the U.S., largely due to the location of supply basins, demand centres, the availability of transportation infrastructure, and

existing Canada–U.S. trade agreements. Figure 10 provides an overview of some of the largest natural gas pipelines that transport western Canadian production to markets in eastern and western Canada and interconnect with U.S. pipeline systems to transport natural gas to markets in the U.S. Northwest, Midwest and Northeast.



Jordair – Énergir (formerly Gas Metro) NG compressor and refueling facility in Québec, Que.



**Figure 9:** Shale Deposits in Canada



**Figure 10:** Natural Gas Pipelines Across Canada

## Natural Gas Price Outlook

Global natural gas prices increased slightly in 2018 due to the rising cost of crude oil and stronger-than-expected demand for LNG, but remain below the 10-year average. Across the major global natural gas hubs, the U.S. remained the lowest, with prices half those in the European Union and more than 60% less than in Asia.

The rate at which natural gas is developed depends on the extraction technology used, the cost and the anticipated market price for natural gas. Higher market prices encourage more natural gas development. If prices rise too high, this dampens the demand from industrial and commercial gas users.

The marketed price of natural gas is the sum of the unregulated producer price, regulated pipeline tariffs, certain taxes (in Canada, either Goods and Services Tax/Harmonized Sales Tax or Quebec Sales Tax, depending on the province), and local distribution charges. For transportation users, the final price may include liquefaction and/or compression costs, plus retail margin if infrastructure is not owned by the end-user. Depending on the availability of services, the end-user may pay a price for natural gas that includes services such as rental of compression and dispensing equipment, or amortized incremental cost of vehicles. Smaller fleets may purchase natural gas at a cardlock facility shared by other users, while larger fleets may negotiate a unique contract price. Alternative business models continue to take shape with collaboration between producers, brokers and marketers to ensure that pricing of natural gas fuel can be made attractive for transportation end-users.

## Renewable Natural Gas

### Why RNG?

Interest in renewable natural and biogas is increasing for many reasons, including:

- Renewable gases can be a more affordable energy solution than other renewables.
- Renewable gases can be blended into the conventional gas delivery system supply, helping to maintain customer service, reliability and choice in energy delivery.



CNG collection trucks at the Gaudreau Environnement Inc. fleet station in Québec, Que.

- Renewable gas blending with conventional natural gas can be used in many sectors across the economy, including buildings, industry and transportation.

### What is RNG? How is it Made?

It is estimated that Canada could have the potential to eventually produce 1,415 BCF of RNG<sup>2</sup>, representing over half of Canada's total current annual natural gas demand. RNG is typically derived through two processes that include the following.

#### 1) Conversion of Biomass

There are two ways of chemically producing an RNG supply – anaerobic digestion and gasification.

##### *i. Anaerobic digestion (microbial process)*

Anaerobic digestion is a natural process of decomposition of organic materials by microbes in the absence of oxygen, which produces a biogas. Anaerobic digestion occurs in landfills and sewage treatment, and in industrial processes to convert manures, agri-food residues, industrial by-products and sorted municipal wastes to biogas. The resulting biogas contains a much lower methane concentration than conventional natural gas and can be used on-site with minor processing for its heating value or to run a generator to produce electricity. However, upgrading technologies are available that can produce a clean, high-energy RNG suitable for direct injection into existing natural gas pipeline infrastructure and able to be mixed with conventional natural gas.

---

2 2018 Canadian Gas Association (CGA)



UPS delivery and Class 8 CNG trucks fueled with CNG from FortisBC Energy Inc. on display in Vancouver, B.C.

#### ii. Gasification (thermal process)

Biomass gasification is a high temperature (>500 °C) process in which organic material is converted into syngas in the presence of oxygen and/or steam. The syngas can be converted into RNG through a process called methanation and then be introduced into the natural gas pipeline infrastructure and mixed with conventional natural gas.

Currently, 100% of Canada's RNG is produced through anaerobic digestion. The majority of RNG is generated at dedicated anaerobic digestion facilities, with a small percentage contributed from landfill gas projects

#### 2) Biogas-Derived RNG

Very often, raw biogas (methane) produced from municipal waste sites and other waste treatment processes escapes or is vented to the atmosphere as fugitive emissions, or is flared off. A more sustainable use of this energy resource is to capture and blend it into existing natural gas streams. This reduces or eliminates methane emissions from waste facilities, yielding a carbon-neutral outcome.

Biogas contains compounds that pose potential hazards to health, pipeline systems and the environment, and must be treated to reach pipeline-quality before the RNG can be blended into the natural gas delivery stream. In the absence of an existing provincial standard or specification, this conditioning is done in accordance with the Canadian Gas Association (CGA) "Guideline for the Introduction of Biomethane into Existing Natural Gas Distribution & Transmission Systems"<sup>3</sup>.

#### Bringing RNG to market

There are two basic methods to bring RNG to end-users: 1) blend RNG into natural gas streams feeding the natural gas delivery grid system; or 2) use it in a closed-loop system specific to one site or situation.

<sup>3</sup> 2012 CGA Guideline for the Introduction of Biomethane into Existing Natural Gas Distribution & Transmission Systems

## 1) Integration into Existing NG Distribution Infrastructure

RNG can be delivered to end-users by injecting or blending it into a local distribution company's natural gas delivery grid, allowing it to be used in any way that natural gas is used, as a transportation fuel, for building and water heating, as process energy, and in power generation. RNG stakeholders—natural gas utilities, biogas producers, technology suppliers, the R,D&D community and federal and provincial governments—are working towards the expansion of infrastructure and associated processes that can collect, clean and introduce biogas into the natural gas delivery grid at a competitive price for both general energy markets, as well as the transportation market specifically.

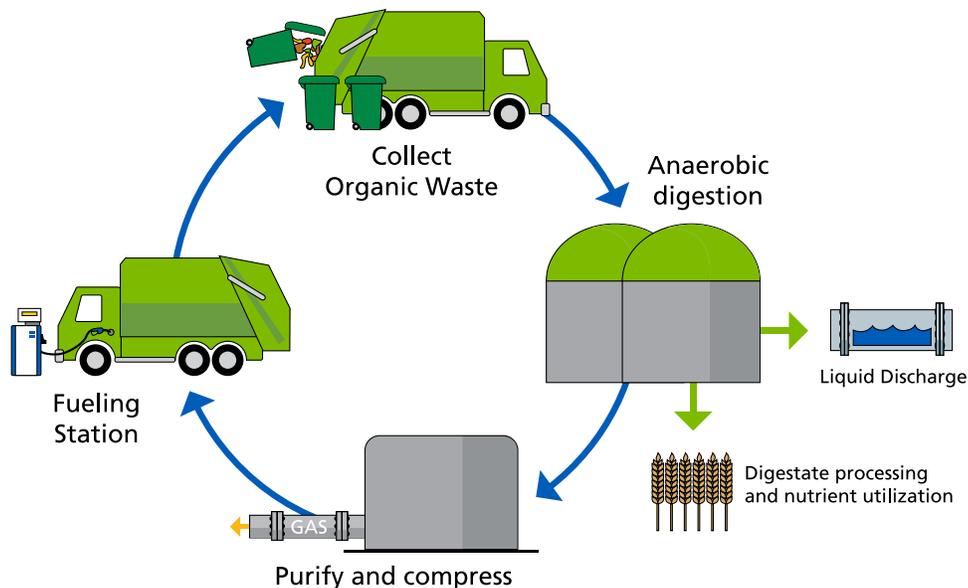
## 2) Localized RNG Infrastructure

With RNG, as with other infrastructure development, the emergence of local-scale projects precedes large-scale infrastructure investments. Local-scale RNG projects can uniquely integrate the management of energy streams and waste streams, in some cases creating a 'closed-loop' process that offers

a renewable fuel source and mitigates a waste management issue at the same time. Organizations that have energy requirements at or near an RNG production site can make use of this energy to fuel their own energy needs, subject to applicable codes and standards.

Figure 11 illustrates the internal use of biogas by the City of Toronto. The City of Toronto Solid Waste Management Services, in partnership with Enbridge Gas Distribution Inc., installed new equipment at the Dufferin Solid Waste Management Facility in 2018. The new equipment, known as a Bio-methane Upgrading System, turns raw biogas—produced from processing Green Bin organics—into RNG.

Building on this project, the City of Toronto also identified RNG production opportunities at two landfill sites and its other anaerobic digestion facility. Once all four RNG sites are up and running, estimates suggest that the City will be able to produce approximately 65 million cubic metres of RNG per year.



**Figure 11:** Flexible Closed-Loop RNG Process, City of Toronto

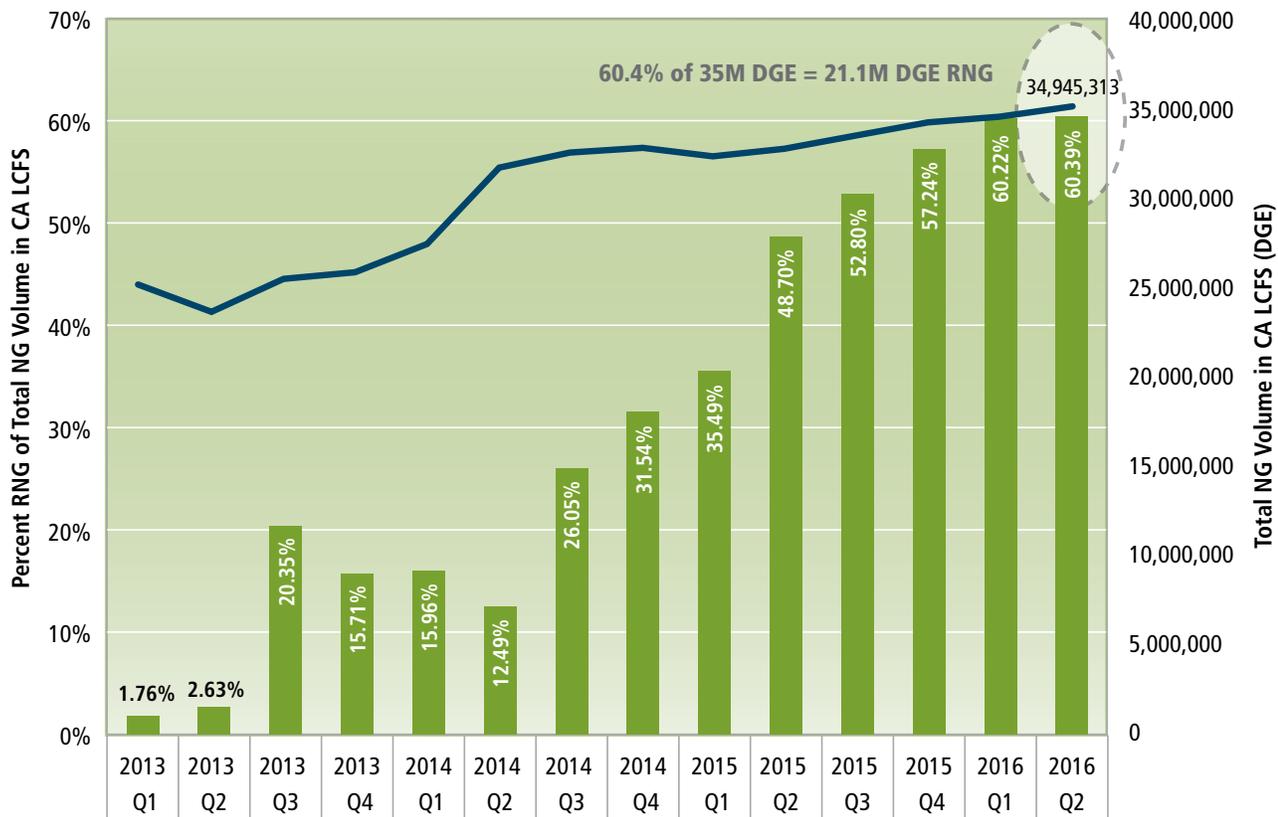
Source: Canadian Biogas Association Closing the Loop Primer 2015 and City of Toronto

The City of Toronto’s existing and closed landfill sites and anaerobic digestion (organics processing) facilities are some of the largest producers of biogas and landfill gas in Ontario. Over the last few years, the City’s Solid Waste Management Services Division has been looking for opportunities to harness the green energy potential of these gases. This most recent project uses a closed-loop approach in which organics collection trucks are ultimately powered by the waste product they collect. This advances the Division’s mandate to be an international leader in sustainable solid waste management and supports the City’s move towards achieving a circular economy.

### Benefits for Fleet Operations

In addition to reducing GHG emissions, there is the potential to generate credits through the use of RNG.

Figure 12 shows how natural gas blended with RNG is generating credits in California. The blue trend line shows the annual volumes of total natural gas fuel reported under California’s Low-Carbon Fuel Standard (LCFS) up to the second quarter of 2016. The green bars indicate the growing percentage of RNG being used in place of geologic natural gas to generate LCFS credits.



**Figure 12:** Impact of RNG on Carbon Credits for Transportation in California

Source: CARB LCFS Data.

Available at [https://www.arb.ca.gov/fuels/lcfs/dashboard/quarterlysummary/media\\_request\\_011717.xlsx](https://www.arb.ca.gov/fuels/lcfs/dashboard/quarterlysummary/media_request_011717.xlsx)



FortisBC – Renewable natural gas production site in Surrey, B.C.

### **Benefits for Canadians**

Canada can apply its extensive knowledge in the natural gas, agricultural and forestry sectors toward the increased production of RNG. Potential outcomes could include operational cost savings, new revenue streams for these industries, and local development opportunities.

While there are limited RNG projects that directly serve transportation applications, several projects, identified in Figure 13, are building Canada's expertise in RNG systems where biogas is captured and injected into a natural gas stream.

With over 450,000 km of natural gas piping delivering energy to almost 7 million customers, there is great opportunity for RNG to reduce Canada's GHG emissions and air pollutants on a national scale, improve environmental management of organic waste, and optimize use of the existing pipeline network.

## Canadian Renewable Natural Gas (RNG) Projects

Operating & In development as of 2018



Figure 13: Canadian Renewable Natural Gas (RNG) Projects

In Surrey, B.C., the City built an organic waste biofuel processing facility that uses RNG to power Surrey's waste collection fleet. This closed-loop system processes 100% of the City's residential waste. Together with FortisBC, the facility will produce RNG for vehicles and for injection into the FortisBC NG pipeline network, as well as fertilizer and soil amendment for distribution to local retailers. The partnership extends to all levels of government with provincial support through carbon credits and federal support from the public/private partnership that will contribute up to 25% of the capital cost to build the facility.

In St-Hyacinthe, Quebec, the City and Gaz Metro, now Energir, collaborated on the purchase and injection of RNG in the City's RNG facility. Beginning in 2014, Gaz Metro agreed to purchase up to 13 million cubic metres of RNG per year for 20 years. The existing digesters, established in 2010 to treat sewage sludge, are being upgraded to process multiple waste streams. New anaerobic digesters are being purchased for the City's wastewater treatment plant and will be operational in 2017. This will be the first facility in Quebec to turn organic waste into RNG for local use and injection into the local pipeline, and is anticipated to process 150,000 tonnes of organic waste per year. The \$50M facility is jointly funded through the Green Municipal Fund, the Government of Quebec and the City.<sup>4</sup>

## Conclusion

Since 2010, commercial development of shale deposits continues to expand due to advancements in drilling technology. There is a large natural gas supply available and production in Canada remains competitive, so long as natural gas prices remain relatively low. Today's natural gas prices remain attractive to users given the relatively higher prices of petroleum fuels and electricity. According to industry, it is estimated that the price differential between natural gas and crude oil will remain relatively steady.

A nationally recognized RNG marketplace is needed wherein infrastructure and associated processes can deliver RNG into the existing natural gas grid at a competitive price for both general energy markets as well as the transportation market specifically. Several strategic opportunities could advance this objective:

- A cross-government "Green Fund" to connect RNG supplies from farms, landfills and forestry operations to the Canadian natural gas infrastructure network.
- Targeted outreach on the benefits of RNG.
- Innovative approaches to taxation, such as exempting RNG from emissions reductions taxes when sold within Canada.
- Other tax mechanisms to encourage development of the required infrastructure.
- Including natural gas refuelling infrastructure and facility upgrades for municipal fleets and at ports as eligible costs for federal infrastructure funding through federal/provincial agreements.
- Funding of RNG transportation opportunities not currently economically feasible and outside of the industry's policy framework.

---

4 2018 Canadian Biogas Association



## MARKET NEEDS AND INNOVATION

Powered by natural gas





## Chapter 5: Validating the Business Case for NGV Adoption

Business case modelling tools were first developed in 2010 for Roadmap 1.0 to provide a rigorous assessment of the NGV market opportunities and to determine where the best business case exists for investing in and converting fleets to use natural gas. Roadmap 2.0 uses an expanded modelling tool, with current data, to analyze and predict market development so that ongoing efforts and investments, including those around the use of RNG, remain well-informed. Updates to the modelling tool include a growth model in order to enable forecasts of market penetration, capital costs, jobs, and environmental benefits.

### What Goes Into the Model: Data

Capital and operating costs are a significant input to the model. Table 4 provides a list of the region-specific operating and capital costs fed into the

model to inform the prediction of the business case for NGVs within a given region. The model is now capable of assessing four regions (British Columbia, Alberta, Ontario and Quebec).

**Table 4:** Capital and Operating Costs for Fuel Value Index

| Capital Costs   | Operating Costs   |
|---|---|
| <ul style="list-style-type: none"> <li>• Vehicle cost premium compared with diesel vehicle</li> <li>• Vehicle residual value compared with diesel vehicle</li> <li>• Station cost, if private refuelling station used (includes all equipment, engineering, construction, approvals, commissioning)</li> <li>• Facilities modification costs</li> <li>• Cost of money</li> <li>• Economic life of equipment and vehicles</li> </ul> | <ul style="list-style-type: none"> <li>• Fuel consumed</li> <li>• Vehicle refuelling frequency/duration</li> <li>• Incremental vehicle maintenance</li> <li>• Incremental insurance</li> <li>• Station maintenance*</li> <li>• Training (operators, mechanics)</li> <li>• Electricity, gas/liquid handling, ancillaries*</li> <li>• Natural gas (commodity, liquefaction if LNG, delivery, contract costs)*</li> <li>• RNG and % blend</li> <li>• Operating engineer*</li> <li>• Taxes*</li> <li>• Retail margin</li> </ul> |

\* Many cost factors are jurisdictional, requiring data from multiple sources across the country. Assumptions are made to tabulate costs that are unknown or variable.

In addition to the above costs, vehicle data that has changed since 2010 is incorporated for each of 15 target applications. Typical changes included vehicle population, vehicle premiums, engine performance, and efficiency and emissions data. Other notable parameters that have been updated across all applications include:

- Oil and natural gas costs
- RNG availability and cost
- Gas utility and electric utility rates
- Equipment catalogue data
- Tax and incentive information

### What Comes Out of the Model: Fuel Value Index

The Fuel Value Index (FVI) quantifies the **value proposition** of using an alternative fuel across different market applications and locations, over a defined period of time. The value proposition is defined as the collective set of benefits that a purchaser or adopter can justifiably expect to achieve, based on the specific attributes of a product. An FVI of one (1.0) means that the alternative fuel offers an equivalent value proposition relative to a designated baseline fuel. The FVI can calculate three sets of benefits: economic (savings), environmental (GHG reductions), and social (job creation). For the purposes of the base case, only economic benefits are considered in the FVI calculations.

Four jurisdictions (British Columbia, Alberta, Ontario, and Quebec) are considered in this report given the lower market uptake of NGVs in remaining provinces and territories. Figure 14 below details the updated FVI results for all modelled applications in these jurisdictions. All vehicle and fuel supply costs are expressed as cost-per-diesel-litre-equivalent, or DLE, and combine to give a single 'all-in' cost of fuel. This price is divided into the local cost of the baseline fuel to allow comparison with other fuels, applications and locations. To assess the value of fuel as the market develops, the FVI is evaluated over a ten-year timeframe to consider changes in fuel pricing, value of carbon, inflation, decrease in cost of new technology, and others.

### The Base Case – Comparing Current and 2010 Modelling Results

Figure 14 shows that, in all four jurisdictions, natural gas fuel continues to provide a compelling value proposition for the market development of several commercial medium- and heavy-duty applications.

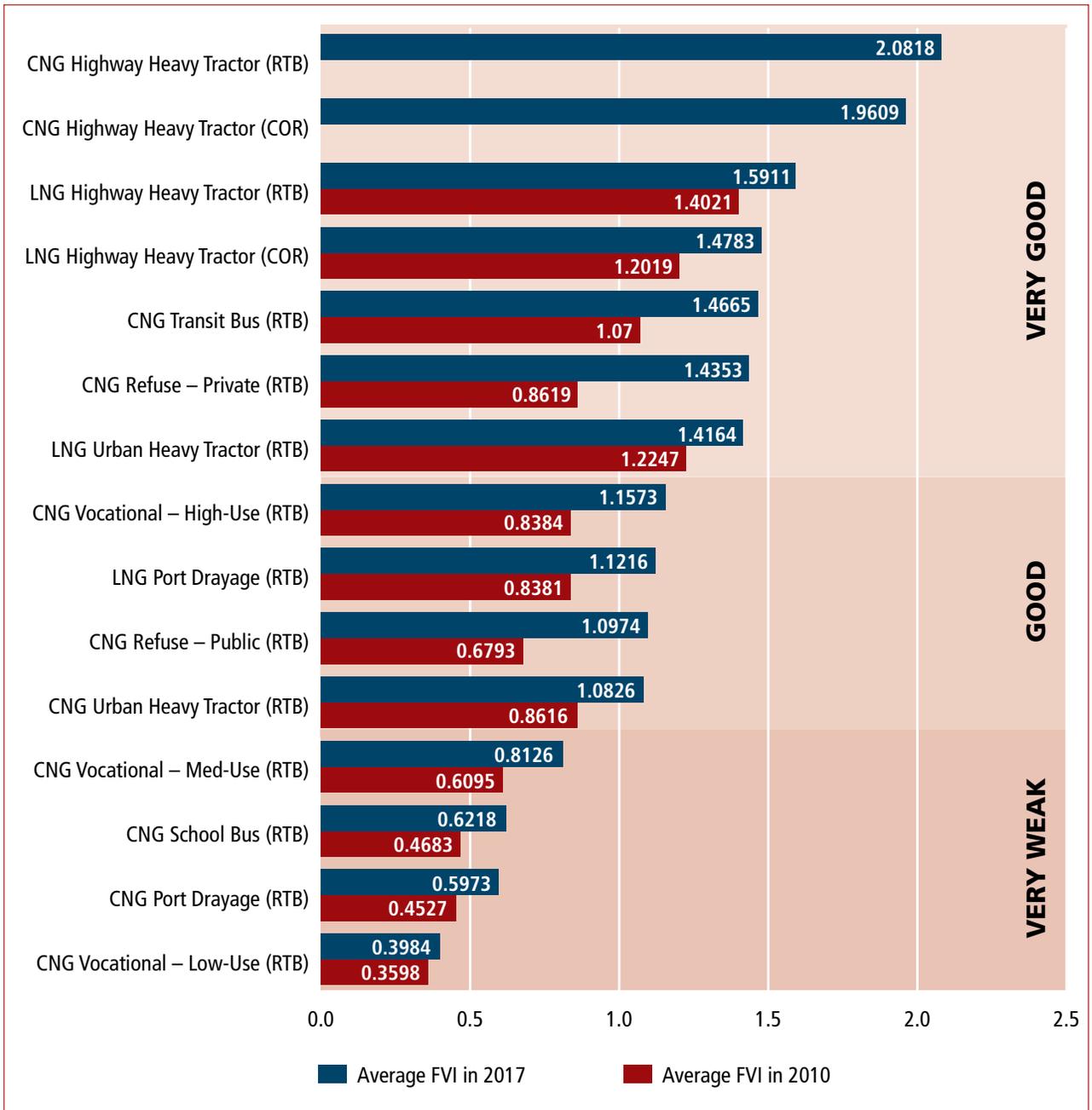
Seven applications are rated as offering a 'very good' value proposition. Of these, four are highway heavy tractor vehicles (both CNG and LNG) with return-to-base or corridor operations. A fifth 'very good' heavy tractor application, fuelled by LNG, operates strictly on urban routes. High fuel consumption is a large part of the attractive value proposition that heavy tractors make for natural gas.

The remaining two applications achieving this high rating are CNG Transit Buses and CNG Private Refuse Haulers, both return-to-base applications. Four additional 'good' applications clear the FVI threshold of 1.0, but their lower value proposition indicates a slower payback period than the ones mentioned above.

Among the seven top applications, two are CNG Highway Heavy Tractors. These were added as a category to the original 2010 selection of 13 applications due to the current lack of a 15 L dedicated natural gas engine. This created the assumption that all CNG applications will instead use a lower-power, 12 L CNG engine. While the modelling results indicate a very good value proposition, the lack of a higher-powered engine is nevertheless expected to have a negative impact on market penetration.

In 2010, CNG Transit Buses were the only non-heavy tractor applications that rated 'very good'. CNG Private Refuse Haulers now also have this distinction. Refuse haulers show the most robust market growth in the 2010–2017 period, mainly due to two key factors:

1. Market acceptance and promotion in the U.S. created greater familiarity and acceptance among the Canadian refuse hauler community as well as a well-established OEM supply chain; and
2. Municipal governments place a higher value on the environmental benefits of CNG and are the ultimate end-users for this application



**Figure 14:** 2017 Modelling Results of Target Vehicle Applications

Additional applications that showed a notable variance compared with 2010 include:

- LNG Highway Heavy Tractor (corridor)
- CNG Transit Bus (return-to-base)
- CNG Private Refuse (return-to-base)
- CNG Vocational High-Use
- CNG School Bus (return-to-base)

Variations in results between regions could be accounted for by: 1) lower gas delivery pricing in Alberta; 2) lower diesel pricing in Ontario; 3) fully loaded cost of operating engineers in Ontario; and 4) corrected (reduced) refuelling time requirements.



Waste Management roll-off truck with a CWI 12-litre engine

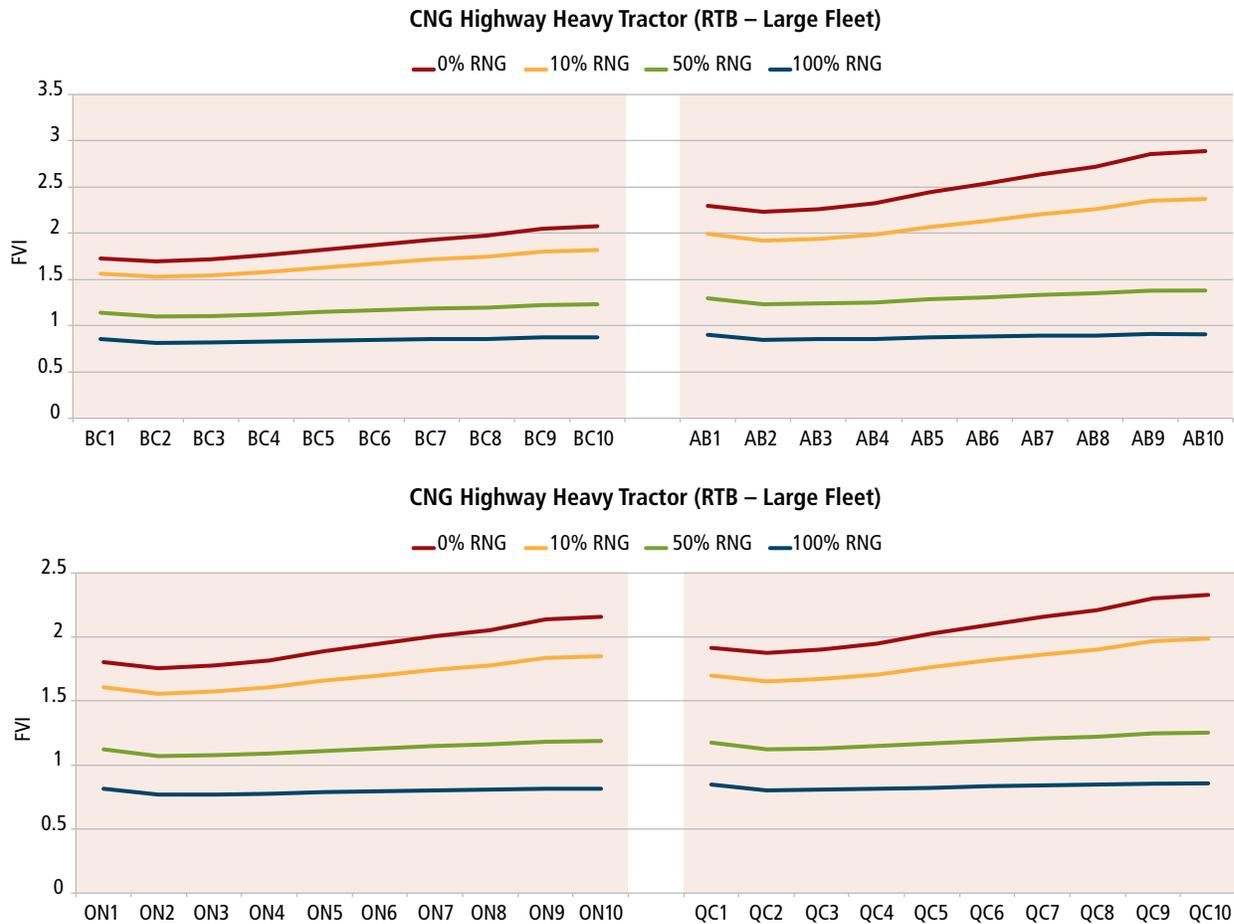
## Additional Scenarios – RNG, Growth Rate and Social Benefits

The updated model now enables a determination of the impact that RNG can have for fleets operators, and an understanding of how the rate of adoption of NGVs affects emissions reductions, job creation and economic growth in Canada.

### 1. Impact of RNG on Modelling Outcomes

The modelling tool can assess the sensitivity of the FVI to the use of a straight RNG stream or as a blended portion as a percentage of the fuel. When sold on a straight supply contract to a utility, the price of RNG tends to be close to its production cost, approximately \$10/GJ. This study assumes a cost of \$20/GJ to accommodate the fact that many RNG developers plan to sell into jurisdictions where there are additional credits, potentially driving the price up to \$30/GJ. Subsets of CNG applications using RNG blends of 10, 50, and 100% are considered.

The effect of RNG on the economic FVI was examined for three RTB applications (CNG Highway Heavy Tractor, CNG Transit Bus, CNG Private Refuse Hauler) in the four provinces modelled. Although the use of RNG does erode the FVI somewhat, in most cases a threshold value close to 1.0 is still achievable, with even higher values where incentive programs are established. CNG highway heavy tractors can essentially achieve an FVI of 0.8 in the first year, even for a pure stream of 100% RNG, as shown in Figure 15. For the other two applications (not shown), blending RNG at 50% (or less) can readily achieve an FVI of 1.0 or more, with some variation between jurisdictions. As long as RNG is more expensive than NG, the FVI will always be better for NGVs operating on NG. The reward is an environmental benefit and the value attached to that reward will vary from organization to organization.



**Figure 15:** Impact of RNG Use for CNG Highway Heavy Tractor (RTB) Applications

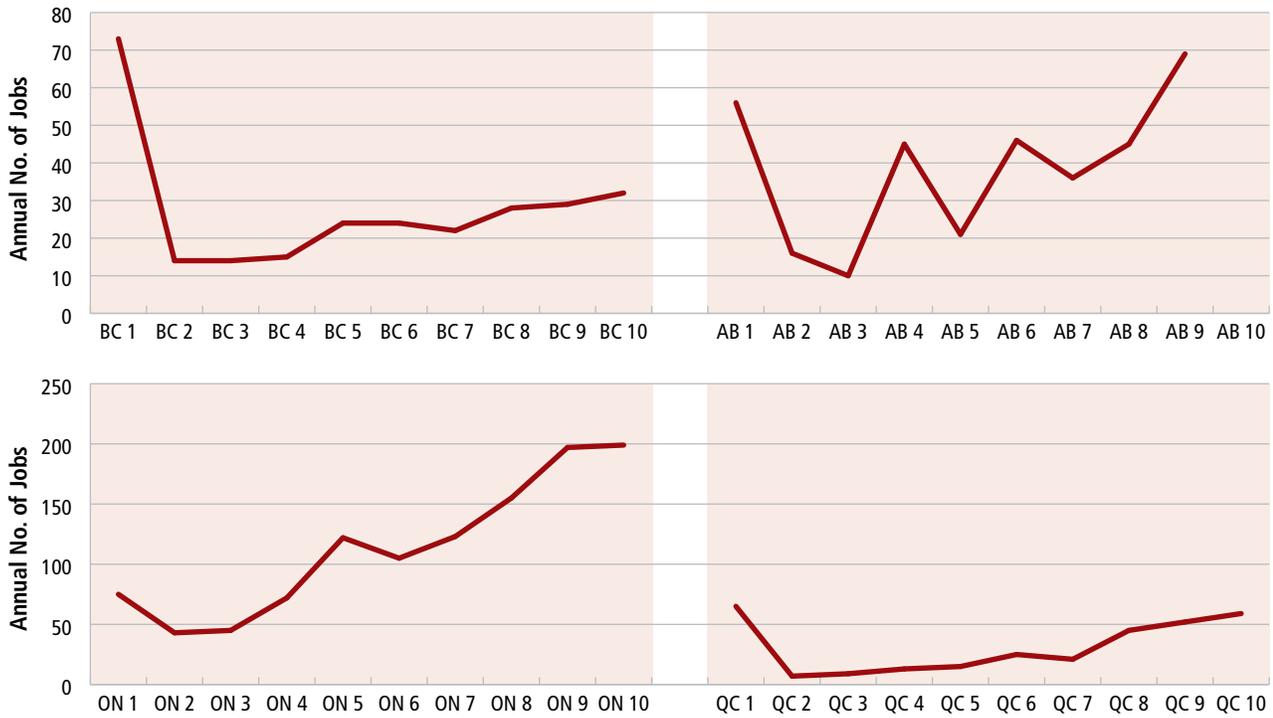
## 2. Impact of Growth Rate on Future Outcomes

Growth modelling provides a prediction of how, when and by how much the population of vehicles within a given market segment will evolve. This kind of information can be useful for policy makers as it allows for a prediction of the required capital expenditures, overall environmental benefits, jobs arising from infrastructure development and equipment maintenance, and vehicle and fuel sales.

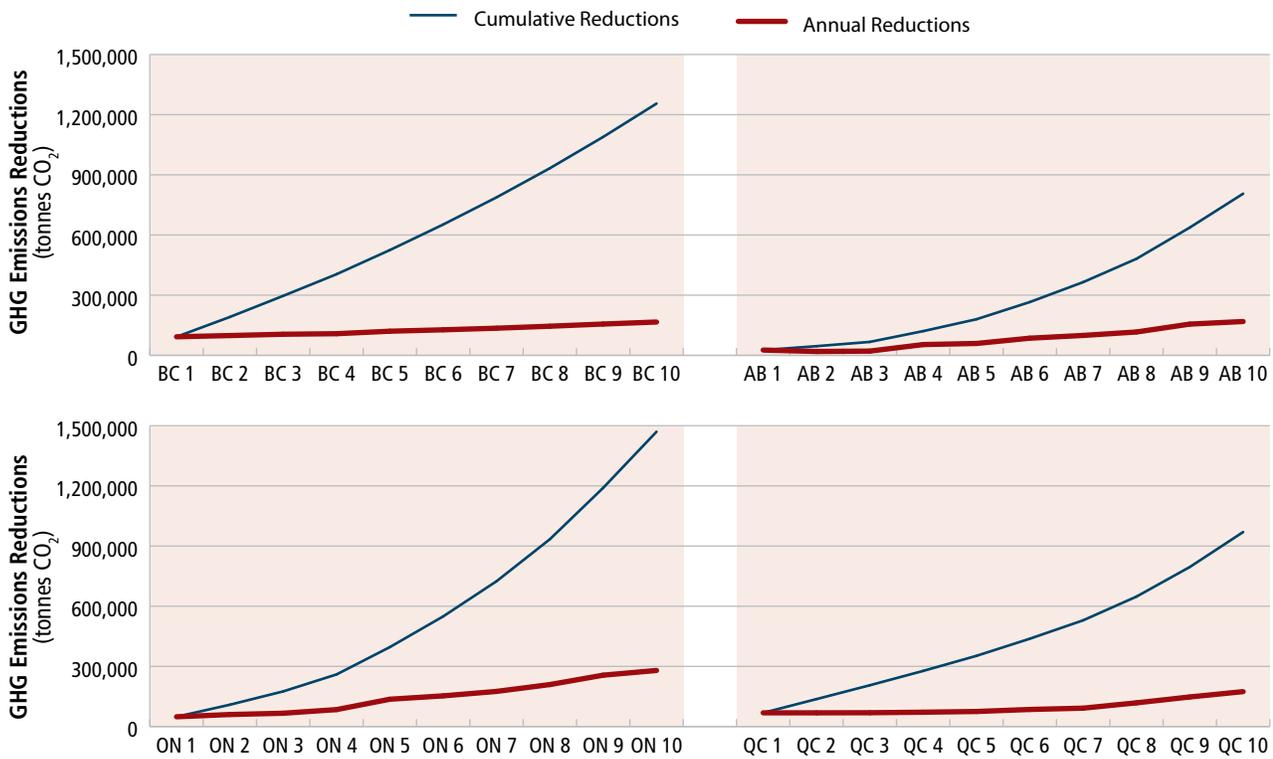
Industry participants provided input to develop an assumption for future expected growth, which resulted in the growth model outputs for British Columbia, Alberta, Ontario and Quebec.

- Jobs Created:** These curves (Figure 16) show the total annual manpower required to develop and operate the CNG refuelling infrastructure necessary to accommodate the growth anticipated for all modelled applications. The number of jobs is based on direct jobs associated with installation and maintenance requirements. A small number of 'spin-off' jobs that activity in this sector might attract were also included.
- GHG Emissions:** These curves (Figure 16) show the total annual and cumulative GHG emissions reductions that could accrue from the growth anticipated for all modelled applications. These values were tabulated using GHGenius version 4.03 to determine emissions upstream of the refuelling nozzle, and using fuel consumption and engine efficiency values to determine emissions from the vehicle tailpipe.

### Impact of Growth Model: Jobs Created



### Impact of Growth Model: GHG Emissions Reductions



**Figure 16:** Cross-Jurisdictional Results of Growth Rate Modelling

Growth modelling can also be used to calculate the total cumulative capital investment required to develop the CNG refuelling infrastructure necessary to accommodate the growth anticipated for all vehicle applications modelled. This is not included in this report.

Synergies across operators and transportation modes, including rail and marine end-users, can yield greater economies of scale and improve these growth outlooks. Examples of these synergies include:

- Slow-fill fleet facilities that provide compression for public fast-fill retail stations
- Municipal fleets that share facilities (e.g. refuse, public works, supervisory vehicles)
- Neighbouring municipalities and/or businesses that share refuelling facilities
- Highway corridor refuelling facilities built for one fleet which are made available for many fleets
- Corridor refuelling facilities that serve mobile infrastructure for smaller, off-corridor needs
- Multi-modal facilities that serve trucking, marine and rail needs
- Natural gas used as a feedstock to produce hydrogen as a vehicle fuel

## Expanded FVI Modelling

As mentioned at the beginning of Chapter 5, FVI modelling can also assess the attractiveness of an alternative fuel as it relates to environmental and social (primarily job creation) benefits. To achieve a holistic FVI, an added step is required that uses a weighted scoring system to allow the economic, environmental and social FVI scores to be combined. To get to the final decision-making FVI, individual weighting factors (specific to an organization's values, needs and expectations) are applied to each of these scores, producing three individual weighted scores:  $FVI_{wec}$  (Economic),  $FVI_{wen}$  (Environmental) and  $FVI_{wes}$  (Social). These are then totalled to achieve a final FVI ( $FVI_{wtotal}$ ) that can be subjected to the organization's 'go/no go' criteria.

This 'bigger picture' FVI can better predict actual market uptake. As an example, three vehicle applications in B.C. are considered, all with good economic value propositions but varying organizational priorities.

1. CNG Highway Heavy Tractor: Almost entirely weighted to the economics of a fuel switch
2. Privately owned and operated CNG Municipal Refuse Haulers: Mostly weighted to economics with significant weighting to environmental as well.
3. Municipally owned and operated CNG Municipal Refuse Haulers: Fairly equal weighting for economics and environmental, some weighting to job creation

When only the economic FVI is calculated, the indication is that uptake should be greatest in the same order as the above list (1-2-3). When expanded to a holistic FVI, the order changed to 2-1-3. This reflects the actual case as the private refuse hauler market did in fact experience the greatest CNG adoption in recent years.



Emterra Environmental waste and recycling collection truck in the Region of Peel, Ontario.

## Conclusion

NGVs continue to present an economic value proposition for several MHDV applications relative to similar diesel-fuelled fleets. Some key points are highlighted below:

- Seven NGV applications, including two new CNG heavy tractor applications scored a 'very good' rating, up from four in 2010.
- Heavy tractor applications, which consume larger amounts of fuel, continue to show high potential for natural gas fuelling.
- The relative uptake of CNG refuse fleets indicates that some fleets do take other factors into consideration, such as acceptance by peer markets and meeting environmental objectives, rather than relying solely on the economic business case.

Based on the enhanced model, the use of RNG can be one way of meeting these environmental objectives. Although the use of RNG, whether as a 'pure' stream or as part of a blended stream, does erode the economic FVI somewhat, in many cases, an FVI close to 1.0 is still achievable, together with considerable GHG reductions. The value attached to this environmental benefit will vary from organization to organization. A holistic approach to modelling which adds environmental considerations to the FVI assessment can help organizations weigh these considerations.

The application of growth modelling indicates that Canadians stand to gain from the adoption of natural gas in the MHDV sector, in terms of jobs created and GHG reductions. Leveraging synergies across modes and users can also serve to accelerate these growth outlooks.



## Chapter 6: End-User Needs

The previous chapter provided a high-level economic and environmental analysis of which fleet applications present the best opportunities for switching to natural gas as a fuel. This chapter now presents the more granular views of different end-users along with the barriers encountered by earlier adopters. These insights provide additional context for the updated set of recommendations in Roadmap 2.0.

### Learning from Each Other

As a result of Roadmap 1.0, the Implementation Committee supported outreach activities for fleet users, industry associations (Canadian Trucking Alliance, Canadian Urban Transit Association, and Ontario Waste Management Association) and federal and provincial/territorial governments. Formal consultation activities advanced an understanding of factors that influence investments in natural gas in the transportation sector. These efforts were supported by a new 'Go with Natural Gas' website where information could be shared and knowledge exchanged in an unbiased format and through the delivery of workshops by the three regional hubs where participants learned from the experience of others.

As part of informing Roadmap 2.0, two workshops were conducted in Ontario and British Columbia with end-user groups that own and operate medium-duty and heavy-duty fleet vehicles. The objective of these workshops was to identify barriers and opportunities to NGV adoption and deployment and to determine the necessary conditions for increased market uptake.

### Stakeholder Insights

Discussions with stakeholders, during and after the workshops, identified their primary needs (e.g. cost savings) and the barriers (e.g. lack of infrastructure) they encountered when investing in and adopting

NGV into their operations. These insights, as well as additional considerations offered by various industry stakeholders and report contributors, are expanded upon in Appendix A.

The following three groups were defined according to the similarity of their needs and/or operations:

- 1. Highway trucking:** This large stakeholder group is highly motivated by cost or cost savings. Environmental benefits are a considerably lower priority. The group has a strong need for publicly available infrastructure, especially on corridor routes.
- 2. Vocational, trucks, refuse, municipal and transit:** For this group, incremental vehicle cost and other upfront costs may be amortized over a longer period of time, and overall fuel use is somewhat lower than highway trucking. The group has the leeway for longer investment and less sensitive payback periods, but must also assess the fuel-switching decision over a longer period, and often with a high degree of public scrutiny and support for emissions reductions. Fleets in this group are primarily return-to-base.
- 3. Supply chain, OEMs and dealerships, academia, investors and government:** While not characterized as end-users (except for government fleets), this group has distinct needs that influence the ability to meet the needs of fleet end-users and therefore require understanding and consideration.

Four barriers have been identified as persistent and the most significant for end-users. These include:

1. *Exposure to risk because of the higher cost of NGVs and their operational requirements* – There remains a strong need to defray the incremental costs of NGV relative to the lower purchase costs for a diesel vehicle. Workshop participants spoke strongly to the need for temporary fiscal measures to help bridge the current cost gaps that prevent operators from making this investment decision.
2. *Access to reliable refuelling* – While federal funding has recently gone toward establishing seven new public stations along the main corridors in British Columbia, Ontario and Quebec (which brings the total to 41 public CNG stations), access remains spread out and uneven across the country. The high cost of infrastructure presents a ‘chicken and egg’ situation, as infrastructure developers are reluctant to invest ahead of significant demand. Likewise, this high cost affects the investment in private refuelling stations by return-to-base fleets. As proposed in the previous chapter, partnerships and business models that allow access to multiple modes and users can significantly improve the value proposition for development of both corridor and RTB refuelling.
3. *Availability of high-horsepower engine* – As detailed in Chapter 3, a significant market (in number of vehicles and magnitude of emissions) of heavy haulers operate in terrain that requires a suitable +400 hp engine that does not yet exist in Canada. Canada’s regulatory framework allows higher weight limits for heavy-duty vehicles than those established by the U.S. Department of Transportation. Workshop discussions pointed to the need for a possible solution to include the establishment of a coordinated, multi-stakeholder approach including OEM, fleet owners and government regulators.

4. *Uncertainty that switching to natural gas fuel is right for their fleet*

- a. *Need for Information and Resources:* Operators need useful and up-to-date resources and tools to evaluate what natural gas (and RNG) can specifically mean for their operation from all angles—technical, financial, and environmental. This includes adding clarity around what an RNG framework will entail. It also involves sharing current information on R&D advances and technology demonstration outcomes. Chapter 9, Education and Outreach, adds further context to these needs.
- b. *Need for a National Strategy:* Greater coherence between federal, provincial and local policies and regulations (e.g. weight restrictions) is required to give fleet owners and managers confidence in evaluating and selecting alternative fuel options. As more complex concepts (e.g. life-cycle analysis, costing and availability of RNG, etc.) are incorporated into policies and regulations for transitioning to lower carbon transportation, fleets need to be consulted and provided with comprehensive information to help inform their investment. Industry stakeholders also request an approach that is consistent across fuels (including EVs) and vehicle sectors. The updated Roadmap provides a foundation with strategic recommendations and research that will help to develop the strategy for implementing them.

## **Conclusion**

The end-user is a key part of the equation when it comes to the adoption of natural gas as a lower carbon option in transportation. Stakeholders along the value chain have taken a multitude of actions since the release of Roadmap 1.0; interest in adoption continues, but barriers still persist. This is not a situation isolated to natural gas adoption, but one that is faced by any disruptive technology.



## Chapter 7: Cross-Canada Case Studies Show the Way

Across Canada, an increasing number of operators are integrating NGVs into their fleets. In some cases, it is entirely a bottom-line business decision. In others, the desire to reduce their carbon footprint also weighs into the decision. The shared experiences of these early adopters help others better understand if natural gas fuelling might be right for their operations. A number of early adopters have profiled their use of NGV and shared insights on how the switch is better supporting their operations.

### British Columbia



#### **Vedder: LNG High-Horsepower Daily Delivery and Regional Logistics**

Vedder Transportation hauls 1.6 million litres of raw milk each day with more than 300 tractors, 800 trailers and significant logistical support facilities. In 2011, Vedder was one of the pioneer companies in Canada to purchase factory-built tractors powered by LNG.

Vedder has enjoyed significant maintenance and reliability advantages with our natural gas vehicle fleet. When we compared natural gas and diesel vehicles on an equal basis, our NGVs enjoyed a consistent advantage both in terms of maintenance costs and down time.

Vedder's interest in using natural gas-powered vehicles was twofold: to reduce fuel costs and to reduce emissions.

*"In the early days, we had many customers who called our offices wondering when we were coming to pick up the milk. Funny thing was that we already had, they just hadn't heard the trucks come and go. That's what I call discrete pick-up and delivery!"*

"With nearly a decade of NGV experience under our belt, Vedder will stay the course and in the future, we plan to expand our NGV fleet as much as possible." Fred Zweep, President, The Vedder Transportation Group.

#### **ColdStar Solutions: CNG Daily Delivery and Regional Logistics**

ColdStar Solutions is a leading provider of logistics services, delivering fresh and frozen food to the lower mainland of British Columbia and Vancouver Island. ColdStar was one of the first in Canada to use CNG highway tractors with their first 10 CNG tractors in 2014. ColdStar was motivated by the combined desire to reduce costs and emissions.



### **Coast Mountain Transit: Translink Daily Commuter Service**

Coast Mountain Transit operates all bus services in Metro Vancouver. Coast Mountain began its use of CNG buses with an early pilot project in 2001, after which 50 New Flyer buses were purchased in 2006. These were equipped with Cummins Westport C Gas Plus engines, now evolved into the modern ISL G and Near Zero engines. Since 2014, 96 new CNG buses have been added.

### **Alberta**



### **Red Deer Transit: Mid-Sized Daily Transit**

With a total of 58 transit vehicles serving 12 transit routes, Red Deer Transit is an example of a mid- to small-sized Canadian public transit system. The company began deploying CNG buses in its fleet in 2015 and 17 New Flyer vehicles were delivered in 2017. The transit company will continue to replace its existing buses with new CNG units over the next few years. In 2017, 6 new CNG Paratransit vehicles were purchased. Refuelling takes place at the company's on-site station.

### **Manitoba**

The province of Manitoba has been integral to the deployment of NGVs in Canada. Red River College undertook cold weather vehicle testing and was part of a 2013 study that demonstrated the effective performance of natural gas engines in refuse trucks. Of the approximately 60 NGVs purchased in the province over the last few years, most are refuse trucks.

### **Ontario**



### **Waste Management (WM): Waste Hauling Fleet**

WM has deployed over 7,000 NGVs operating throughout North America. Its first CNG refuse fleet was deployed in Ottawa, Ontario in 2012, aligning with the company's overall direction to reduce fleet emissions. According to Sherry Stevenson, Municipal Affairs Manager for WM Canada:

*“Waste Management is embracing clean fuel technology as part of our commitment to achieving a zero emissions future. Introducing CNG trucks is an important part of our long-term sustainability strategy to reduce emissions by 15% and also increase fuel efficiency by 15%.”*



### **Hamilton Street Railway (HSR): Daily Transit Service**

A long-time leader in deploying natural gas-powered buses, HSR has operated CNG buses since 1985. HSR's legacy fleet included 94 CNG buses. In 2015, faced with the decision to either depart from CNG or reinvest in its CNG vehicles and infrastructure, HSR reassessed and made the business decision to purchase up to 120 new CNG buses.

### **Oxford County: Municipal Fleet**

As an upper-tier municipality in Southern Ontario, Oxford County provides services such as waste collection and roadway maintenance. With a desire to lead in emissions reductions (while reducing costs), the county began converting light- and medium-duty vehicles to natural gas in 2016. Oxford County is the first municipality in Canada to use natural gas for snow removal operations.

### **Quebec**



### **EBI: Waste Hauling Fleet and Natural Gas Demonstration Fleet**

Based in Berthierville, Quebec, EBI fleet operations include heavy construction and machinery, refuse collection and waste management. The company develops biogas and renewable natural

gas resources. Beginning in 2011, EBI launched a program to replace its fleet with NGVs. The company now owns and operates 3 public access CNG stations in Berthierville, Montreal and Joliette. In addition to its public access refuelling operations, EBI helps fleets try natural gas by leasing one of their 40 heavy duty tractors. EBI also offers qualified vehicle conversions for those interested in adapting existing vehicles to natural gas.

### **CAT: Long-Haul/Interstate Logistics**

Based in Coteau-du-Lac and with facilities in Laredo Texas, CAT Transport is a leading Canadian trucking provider serving all of North America. In 2014, CAT initiated a plan to replace 100 trucks with CNG-powered units. Planned routes for these vehicles will support a supply chain from Canada through to Mexico. While significant cost savings were a key consideration, the opportunity to reduce emissions was equally important. In the first month of CNG fuelling, CAT lowered GHG emissions by over 18 tonnes. Expansion continues in 2018 with plans to add 10 more NGVs to the fleet. The company is positioned to reduce up to 297 tonnes annually.

### **Nova Scotia**

The use of natural gas is relatively new in the province of Nova Scotia, and limited to a few key regions, including the Halifax region where there is significant interest in the use of NGVs. Over the past few years, more than 30 new NGVs were registered in the province, primarily in the refuse sector.

### **Conclusion**

Canada has produced many leaders, across many sectors, in the switch to cleaner, more cost-effective natural gas fuelling. As early adopters, they all experienced numerous decision points and lessons learned on the journey. These experiences are invaluable to the next wave of adopters that may need encouragement to take their own first steps. To this end, industry and government should take active measures to recognize and leverage the positive outcomes of these fleets, including exploration of the practicality of sharing refuelling facilities with other fleets.

**Table 5: Fleet Profiles**

| Fleet                   | Application   | Fleet (LNG/ CNG)     | Truck   | Engine (Vehicle Use)   | Fuel Storage (DLE)             | Daily Distance Travelled                                 | Refuelling (Private/Public)  | Station Owner               | Dealer Support               |
|-------------------------|---|----------------------|---|--|--------------------------------|--|--|-----------------------------|------------------------------|
| <b>British Columbia</b> |   |                      |   |  |                                |  |  |                             |                              |
| Vedder                  | Daily delivery and regional logistics                                       | LNG (65 out of 425)  | Class 8   | Westport 15L HD 475 hp (386s at 63,500 kg GVW) (367s at 47,500 kg GVW) (367s at 63,500 kg GVW) | 520-890                        | 675 km operating radius                                  | On-site Abbotsford, Kamloops   | FortisBC                    | Peterbilt Pacific            |
| ColdStar                | Daily delivery and regional logistics                                       | CNG (18 out of 45)   | Class 8 Freightliner M112 5-ton                                       | Cummins Westport 11.9 L ISX G – 400 hp and 8.9 L ISX G – 300 hp [80,000 lbs GVW (highway)]     | 45-90                          | 210 km/day   | Fast fill Langford, Nanaimo  | FortisBC                    | Victoria Mack/ First Truck   |
| Coast Mountain Transit  | Bus service in Metro Vancouver  | 252 CNG buses        | N/A   | Cummins Westport C Gas Plus ISL G and Near Zero engines  | N/A                            | N/A  | N/A  | N/A                         | N/A                          |
| <b>Ontario</b>          |   |                      |   |  |                                |  |  |                             |                              |
| Waste Management        | N/A   | 41 CNG trucks        | Freightliner chassis McNeilus side-loader                             | Cummins Westport 8.9 litre ISL G (Daily waste collection)                                      | 280-370                        | 200-300 km/day   | On-site station, slow and fast fill Ottawa                           | Waste Management            | Cummins Eastern Canada LP    |
| Hamilton Street Railway | Daily transit service   | 103 CNG buses        | New Flyer XN60/ Nova Bus LFS/ Vicinity                                | Cummins Westport C-Gas Plus, 8.9 litre ISL G, 6.7 Litre ISB G                                  | N/A                            | N/A  | On-site station, Hamilton  | City of Hamilton/ Union Gas | Metrolinx/ Cummins           |
| Oxford County           | Road patrol and maintenance   | 20 CNG vehicles      | Light-duty pickups and SUVs /CNG snowplows                            | GM 1.5 & 2.5 L, Toyota 2.7L and Dodge 3.6L with Landi Renzo Cummins Westport ISX 12 G          | CRN compliant steel and Type 4 | 150-400 km   | Rural Green Energy Inc. Fast fill                                    | Rural Green Energy Inc.     | Schultz Auto, Protruck, OEMs |
| <b>Quebec</b>           |   |                      |   |  |                                |  |  |                             |                              |
| EBI                     | Daily waste collection/ Waste transfer/ Daily delivery & regional logistics | 157 CNG vehicles     | Waste collection vehicles/ Roll-off waste transfer vehicles /Tractors | Cummins Westport 8.9 litre ISL G and 11.9 L ISX G  | N/A                            | 200-300 km/day (waste) 300-500 km (delivery & logistics) | On-site station, Berthierville Montreal Joliette                     | EBI                         | N/A                          |
| CAT Transport           | Regional and long-haul  | CNG (110 out of 900) | Freightliner Cascadia   | Cummins Westport 11.9 L ISX G – 400 hp   | 605                            | 965-1,100 km   | On-site station, Coteau-du-Lac/ Mississauga/ 3 Locations in the U.S. | U.S. Gain                   | Ryder Canada                 |

DLE: diesel litre equivalent



## Chapter 8: Research and Development – Addressing User Needs Helps to Deploy NGVs

Continued investment in R&D is part of helping any technology reach its full potential and maintain market share. NGVs and their fuelling systems are no different. As the incumbent technology, the diesel engine continues to get better. This adds increased impetus to NGV evolution and improvements.

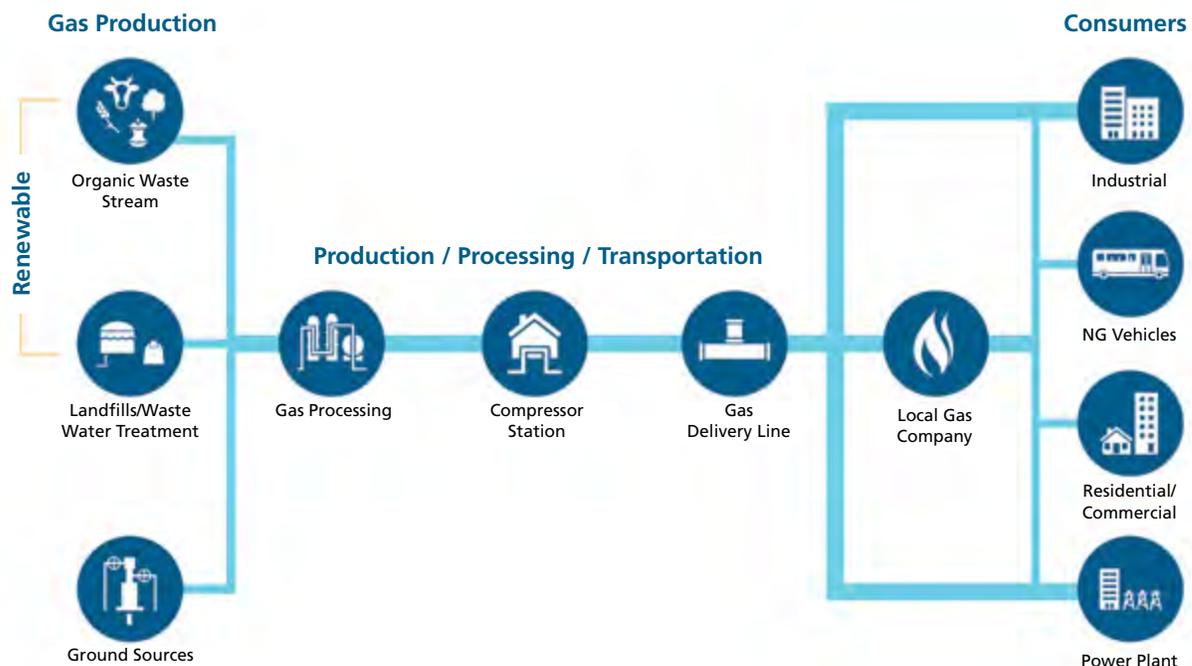
### Why Invest in R&D

R&D is used to reduce costs, improve environmental performance and engines, as well as overall system efficiencies. Progress in these key areas will harness all this technology to compete in markets that are largely driven by cost savings. Canada is home to many clean technology advancements in this area—natural gas vehicle technologies are being exported and deployed around the world.

### The Lifecycle Perspective

Tackling R&D goals simultaneously requires a lifecycle perspective of the fuel and vehicle system, as illustrated in Figure 17 below.

Many regulations being developed at both the federal and provincial level impact various aspects of the vehicle/fuel system. These are described in Chapter 2.



**Figure 17:** Lifecycle Perspective for Natural Gas Vehicles

## The Last Decade in Review

Since 2010, the Canadian market has seen the deployment of various products targeting the MHDV market. In fact, over the last decade, R&D has advanced natural gas products for all market segments except rail. Canadian companies have merged and expanded in response to the growth of the NGV market in Canada and elsewhere. For example:

- Cummins Inc. and Westport Innovations launched a joint venture in Canada to produce spark-ignited engines to serve the MDHV market.
- Cummins Inc., headquartered in the U.S., continues to manufacture, service and export diesel and alternatively fuelled engines, such as NGVs, into Canada.
- Westport Fuel Systems, a Canadian company, provides clean natural gas fuelling systems for cars, trucks, boats and buses, as well as fuelling components.

R&D developments have partially addressed three key barriers to natural gas uptake in transportation identified in Roadmap 1.0, including:

- Improved speed of refuelling through the development of higher flow rate refuelling equipment;
- Reduced price differential for supply and tank capabilities relative to diesel vehicles; and
- Reduced methane emissions from multiple lifecycle stages including refuelling, engine design, after-treatment, and system level improvements.

Nevertheless, additional R&D is required to ensure NGV technologies remain competitive with diesel HDV and their more widespread refuelling infrastructure.

## Vehicle R&D

The situation for the transit and vocational truck market in Canada is much better than for the HD truck market. Cummins Westport has continued to improve the reliability of its mainstay ISL G engine to the point that today, several fleets report that it is more reliable and easier to maintain than the equivalent diesel engine and associated after-treatment system. These systems can continue to be improved to achieve even better efficiencies and increase GHG reduction potential.

- Methane emissions have been dramatically reduced with the introduction of the closed crankcase ventilation system.

- In October of 2015, the ISL G engine was improved to meet the 0.02 g/bhp-hr optional Near Zero NOx Emissions standards for MDV applications, which are 90% lower than current 2010 standards.
- As of 2018, all three products, B6.7N, and the L9N and ISX12N engines, come standard with this emissions reductions equipment, which means that refuse collection, transit bus and trucking operations can simultaneously improve urban air quality while saving money on fuel.

## Fuel Storage

Technology developments have not just been confined to natural gas engines. Advances in both LNG and CNG storage solutions have improved the value proposition for customers looking to adopt natural gas fuel.

- CNG storage systems are now 40% lighter, 30% cheaper and provide 40% more range compared to the 2010 models.
- LNG tank systems are now half the price they were in 2010 and innovations like the Westport iCE PACK LNG tank system have improved the range and performance of LNG trucks.

Nevertheless, the fuel storage system still represents the majority of the incremental cost for NGVs and incentives that offset this cost play a critical part in helping fleets make the switch to natural gas fuel.

**CNG storage systems are now 40% lighter and 30% cheaper and provide 40% more range compared to the 2010 models.**



Luxfer Gas Cylinders – A type 4 lightweight composite cylinder for compressed natural gas

## Codes and Standards

In 2014, efforts to align and harmonize codes and standards were formalized through the Regulatory Cooperation Council. Having a common set of codes and standards ensures consumers and fleet operators that NGVs and refuelling infrastructure components are compatible in both markets. It also enables clean technology companies to build to one set of technical specifications for both markets, lowering their design and certification costs.

As natural gas technologies continue to evolve, it will be essential that the code and standard communities continue to be engaged to ensure code development keeps pace with the state-of-the-art technologies. One area where additional technical data is required is conformable fuel storage tanks.

## R&D Goals Moving Forward

Canadian NGV stakeholders have indicated that, moving forward, R&D efforts should focus on the following goals:

- The promise of clean transportation;
- Cost-effective ownership;
- Vehicle performance that meets operational needs.

As indicated below, six key areas across the NGV lifecycle have been identified as requiring further R&D in order to address these three goals. Upstream natural gas extraction, processing and distribution are outside the scope of this report. Appendix C provides a greater level of detail on the specific R&D areas.

- 1. Refuelling** – Consists of the refuelling station and its interaction with the vehicle. Important considerations include capital and operating costs, fugitive methane emissions, and maximizing fuel tank fill.
- 2. Fuel storage** – Consists of the storage tank that contains the natural gas on board the vehicle.
- 3. Engines** – Includes the engine, control algorithms and peripheral systems that convert the natural gas into mechanical energy.
- 4. Exhaust aftertreatment** – Includes the equipment in the exhaust system which lowers the level of pollutants.
- 5. System-level analysis and data** – Addresses the many possible configurations of the fuelling and vehicle technologies to gain an overall measure of the environmental impacts and costs.
- 6. Codes, standards and guidelines** – Addresses the need to keep pace with changes in technology.

U.S. Gain-Emterra Mississauga, Ont. – Canada’s largest CNG refueling facility



**Table 6: Specific R&D Needs and Challenges**

| Lifecycle Areas                | Challenges and Needs   | Priority R&D Areas  |
|--------------------------------|--|---|
| <b>Refuelling</b>              | <ul style="list-style-type: none"> <li>• High capital cost of refuelling stations</li> <li>• Achieving a maximum fill due to the heat of compression (CNG only)</li> <li>• Longer refuelling time compared to a diesel vehicle</li> <li>• Fugitive methane emissions</li> <li>• Lack of clarity regarding NGV fuel quality needs</li> </ul>  | <ul style="list-style-type: none"> <li>• Improve fill quality (CNG only)</li> <li>• Smaller scale</li> <li>• Refuelling facilities</li> <li>• Operational efficiency</li> <li>• Smart refuelling</li> <li>• Fuel quality</li> </ul> |
| <b>Fuel storage</b>            | <ul style="list-style-type: none"> <li>• CNG – Storage capacity, size, weight, energy density, shape and cost</li> <li>• LNG – Size, weight, energy density, cost and possible venting</li> </ul>  | <ul style="list-style-type: none"> <li>• Adsorbent-based storage (CNG only)</li> <li>• Conformable storage vessels</li> <li>• Low-cost storage</li> <li>• Venting for LNG</li> </ul>  |
| <b>Engines</b>                 | <ul style="list-style-type: none"> <li>• Natural gas spark ignition engines (SI): challenge is lower efficiency than diesel engines, and high methane emissions.</li> <li>• Natural gas compression ignition engines: challenge is achieving a suitable dual fuel strategy.</li> <li>• Dual fuel compression ignition engines (DF): challenge is having high methane emissions due to high in-cylinder sources and difficult conditions for methane oxidation catalysts.</li> <li>• Direct injection compression ignition engines (HPDI): <ul style="list-style-type: none"> <li>– Diesel pilot adds complexity</li> <li>– Sourcing a hot surface material that can withstand high and cycling temperatures</li> </ul> </li> </ul> | <ul style="list-style-type: none"> <li>• Methane emissions</li> <li>• NOx emissions</li> <li>• Engine efficiency</li> <li>• Emissions control durability</li> <li>• Powertrain hybridization</li> </ul>                             |
| <b>Exhaust after treatment</b> | <p>Need for an efficient methane conversion catalyst system that:</p> <ul style="list-style-type: none"> <li>• Operates at the lower exhaust gas temperatures of lean burn engines</li> <li>• Is tolerant of typical levels of sulfur and water found in natural gas engine exhaust</li> <li>• Contains the lowest possible catalyst loading</li> <li>• Is as small as possible</li> <li>• Is economical</li> <li>• Is operational for at least the lifetime of an NGV</li> </ul>  | <ul style="list-style-type: none"> <li>• Lower temperature operation</li> <li>• Catalyst deactivation</li> <li>• Ammonia slip</li> <li>• System integration</li> </ul>  |

| Lifecycle Areas                 | Challenges and Needs   | Priority R&D Areas   |
|---------------------------------|--|--|
| System level analysis and data  | <ul style="list-style-type: none"> <li>Requirement of comprehensive, up-to-date data specifically for assessing the performance, cost and emissions reductions from the various technologies being developed.</li> </ul> | <ul style="list-style-type: none"> <li>Lifecycle assessment</li> <li>Techno-economic assessment</li> </ul>   |
| Codes, standards and guidelines | <ul style="list-style-type: none"> <li>Codes, standards and guidelines must be integrated quickly into easily accessed training materials to facilitate the use of new technology in a consistent fashion.</li> </ul>    | <ul style="list-style-type: none"> <li>New tank technologies</li> <li>Fuel quality</li> <li>Communication protocol</li> <li>Retrofitted engines</li> </ul> |

## Priority Setting

Within these specific needs and challenges, stakeholders identified the following priority areas for R&D:

1. Reducing methane emissions across lifecycle, including developing methane catalysts for lean burn engines and reducing venting and fugitive emissions during filling and storage.
2. Developing better process control along the lifecycle using sensors and communication technologies.
3. Developing better fuel tanks for more range, less size, weight and cost.
4. Continuously improving natural gas engines as diesel engines continue to improve.
5. Updating lifecycle assessment tools such as GREET and GHGenius with the most accurate Canadian process pathways and environmental impacts.
6. Addressing challenges within new opportunities most notably in marine, rail and off-road vehicles.
7. Engaging regulators more holistically across all alternative fuel types to help streamline their efforts and ultimately improving safety by accelerating their adoption.

## Conclusion

Stakeholders along the value chain have invested significant time, effort and funding to get NGV technologies to where they are today. The increasing emphasis on carbon-reduction-related regulations federally and provincially as well as competition from other technologies are setting the stage and need for increased R&D investments to allow NGV technologies to be competitive.

R&D activities happen in various settings. OEMs have a leadership role, especially pertaining to commercialization, while university and government researchers provide much-needed expertise and facilities. In this sharing of roles, it is critical for R&D to be a coordinated effort to reduce costly duplication or lack of relevance.

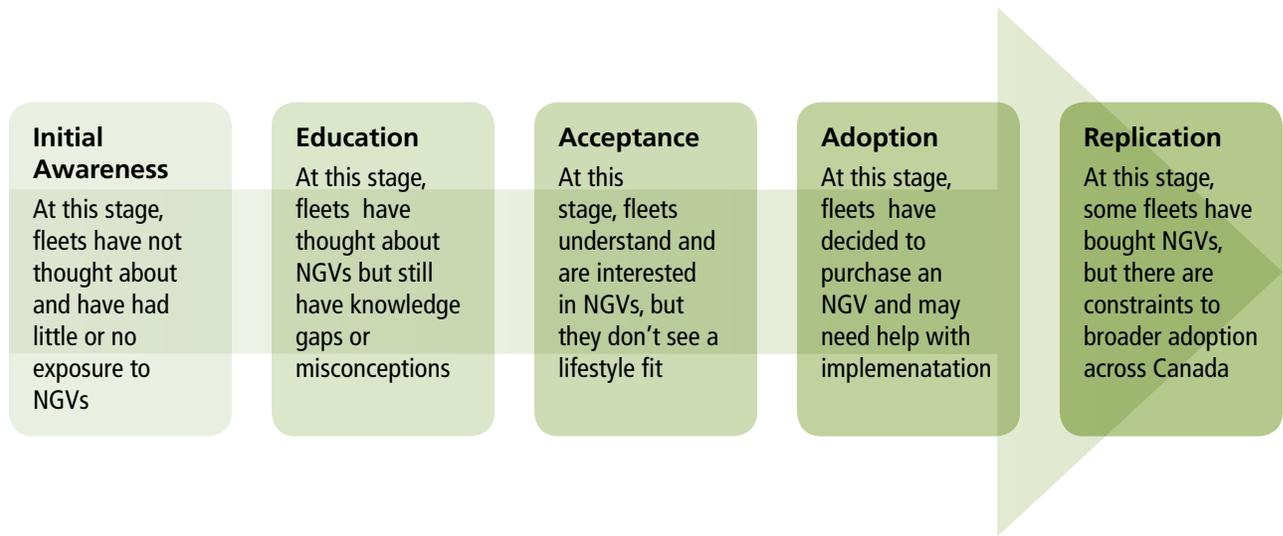


# ROADMAP – PATH FORWARD FOR TRANSFORMING THE NGV MARKET



## Chapter 9: Education and Outreach

Past experience indicates that, when adopting new products and technologies, consumers progress through a series of stages beginning with initial awareness and education, moving on to acceptance, and then adoption, which ultimately supports broader replication. The model encompassing these five stages is the consumer continuum model.



**Figure 18:** Consumer Stages of Adoption

Addressing Canadian consumers' awareness and knowledge gaps is critical to start the progression to NGV adoption. Given that NGV technologies and their market adoption are evolving at a fairly fast pace, there are also barriers related to out-of-date information and misperceptions associated with earlier generation technologies that need to be addressed.

### Progress Since Roadmap 1.0

Recommendations and actions stemming from Roadmap 1.0 resulted in training and awareness-raising programs that helped to fill many knowledge gaps among all audiences, and end-users in particular. The transportation energy space is a

dynamic and changing environment, and staying current is a challenge. It is important to ensure that stakeholders are able to make informed decisions with accurate and up-to-date information. The consultations and evaluations in 2010 led to the conclusion that education and awareness efforts should be more targeted and focus on concrete actions for core audiences.

Key messaging, such as that identified below from Roadmap 1.0, provided a solid basis for ongoing education and outreach:

- Natural gas supplies remain high and cost continues to be very affordable.
- RNG is emerging to add a much-enhanced carbon reduction potential.

- Technologies for medium- and heavy-duty vehicles continue to improve. Canadian suppliers continue to lead in engine, storage, compression and dispensing technologies that are marketed globally.
- Growing industry interest aligns with Canada's deepened carbon reduction commitment.
- A full Canadian supply chain exists and is equipped to grow.

This messaging and other information necessary for the adoption of NGVs was included in the following outreach and education tools developed through funding from the ecoENERGY for Alternative Fuels program:

- Go with Natural Gas Website, – A web portal containing consistent fact-based information to guide investments in and the adoption of alternative fuels (particularly natural gas) in medium- and heavy-duty vehicles;
- Local support networks (i.e., hubs) to provide on-the-ground resources for end-users (i.e. fleet managers) and other key stakeholders (e.g. vehicle manufacturers).

The hubs held 25 workshops throughout the country, reaching more than 700 attendees over a 3-year period.

## Target Audiences for Roadmap 2.0

Active participants within the NGV supply chain, including end-users, have different needs. Education and outreach efforts need to be tailored to address how information and support can be provided to these different stakeholders.

### End-users

Early adopters are engaged, knowledgeable and able to articulate the business case or rationale for adopting a new technology. Market participants who put a high priority on things such as reducing the carbon footprint may also be able to see where a business case can be made.

A great diversity of firms operate in the MHDV marketplace. This impacts how and when a value proposition or business case for fuel switching can materialize. There are still fleet operators that are just beginning to learn about the prospects and

opportunities for fuel switching to natural gas and how this could benefit their operations. In these cases, a source of unbiased information is required to raise awareness and stimulate interest. In 2019, firms now also have the benefit of seeing what other fleets have accomplished through the use of natural gas use in their operations. This was not necessarily the case in 2010. This includes end-users such as transit operators, which until now have been reluctant to engage, especially in cases where they may have had a negative experience in the past.

Education and outreach efforts for end-users currently need to focus on tools and activities in four areas:

- NGV ambassadors -Creating recognition and visibility of early adopters as a reference and resource for potential new adopters;
- Business case development – Educating and equipping interested operators on the evaluation and decision-making process that will inform them if natural gas is right for their operations;
- Access to information – Maintaining easy-to-access, usable information that is current with trends and changes in the NGV space: and
- Informing hubs – Developing channels with organizations that end-users associate with and rely on for news and information.

In 2010, the recommended strategy was to create a top-down approach with a central, information-rich website supported by the bottom-up development of a national support network that brought people together for a series of meetings and workshops—new programming provided funding for these activities.

Since 2010, we have seen the emergence of Web 2.0, with tools such as social media—offering networking and graphic-rich sharing—and popular software applications ('apps'). These real-time, community-building capabilities can essentially bring the top-down and bottom-up approaches together to advance efforts in all four focus areas of education and outreach. For example, Cummins Westport offers a free Natural Gas Playbook that provides tools and guidance for evaluating the costs and environmental benefits of operating natural gas vehicles relative to diesel.



EBI's facilities and refuse fleet in Berthierville, Que.

## OEMs and Dealerships (Vehicle Supply Chain)

OEMs and dealerships are highly motivated to protect and leverage their brand, which has largely been built on delivering high-performance diesel vehicles. It is entrenched as their formula for success and their marketing materials and activities. Yet, potential NGV adopters often seek out this group first for information, as well as a positive signal that NGVs are an attractive option. Therefore, education and tools need to focus on helping fleet sales personnel be knowledgeable and equipped with up-to-date information to answer questions and concerns from potential NGV buyers. They need to know where to direct potential adopters for additional NGV-related expertise, especially for their refuelling needs.

Dealerships also need to make a significant investment in building facilities for servicing NGVs, causing some hesitation in actively marketing these vehicles. Education and outreach is required to help address this potential barrier.

It is also common for dealerships to operate within regional multi-dealer groups, with some level of centralized management. A preferred outreach approach might be to target head office managers with education and outreach materials and NGV

training sessions. Timing of outreach is especially critical when an incentive becomes available for operators to purchase NGVs for their fleet.

## Industry Supply Chain

Since Roadmap 1.0, the industry supply chain has become somewhat more diverse, particularly with the emergence of the RNG opportunity and its distinct industry players. Integrating the RNG angle to the natural gas narrative is key to raising awareness that natural gas solutions can now achieve even greater reductions when used in MHDVs.

The industry supply chain is a diverse group and one where much of the NGV and infrastructure expertise resides. The fact that no one player serves the overall sector poses an outreach leadership challenge. While there are competing companies in the mix, Chapter 5 emphasizes the importance of having the supply chain collaborate at a 'pre-competitive' level to offer useful, up-to-date resources and information that is in the common interest of all. This kind of collective effort is also important for ensuring that evolving synergies are captured in real-time within the industry, adding much-needed momentum to NGV adoption by a broad range of applicable vehicle sectors.

## Research and Development

The NGV industry's success in many ways relies on R&D being successful at identifying the technology priorities that require focus and securing long-term partnerships between industry and institutional research. The role of education and outreach is primarily to assist with up-to-date information sharing that ensures that research efforts are timely and relevant and that they address the needs of the targeted market segments. This effort will also ensure that development of new codes and standards stays in step with technology advances and trends.

## Government

In Roadmap 1.0, authorities and regulatory bodies were identified as a target audience, largely in view of the need for additional codes and standards work. Today, the government audience needs to consider two additional functions: 1) policy development and implementation, and 2) fleet procurement.

Policy in the area of climate change is one of today's top priorities and natural gas is one pathway that can play a role for the MHDV and freight segment. At the same time, EVs are commanding a great deal of attention and diesel technology is continuously improving. This combination of knowns and unknowns is blurring the lines on 'what makes sense where.' The contribution of NGVs in achieving policy objectives, such as climate change, need to be communicated regularly and consistently with policy makers.

The NGV industry will need to engage government at all levels—municipal, provincial and federal—to integrate green procurement strategies as part of their purchasing frameworks. Governments have a leadership role to play in showcasing clean technologies such as NGVs. The use of NGVs in this way can provide not only exposure, but key learnings for industry to build on.

## Conclusion

Today, education and outreach require a more targeted approach and range of delivery channels to address a variety of general and targeted audiences. Efforts need to serve end-users across a broader spectrum of the technology adoption curve beyond awareness-raising to cross what is known as the technology adoption chasm that lies between early adopters and larger, semi-mass markets.

Supply chain players and environmentally focused organizations can influence only to a limited degree as their own interests are too closely tied to NGV adoption. It is the experiences of early adopters that can offer the more compelling voice for bringing larger target audiences to the conversation.

To this end, enhancing Roadmap 1.0 outcomes with strategic Web 2.0 and other online capabilities can be highly useful in several 'real-time' ways—growing communications networks for different audiences, sharing new information, learning from the experiences of champions, training, and adding overall momentum and energy to the natural gas opportunity.

Deciding which tools to implement, and for which targeted audiences, requires that education and outreach objectives and plans be established in coordination with overall roadmap plans as they emerge from the roadmap's recommendations, as detailed in the next chapter.



## Chapter 10: Recommendations and Next Steps

The preceding chapters provide context and foundational research for the following strategic recommendations developed with industry experts, researchers, end-users and members of the Natural Gas Roadmap Implementation Committee. There is an understanding that outcomes can be achieved only through a collaborative effort where all stakeholders play a role.

### Roadmap 2.0 Recommendations and Proposed Actions

A total of eleven recommendations are proposed in the same four key broad areas as the first Roadmap:

- De-Risk Investment and Early Adoption
- Address Information Gaps
- Grow and Sustain Markets
- Ensure Ongoing Competitiveness

Eight of the eleven recommendations are similar to those in Roadmap 1.0 as persistent barriers continue to impede the use of natural gas in transportation.

Three similar recommendations to Roadmap 1.0 remain effectively unchanged, as they are critical to continued investment in natural gas applications.

These include:

- Vehicle Premium
- Research and Development
- Use of Natural Gas in Other Applications

Five recommendations have evolved and expanded in response to earlier experiences with natural gas applications, new policy drivers, technological advances, investment, and other factors that have influenced the growth of the NGV market.

These include:

- Corridor and Return-to-Base Infrastructure
- Demonstration
- Education and Outreach Strategy
- Codes and Standards and Regulations
- Implementation Committee

Three new recommendations are proposed in Roadmap 2.0 to address emerging opportunities and newly identified barriers to the use of natural gas in transportation. These include:

- Vehicle Maintenance Facility Costs
- RNG Infrastructure
- RNG Market

The following sections summarize the rationale underpinning each recommendation. They also propose potential actions and considerations raised in stakeholder discussions which can guide the implementation of each recommendation.

# Section 1: De-Risk Investment and Early Adoption (Recommendations 1-6)

To accelerate adoption of NGVs in greater numbers, end-users require an anticipated return on investment within an acceptable time frame, as well as assurances that their investment will help achieve their organization’s GHG reduction targets. Investment risks need to be addressed across the totality of NGV adoption requirements, including vehicle costs (purchase and maintenance), refuelling infrastructure costs, and any added cost related to the use of RNG to achieve greater carbon footprint reductions.

---

## Vehicles – Premium and Maintenance

### Vehicle Premium

The diesel-fuelled vehicle, being the incumbent technology in the MHDV space, continues to dominate transportation market segments being targeted by NGVs that have a higher upfront capital cost. This creates a barrier to adoption.

Offsetting these capital costs continues to be a way of de-risking adoption and decision-making for end-users. Financial support, such as incentives or tax instruments, could help offset this price premium.

Precedents exist for market intervention by governments and industry to assist in lowering purchase barriers.

For example, financial incentives for the purchase of NGVs in jurisdictions such as Quebec and British Columbia, have proven to be successful. Such measures, typically introduced on a temporary basis, can help NGVs compete on a level playing field. As sales increase, economies of scale often help further accelerate reductions in the purchase price of new technologies and these types of incentives are no longer required for the new technology to be competitive.

**1. Vehicle Premium** – Need for financial support to offset price premium and de-risk decision-making for end-users ('continue')

**Rationale** – The vehicle price premium remains a significant barrier to adoption across all market segments. Offsetting capital costs on vehicle purchases will help de-risk adoption. Future savings will lead to replication.

## Vehicle Maintenance

Beyond the vehicle premium, end-users will also incur **upfront costs for building and/or retrofitting their facilities** to store and maintain NGVs. Industry associations and end-users have indicated that costs associated with vehicle repair and maintenance are higher for NGVs than diesel vehicles. This has become a barrier, not only for NGV adoption by fleet operators, but also for vehicle dealerships to proactively promote NGV sales, thereby creating a barrier to adoption.

Finally, **funding support for transitioning operations to lower carbon, i.e. change management**, can help fleet and maintenance managers when making increasingly complex decisions on optimal fleet and fuel mix.

### 2. Vehicle Maintenance Facility

**Costs** – Provide financial support to partially offset costs to build/ retrofit maintenance facilities ('new')

**Rationale** – The added cost of building and/or converting, and/or upgrading NGV maintenance facilities is a barrier to adoption. NGV-friendly maintenance facilities are needed at both the dealerships' and the owners' facilities to ensure ongoing maintenance of fleet vehicles.

## Infrastructure

Investment in NGV refuelling infrastructure is still part of the chicken and egg conundrum when it comes to deploying NGVs in Canada. **Infrastructure deployment and maintenance costs remain high** and are not spread widely across a large user base in some cases, presenting an ongoing and significant barrier to the adoption of NGVs. Fiscal measures implemented on a temporary basis have been shown to effectively address this infrastructure barrier and de-risk decision-making for fleets.

As additional NGVs are deployed, there will be an even greater need for widespread infrastructure along key corridors and in areas where NGV use is anticipated to be highest. Temporary financial support for investing in infrastructure can reduce the risk of investment, as proven through the Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative, which to date has resulted in seven new natural gas stations being constructed in key locations.

### 3. Corridor and Return-to-Base Infrastructure

– Continue to deploy fuelling infrastructure involving public/private partnerships to expand use of infrastructure to other modes (i.e. off-road, ports and rail) and multiple users (trucking, transit, fleets and municipalities)

**Rationale** – High refuelling infrastructure installation costs remain a significant barrier to deployment. Access to infrastructure remains uneven across the country and not optimally used by multiple types of users, different modes and more than one fleet. Cost savings can be realized by fleets and business cases improved for infrastructure developers by providing refuelling solutions for multiple types of users and modes.

---

## RNG

### RNG Market

RNG is emerging as a **near-term solution for lower carbon fuels**. The technology developments in the last five years have allowed this renewable energy source to better integrate itself into existing energy infrastructure. Although early adopters have developed systems for integrating RNG into local refuelling stations, there remains a lack of understanding on the process and costs involved in using RNG as a transportation fuel. Similar challenges exist when developing closed-loop systems, as standards and best practices are not widely shared. The policy and regulatory framework for developing the RNG marketplace is also evolving. There is a need to **ensure that stakeholders (e.g. policy makers) are aware of its benefits, that early experiences and successes are shared** widely, and that stakeholders work together to create and expand the RNG marketplace.

### RNG Infrastructure

While RNG is gaining interest as a low-carbon fuel to decrease GHG emissions, capital investments for its production, processing and blending within existing natural gas distribution networks (e.g. pipelines) is **lacking**. Although the supply of RNG can be obtained from municipal waste, wastewater treatment facilities and other sources without the ability to connect it with markets that can use it (RNG will remain a longer-term solution) for end-users considering fuel switching opportunities, an **adequate dependable and long-term supply** is required.

**4. RNG market** – Engage stakeholders to raise awareness of RNG opportunities with a goal of growing the RNG market

**Rationale** – RNG is an emerging area with benefits that are not fully understood or implemented through a marketplace mechanism that is applicable to transportation.

**5. RNG infrastructure** – Enable capital investment for production, processing, blending and connecting RNG supply to existing pipeline with a goal of increasing availability of RNG for transportation use

**Rationale** – Use of RNG as a transportation fuel is one way to decrease GHG emissions from medium- and heavy-duty engines. Investment is needed to develop RNG infrastructure.

## Demonstration

As NGVs and their associated infrastructure (e.g. refuelling and maintenance) enter the marketplace, real-life data on their use can be helpful in convincing the next level of adopters that this is a proven solution that can work for their fleet. Demonstrations provide concrete evidence that barriers encountered with a new technology can be overcome and that made-in-Canada solutions are readily available. Demonstration at pre- and post-commercial stages can **increase the comfort level with new technologies.**

**As familiarity with emerging applications becomes more widespread,** investor interest will grow while investment risk decreases. For fleets facing a multitude of options, and often with limited investment capital, **demonstrations are a required proof of concept for emerging applications** and key to showcasing the competitiveness of Canadian technologies.

**6. Demonstration** – Create new opportunities to demonstrate the use of natural gas to raise awareness and experience with new applications

Conduct feasibility studies and assessments for specific fleets to address technical barriers

**Rationale** – Demonstration projects provide real-life experience and real-time data, proof of concept, suitability of the application, increase familiarity/comfort with new technologies, decrease investment costs and establish competitiveness of Canadian technology.

## Section 2: Address Information Gaps and Engage (Recommendation 7)

### Education and Outreach

As NGVs gain traction, there is a need to inform and engage stakeholders on their benefits, costs and optimal use. A **targeted and comprehensive outreach strategy** to improve two-way communication, expand reach to target markets, and educate key stakeholders on the benefits of this technology are required. Improving access to accurate and reliable information and fostering the development of audience-focused engagement tools and activities, including in-fleet demonstration opportunities, would counter misinformation and raise the profile of NGVs. Fleet operators would be better equipped to make fully informed decisions, leading to the implementation of optimal fuel-switching solutions for their operations.

The prevalence of social media and other online interactive tools has enabled some end-users, such as fleet managers, to inform themselves quickly and participate within communities of peers in the clean technologies space. However, many end-users remain unaware of the existing tools and information available to inform their decisions. **Improved use of online tools** can significantly and cost-effectively provide technical guidance to end-users on integrating natural gas into fleets.

**7. Education and outreach strategy** – Develop a more targeted strategy to engage and educate key stakeholders on NG/RNG with practical, modern outreach tools

**Rationale** – As the market expands and newer technologies emerge (including RNG integration), there is an increased need for up-to-date reliable information as well as growing the NG/RNG education network.

A targeted and comprehensive outreach strategy that incorporates current online tools can significantly improve two-way communication, expand reach to target markets, educate on the benefits of NG/RNG, and cost-effectively provide technical guidance to end-users on integrating NG into fleets.

## Section 3: Grow and Sustain Markets (Recommendations 8-9)

### Codes, Standards and Regulations

A sustained market uptake of NGVs requires up-to-date codes and standards and consistency in their application so that NGV products can adapt to regional needs and technology innovations. Expanding the existing working group to include additional jurisdictions can also ensure collaboration and consistency in the development and use of natural gas products/applications and address regulatory barriers. More specifically, the codes and standards working group could be expanded to better engage key stakeholders involved in implementation and to coordinate with authorities having jurisdiction. Ongoing **financial support** would be required for updating codes and standards development comprehensively, in a timely manner and across jurisdictions.

#### **8. Codes, Standards and Regulations**

– Continue to develop and update codes and standards, and expand working groups' membership to address ongoing and emerging regulatory issues across jurisdictions to ensure greater implementation

**Rationale** – Priority codes and standards have been developed to address gaps but need to be kept up to date for newer technologies. Jurisdictional gaps in implementation and regulation/enforcement of codes and standards continue to slow widespread adoption.

### Implementation Committee

Expansion of the existing Implementation Committee with representation from a broader membership across industry and governments will ensure that the full spectrum of government and industry expertise is harnessed to develop the natural gas market and that carbon reduction strategies are aligned.

The Implementation Committee has played **a key role in providing oversight and guidance** to strategically implement Roadmap 1.0 recommendations. Its oversight role will continue to be required when implementing this updated set of recommendations and would be strengthened by taking a greater role in prioritizing, planning and leading targeted engagement initiatives. **Additional committee members** should include individuals from other jurisdictions and complementary industry sectors that would benefit from collaboration around government policies and priorities.

#### **9. Implementation Committee**

— Expand membership to include other jurisdictions and additional industry sectors, and evolve role of Implementation Committee (IC) to prioritize, plan and lead engagement initiatives

**Rationale** – Oversight and guidance continue to be required to implement Roadmap 2.0 recommendations. Stakeholders recommend revisiting committee composition and expanding membership in order to further understand and integrate the natural gas /RNG opportunity in GHG regulations and climate change policies.

## Section 4: Ensure Ongoing Competitiveness and Advancements (Recommendations 10-11)

### Research and Development

Increased R&D is required to continue developing the clean technology market in Canada. Further investment in R&D specifically as it relates to reducing the cost premium of NGVs while maximizing their operational and environmental benefits.

**Establishing an R&D working group** would provide better coordination and guidance to prioritize R&D investments.

**10. R&D** – Further investment in R&D with a focus on reducing/eliminating the cost differential and maximizing NGVs’ operational and environmental benefits

**Rationale** – NG R&D is needed to reduce the incremental cost of NGV-related technologies so that it can be cost-competitive. Further reducing methane emissions across the NGV system lifecycle is also important. R&D is also needed to further advancements in RNG use across other modes. A standalone working group could be established to prioritize work in these areas.

### Use of Natural Gas in Other Applications

**Financial support for the use of natural gas in other transportation applications** (e.g. rail and mine haul, targeted LDV applications) should continue to be explored to **stimulate NGV growth in on-road transportation markets by better leveraging infrastructure and R&D investments** across a larger group of end-users. It will also ensure that environmental benefits are more widespread across transportation.

Table 7 identifies where stakeholders can take a leadership role in implementing recommendations. For 9 of the 11 recommendations, all key stakeholder groups are involved, including natural gas producers, transporters and distributors, infrastructure developers and vehicle suppliers, end-users, and industry associations. Extensive coordination and collaboration among these stakeholder groups, along with specific stakeholders assuming leadership for implementation, will ensure natural gas is a key solution toward decarbonizing transportation.

**11. Use of NG in Other Applications** – Continue to explore use of NG in other transportation applications to expand market (e.g. rail and mine haul)

**Rationale** – It is important to continue to explore the potential for natural gas use in other transportation applications because it increases demand for NG and offers opportunities to leverage the cost of infrastructure across more applications and users.

**Proposed Actions** – Feasibility studies to further investigate opportunities

**Table 7: Natural Gas Use in Transportation – Roles and Responsibilities**

|  |  | Governments | NG Producers, Transporters, and Distributors | Infrastructure and Vehicle Supply Stream | End-Users | NGOs (e.g. CNGVA, CGA) |
|--|--|-------------|--|--|-----------|------------------------|
| <b>De-Risk Investment</b>                              | Vehicle Premium                            | ■           | ■  | ■  | ■         | ■                      |
|  | Vehicle Maintenance Facility Costs         | ■           | ■  | ■  | ■         | ■                      |
|  | Corridor and Return-to-Base Infrastructure | ■           | ■  | ■  | ■         | ■                      |
|  | RNG Infrastructure                         | ■           | ■  | ■  | ■         | ■                      |
|  | RNG Market                                 | ■           | ■  | ■  | ■         | ■                      |
|  | Demonstration                              | ■           | ■  | ■  | ■         | ■                      |
| <b>Address Information Gaps and Engage</b>             | Education and Outreach Strategy            | ■           | ■  | ■  | ■         | ■                      |
| <b>Grow and Sustain Markets</b>                        | Codes and Standards                        | ■           | ■  | ■  |           | ■                      |
|  | Implementation Committee                   | ■           | ■  | ■  | ■         | ■                      |
| <b>Ensure Ongoing Competitiveness and Advancements</b> | R&D  | ■           | ■  | ■  |           | ■                      |
|  | Use of NG in Other Applications            | ■           | ■  | ■  | ■         | ■                      |

# APPENDICES



## Appendix A: Inputs, Considerations and Reviews by Various Industry Stakeholders

| HIGHWAY TRUCKING – Stakeholder Comments    |   |
|--|---|
| <b>Profitability</b>                       | <ul style="list-style-type: none"> <li>• Incremental cost of using natural gas (either CNG or LNG) is a deterrent. Investment and payback periods are particularly sensitive with a bias toward a faster payback and lower up-front investments.</li> <li>• There is a lack of government incentives to make a business case, and where they exist, the delay between announcement, program launch, fleet purchase, and actual funding is often unworkable.</li> <li>• Additional costs to build or upgrade maintenance facilities to meet gas-safe requirements are prohibitive.</li> <li>• Uncertainty around resale value for NGVs has a negative impact on the business case.</li> <li>• Increased weight of fuel system results in lost revenue for certain “for hire” carriers.</li> <li>• Extra cost of using RNG to reduce emissions is a deterrent.</li> </ul> |
| <b>Availability</b>                        | <ul style="list-style-type: none"> <li>• Vehicles in Canada can carry loads greater than 36,300 Kg (80, 000 lbs) and/or haul over mountainous terrain, which requires engines with greater horsepower than the available CWI 12 L. Aftermarket products for higher horsepower engines are less desirable than OEM supported engines.</li> </ul>   |
| <b>Accessibility</b>                       | <ul style="list-style-type: none"> <li>• Lack of public fuelling presents a risk and constrains routes.</li> <li>• Long Combination Vehicles (LCV) are limited in where they can operate and refuel.</li> </ul>   |
| <b>Assurance/<br/>Level of<br/>comfort</b> | <ul style="list-style-type: none"> <li>• Demonstration vehicles for fleets to “try before your buy” would attract and retain new entrants.</li> <li>• Resources are needed to evaluate what fuel switching can mean for specific operations.</li> <li>• Lack of clarity around the wider introduction of RNG as a fuel.</li> </ul>  |
| <b>Additional<br/>Comments</b>             | <ul style="list-style-type: none"> <li>• Truck OEMs are highly invested in, and generally favour, selling diesel trucks</li> <li>• Media coverage and government support focusses on new technologies that have promise but have yet to enter the market and prove their merits. It distracts from what natural gas can positively accomplish right away.</li> </ul>  |

## VOCATIONAL TRUCKS/REFUSE/MUNICIPAL/TRANSIT – Stakeholder Comments

|  |   |
|--|---|
| <b>Profitability</b>                       | <ul style="list-style-type: none"> <li>• May not have access to the incentives to build a business case. Funding requirements in grants from other levels of government may not consider natural gas an eligible alternative fuel.</li> <li>• Additional cost to build or upgrade maintenance facilities to meet gas safe requirements can be prohibitive. Transit in particular can be very space constrained and face high costs for added space.</li> <li>• Increased weight and distribution of a fuel system can force a reduction in payload and possibly require more frequent refuelling and routing changes.</li> <li>• Use of RNG is attractive for meeting emissions reductions commitments. However, the extra cost requires more clarity on availability and pricing.</li> </ul> |
| <b>Availability</b>                        | <ul style="list-style-type: none"> <li>• Despite wide range of available engines there are limited vehicle OEM offerings.</li> <li>• Desired vehicle run-time exceeds the available capacity of fuel for high-consumption municipal and vocational fleets.</li> </ul>   |
| <b>Accessibility</b>                       | <ul style="list-style-type: none"> <li>• Access to private, public or shared refuelling stations very limited.</li> <li>• Lack of maintenance facilities and trained technicians (home base, multiple bases and along primary corridors where services might be needed or expected).</li> <li>• Canopy height at some public refuelling stations insufficient for raised coach buses.</li> </ul>  |
| <b>Assurance/<br/>Level of<br/>comfort</b> | <ul style="list-style-type: none"> <li>• Insufficient resources to evaluate what fuel switching can mean for specific operations.</li> <li>• Confusion around suitability of competing powertrain technologies.</li> <li>• Shortage of usable information and quantifiable comparisons to satisfy higher public scrutiny and multi-level decision making where there is great attention to optics.</li> <li>• Solutions are very situation-specific – operator has difficulty seeing a clear choice.</li> <li>• Lack of clarity around the framework for the introduction of RNG as a fuel.</li> </ul>  |
| <b>Additional<br/>Comments</b>             | <ul style="list-style-type: none"> <li>• There are various truck duty cycles between different types of busses.</li> </ul>  |

**SUPPLY CHAIN/OEMs & DEALERSHIPS/ ACADEMIA/INVESTORS/GOVERNMENT – Stakeholder Comments**

|                             |  |
|-----------------------------|--|
| <p><b>Profitability</b></p> | <p><b>Supply Chain</b></p> <ul style="list-style-type: none"> <li>• Diversity and fragmentation within target markets makes cost-effective outreach and marketing difficult.</li> <li>• Difficult to present a sellable business case for customers wanting to start small (as many do).</li> <li>• Large distances between early-adopting customers and installations hamper cost-effective onsite servicing.</li> <li>• Technical work requires a well-paid and suitably trained full-time workforce while business tends to alternate between intensive and quiet periods.</li> <li>• Small markets mean slow payback on high cost of specialized tools and equipment.</li> </ul> <p><b>OEMs &amp; Dealerships</b></p> <ul style="list-style-type: none"> <li>• Cost of on-board NG fuel tanks drives up the vehicle cost and can be hard to recoup.</li> <li>• Cost of product R&amp;D and marketing is often not viable for relatively small markets.</li> <li>• Low economies of scale for production keeps vehicle cost high.</li> <li>• Costly to install servicing and refuelling facilities to serve a relatively small market.</li> </ul> <p><b>Academia</b></p> <ul style="list-style-type: none"> <li>• Rely on ongoing proof of competitiveness of Canadian technology, including RNG.</li> <li>• Generally require sustained cash support from industry to leverage provincial and federal matching dollars.</li> <li>• Government research dollars are trending away from combustion engine-related research toward electric vehicle/battery research.</li> </ul> <p><b>Governments (return on investment)</b></p> <ul style="list-style-type: none"> <li>• Other demands for tax dollars; risk of over-investing in one technology at the cost to another.</li> <li>• Under-estimating the uptake of financial incentives or subsidies</li> </ul> |
| <p><b>Availability</b></p>  | <p><b>OEMs &amp; Dealerships</b></p> <ul style="list-style-type: none"> <li>• Vehicle range is highly correlated to market segments and often to the specific end-user needs – economies of scale are difficult to achieve.</li> </ul>   |
| <p><b>Accessibility</b></p> | <p><b>Supply Chain</b></p> <ul style="list-style-type: none"> <li>• Non-pipeline areas or pipelines with low pressure can require repositioning of assets or otherwise significantly add to the cost of building infrastructure.</li> </ul>  |

## SUPPLY CHAIN/OEMs & DEALERSHIPS/ ACADEMIA/INVESTORS/GOVERNMENT – Stakeholder Comments

Assurance/  
Level of  
comfort

### Supply Chain

- Fragmented markets create variation in environmental drivers vs. cost savings drivers.
- Market growth projections are unclear due to competing technologies and evolving government policies.
- Risk/reward of business development investment is new to this segment of the economy. Lacks the high payoff and funding pools that exist for some industries.

### OEMs & Dealerships

- Inconsistency among staff in familiarity with NGV products and benefits.

### Academia

- Industry researchers typically bound by confidentiality requirements, which can make information-sharing a challenge.
- Interval time between understanding the need and accessing funding can affect resource decisions.

### Governments

- Heavy reliance on the availability of a full cross-section of industry to provide balanced, up-to-date knowledge and advice.
- Long cycles for planning and delivering initiatives in an industry that is moving quickly.



## Appendix B: Priority Research and Development Areas

### 1. Refuelling Infrastructure and Procedures:

#### Challenges and Needs:

An important barrier to the deployment of natural gas vehicles is the availability, cost and reliability of the current refuelling infrastructure and procedures. Current challenges for both LNG and CNG include:

- High capital cost of refuelling stations
- Achieving a maximum fill due to the heat of compression (CNG only)
- Longer refuelling time compared to a diesel vehicle
- Fugitive methane emissions
- Lack of clarity regarding NGV fuel quality needs

#### Priority R&D Areas:

*Improve Fill Quality (CNG only):* Increase vehicle range by maximizing the fuel cylinder capacity utilization through better control of the gas temperature throughout the filling process.

*Smaller Scale Refuelling Facilities:* Develop small or modular refuelling facilities to lower cost for small- to medium-sized fleets and to allow operators to scale up as their NGV fleets expand.

*Operational Efficiency:* Increase the refuelling station operational efficiency. An option is to increase on-site CNG storage to reduce fill times and increase capacity.

*Smart Refuelling:* Achieve better monitoring and control of fuel filling with improved sensors, communication and software. This can result in shorter fill time, improved safety, monitoring of fuel quality and maximizing tank capacity without methane releases.

*Fuel Quality:* Minimize vehicle operability and durability challenges by clearly defining a fuel standard to eliminate current ambiguity around practices (SAE J1616) and standards (ISO 15403) that allow fuel quality requirements to be at the discretion to users.

### 2. Fuel Storage

#### Challenges and Needs:

Fuel storage systems are a significant proportion of the additional costs of natural gas vehicles over a diesel vehicle. Primary challenges with on-board natural gas storage include:

- CNG – Storage capacity, size, weight, energy density, shape and cost
- LNG – Size, weight, energy density, cost and possible venting

#### Priority R&D Areas:

A cost-effective storage technology operating at greater energy density and with minimized energy and material costs is needed.

*Adsorbent Based Storage (CNG only):* Develop low-pressure, high-density natural gas storage vessels. Adsorbent materials could provide high-density storage at significantly lower pressures; however, there is a need to make these systems lighter and more tolerant of fuel contaminants (e.g. compressor oil).

*Conformable Storage Vessels:* Increase natural gas storage through enhanced vehicle integration especially for light- and medium-duty vehicles. Conformable natural gas storage vessels would enable integration into the vehicle with less use of passenger or cargo space.

*Low-Cost Storage:* For CNG, develop carbon and glass fiber cylinders that cost less, while minimizing gas permeation. Additionally, lower cost storage for LNG is required.

*Venting for LNG:* Develop cost-effective strategies to eliminate venting of methane to the atmosphere.

### 3. Engines

In North America, natural gas engines are mainly developed for medium- and heavy-duty trucks. Natural gas engines for light-duty trucks are also available.

Engine types can be broadly classified according to how the fuel-air mixture is generated and how the mixture is ignited. This results in three main categories of natural gas engines:

- Stoichiometric or lean burn, premixed, NG/air spark ignition (**SI**) engines;
- Lean burn, premixed NG injection, diesel pilot, compression ignition, dual fuel (**DF**) engines;
- Lean burn, late high-pressure direct NG injection, diesel pilot, compression injection, DF, (**HPDI**) engines.

#### Challenges and Needs:

Heavy-duty natural gas engine development must be targeted to meet existing and developing regulatory requirements. Many natural gas engine challenges and needs are specific to the engine type as follows:

*Natural gas spark ignition engines (SI)* have relatively simple design and low emissions with aftertreatment system typically consisting of only a three-way catalytic converter. Challenges include lower efficiency than diesel engines and high methane emissions.

*Natural gas compression ignition engines* with higher power, torque, and higher efficiency compete with diesel engines in heavy-duty applications. The challenge is achieving a suitable dual fuel strategy. The three-way catalytic converter is not an option.

*Dual Fuel (pre-mixed natural gas, diesel pilot) compression ignition engines (DF)* are a common approach when converting an existing diesel engine platform to operate on natural gas, and use a diesel pilot spray for ignition instead of a spark plug.

These engines have high methane emissions due to high in-cylinder sources and difficult conditions for methane oxidation catalysts.

*Direct injection compression ignition engines (HPDI)* inject natural gas (most suitably LNG) at a high pressure directly into the cylinder using a pilot injection of diesel to initiate the ignition process. HPDI engines have similar efficiency and power output to diesel engines and they currently provide more power (i.e. > 400 hp) and higher efficiency than SI engines, making them the preferred heavy-duty engines. The diesel pilot, however, adds complexity. Igniting the methane jet with a hot surface (such as a glow plug) is an option, but the challenge is sourcing a hot surface material that can withstand high and cycling temperatures. Another challenge of hot surface ignition is spreading the ignition to all injected gas jets beyond the initiation point.

#### Priority R&D Areas:

*Methane Emissions:* Reduce engine-out methane emissions for all engine types. While aftertreatment systems can help, the challenge is that typical exhaust temperatures found in many heavy-duty engines are not high enough for currently available catalysts to effectively lower methane emissions.

*NOx Emissions:* Reduce engine-out NOx emissions for lean burn engines to remain competitive (SI engines are more capable of meeting future NOx limits for heavy-duty engines).

*Engine Efficiency:* Improve the efficiency of all types of natural gas engines to compete with heavy-duty diesel engine efficiency (approaching 55% BTE). Also, to remain competitive for heavy-duty applications, dual fuel engine efficiency must increase relative to SI engines to justify the added cost. Hybridization and electrification are developing quickly and may offer potential to improve overall NGV efficiency.

*Emissions Control Durability:* Develop suitable sensors and related algorithms to facilitate natural gas engine on-board diagnostic (OBD) to ensure emissions compliance over the vehicle lifetime by monitoring components whose failure would cause non-compliance.

*Powertrain Hybridization:* Identify cost-effective ways to utilize powertrain hybridization. Range-extended, dual mode, and mild hybridization could further reduce criteria and GHG emissions from NGVs.

#### 4. Exhaust Aftertreatment

Aftertreatment systems are essential for natural gas engines to meet their emission targets, with methane catalysts to reduce methane emissions being the most important.

##### Challenges and Needs:

An immediate need exists for an efficient methane conversion catalyst system that:

- Operates at the lower exhaust gas temperatures of lean burn engines
- Is tolerant of typical levels of sulfur and water found in natural gas engine exhaust
- Contains the lowest possible catalyst loading
- Is as small as possible
- Is economical
- Is operational for at least the lifetime of an NGV

##### Priority R&D Areas:

*Lower Temperature Operation:* Develop catalyst formulations that lower the light-off temperature and require less platinum group metals (PGM) loading than current methane oxidation catalysts with high light-off temperature and high PGM loading. Also explore effective exhaust gas thermal management strategies by raising exhaust temperature to improve catalyst performance. While the light-off temperature for methane over three-way-catalysts (TWC) is lower than over oxidation catalysts, they are still relatively high. TWC formulations with lower light-off temperature and/or lower PGM loadings are required.

*Catalyst Deactivation:* Ensure catalyst durability by developing catalyst formulations less sensitive to deactivation caused by typical levels of sulfur and water in engine exhaust.

*Ammonia Slip:* Develop catalyst systems or control strategies to lower the amount of ammonia slip from TWCs, typically in SI natural gas engines using TWCs to achieve very low NO<sub>x</sub> emissions.

*System Integration:* Develop engine/aftertreatment integration features that improve catalyst performance. As TWC performance is sensitive to air-fuel ratio control, engine control strategies that maximize the time that the TWC is at the optimal air fuel ratio can ensure minimum emissions over the useful life of the engine. Regeneration of methane oxidation catalysts for lean burn engines can be facilitated by periodically changing the temperature and exhaust gas composition at the catalyst inlet.

#### 5. System Level Analysis and Data

##### Challenges and Needs:

As the natural gas transportation system evolves, system level analyses require comprehensive, up-to-date data specifically for assessing the performance, cost and emissions reductions from the various technologies being developed to transition to lower carbon transportation. It is difficult to measure and compare different technologies without adequate research on the real-life performance of NG applications.

##### Priority R&D Areas:

*Lifecycle Assessment:* Update Lifecycle Assessment tools such as GREET and GHGenius with the most accurate Canadian process pathways and environmental impacts so that accurate environmental impacts of different options can be compared.

*Techno-Economic Assessment:* Explore alternative pathways between natural gas and mobility, including CNG, LNG, dimethyl ether (DME), methanol, Fischer-Tropsch fuels and electricity, to determine the optimum pathways for each transportation sector.

#### 6. Codes, Standards and Guidelines

The development of codes, standards and guidelines has made significant progress with many new ones created or revised under an agreement between NRCAN and the CSA Group. The development of codes, standards and guidelines continues with many under development, as listed in the table below.

**Table 8:** Codes, Standards and Guidelines Being Created or Revised

| Year Forecasted | Designation    | Description  | Type                              |
|-----------------|----------------|--|-----------------------------------|
| 2017            | NGV 4.1        | CNG Dispensing Systems   | New Edition                       |
| 2017            | NGV 4.3        | Temperature Compensation Guideline for Compressed Natural Gas Vehicle Fuelling   | New Standard                      |
| 2018            | B108           | NGV Station Installation Code  | New Edition<br>English and French |
| 2018            | NGV 6.1        | Compressed natural gas (CNG) fuel storage and delivery systems for road vehicles | New Standard                      |
| 2018            | LNG 3.1 – 3.19 | Road vehicles -- Liquefied natural gas (LNG) fuel system components              | New Standards (ISO Adoptions)     |
| 2018            | LNG 4.1        | LNG Dispensing Systems   | New Standard                      |
| 2018            | B401           | NGV maintenance facilities code  | New Code                          |
| 2018            | NGV 2          | Compressed natural gas vehicle fuel containers                                   | New Editions                      |

With the development of new technology within natural gas transportation, codes, standards and guidelines must be synchronized and integrated quickly into easily accessed training materials to facilitate the use of this technology in a consistent fashion. The following details where there are current gaps in technology.

*New Tank Technologies:* Currently under development, certification procedures are required for natural gas conformable storage tanks and adsorbent based-storage tanks.

*Fuel Quality:* Available NGV fuel quality control instruments (SAE J1616 and ISO 15403) lack clearly defined mandatory limits with the potential to impact vehicle operability and reliability. A significant increase in NGV usage would justify development of a Canadian fuel quality standard for NGVs focused on ensuring that contaminants controllable

at refuelling sites (water, heavier hydrocarbons, particulates and potentially corrosive components) would have minimum impact on vehicle performance. A better and standard metric is also required for measuring energy delivery to a vehicle as engine performance is predicated by fuel quality.

*Communication Protocol:* A standardized communication protocol to allow the vehicle to communicate with the station would improve accuracy and simplify the maximization of fuel cylinder capacity utilization. Such a system could also be designed to handle transactional data automatically.

*Retrofitted Engines:* It is increasingly difficult to adequately retrofit diesel engines for natural gas operation, creating a need to tighten regulations on retrofitted engines especially regarding methane emissions. Doluptati num eum facea saecide officip sanimet et, sum voluptatem qui sitemodias imaximpore eum eum dem voloressita vita nonet et quas acipiendel magnimi, aut eum lam, con re velecum rerumque voluptat que restinis eos quame molupicae pori blaccum nit voloreicto voluptiatur?

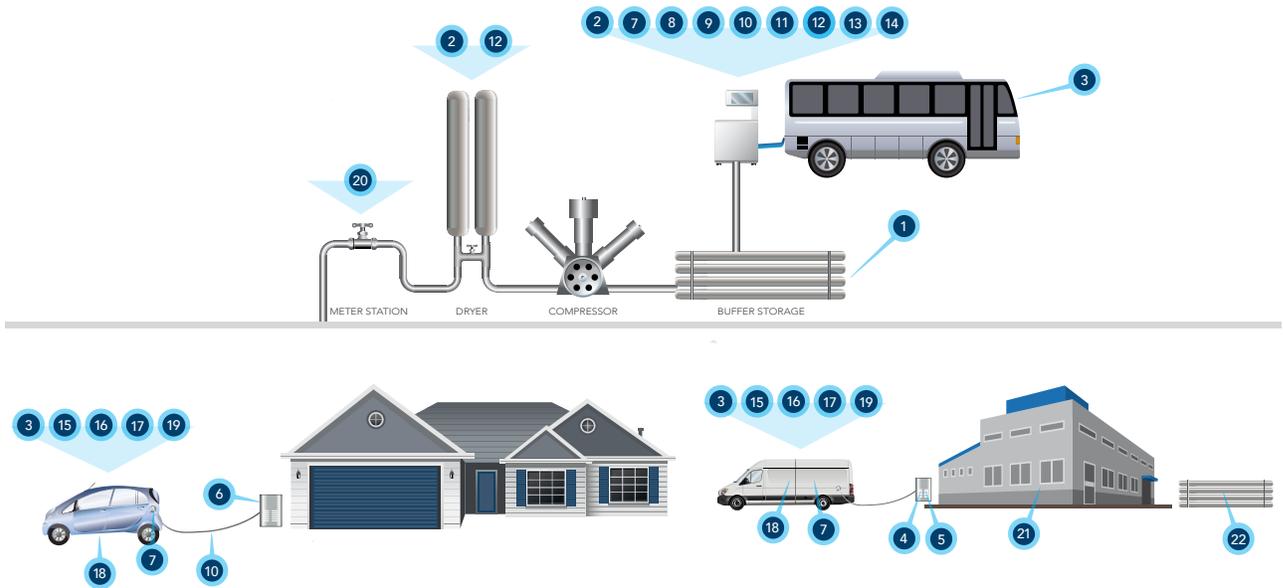
# APPENDICES



## Appendix C: Natural Gas Standards

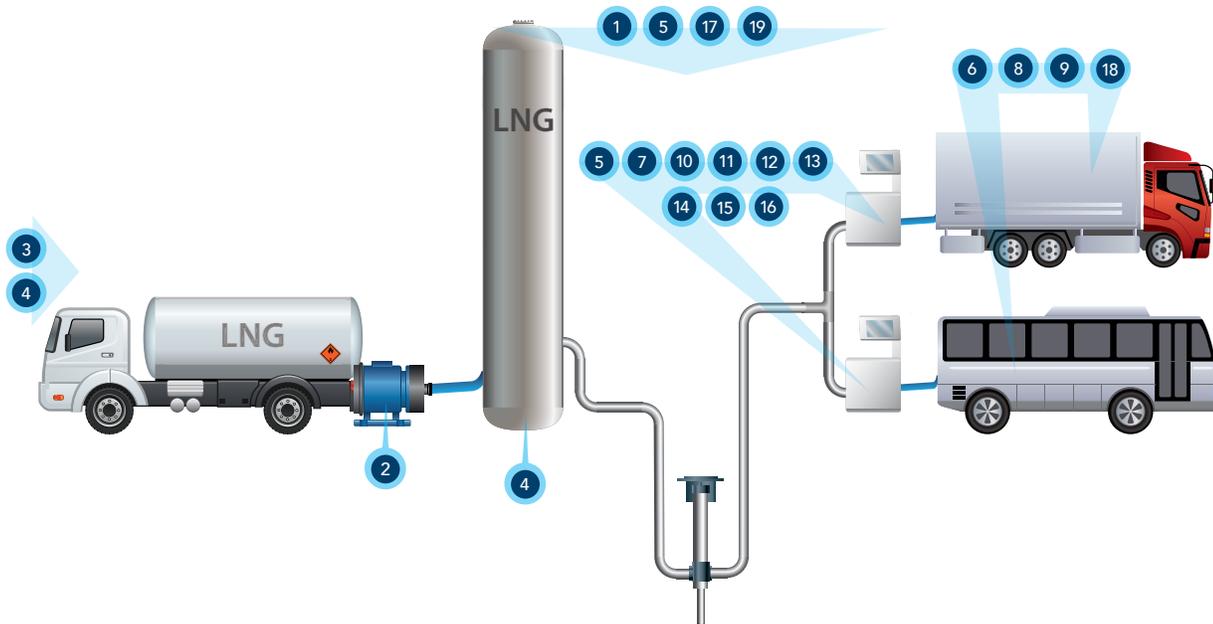
### ALTERNATIVE FUELS

## Compressed Natural Gas (CNG)



- |   |   |  |   |
|---|---|--|---|
| <p><b>1 CSA B51 PART 3</b><br/>Compressed Natural Gas and Hydrogen Refueling Station Pressure Piping Systems and Ground Storage Vessels</p> <p><b>2 CSA B108</b><br/>Natural Gas Fueling Stations Installation Code</p> <p><b>3 CSA B109</b><br/>Natural Gas for Vehicle Installation Code, Part 1</p> <p><b>4 NGV 5.2</b><br/>Vehicle Fuelling Appliances (VFA)</p> <p><b>5 B149.1</b><br/>Natural Gas and Propane Installation Code</p> <p><b>6 NGV 5.1</b><br/>Residential Fuelling Appliances (RFA)</p> | <p><b>7 NGV 1</b><br/>Compressed Natural Gas Vehicle (NGV) Fuelling Connection Devices</p> <p><b>8 NGV 4.1</b><br/>NGV Dispensing Systems</p> <p><b>9 CSA 12.52 / NGV 4.2</b><br/>Hoses for Natural Gas Dispensing Systems</p> <p><b>10 NGV 4.3</b><br/>Temperature Compensation Systems for Compressed Natural Gas Vehicle Fueling Stations</p> <p><b>11 CSA 12.54 / NGV 4.4</b><br/>Breakaway Devices for Natural Gas Dispensing Hoses and Systems</p> <p><b>12 CSA 12.56 / NGV 4.6</b><br/>Manually Operated Valves for Natural Gas Dispensing Systems</p> | <p><b>13 NGV 4.7 PENDING</b><br/>Automatic Valves for Natural Gas Dispensing Systems</p> <p><b>14 CSA 12.8 / NGV 4.8</b><br/>Natural Gas Vehicle Fueling Station Reciprocating Compressor Guidelines</p> <p><b>15 CSA NGV 2</b><br/>Compressed Natural Gas Vehicle Fuel Containers</p> <p><b>16 CSA B51 PART 2</b><br/>High Pressure Cylinders for the On-Board Storage of Natural Gas and Hydrogen as Fuels for Automotive Vehicles</p> <p><b>17 CSA 12.3 / NGV 3.1</b><br/>Fuel System Components for Compressed Natural Gas Powered Vehicles</p> <p><b>18 NGV 6.1</b><br/>CNG Fuel Storage And Delivery Systems for Road Vehicles</p> | <p><b>19 CSA PRD 1</b><br/>Pressure Relief Devices for Natural Gas Vehicle (NGV) Fuel Containers</p> <p><b>20 CSA Z662</b><br/>Oil &amp; Gas Pipeline Systems</p> <p><b>21 B401</b><br/>Vehicle Maintenance Facilities Code</p> <p><b>22 SPE 2.1</b><br/>Best Practices for Defueling, Decommissioning, and Disposal of Compressed Natural Gas Vehicle Fuel Containers and Liquefied Natural Gas Vehicle Fuel Tanks</p> |
|---|---|--|---|

# Liquefied Natural Gas (LNG)



- 1 **CSA B622**  
Selection and Use of Highway Tanks, TC Portable Tanks, and Ton Containers for Transportation of Dangerous Goods, Class 2
- 2 **CSA B51**  
Boiler, Pressure Vessel, and Pressure Piping Code
- 3 **CSA Z662**  
Oil and Gas Pipeline Systems
- 4 **CSA Z276**  
Liquefied Natural Gas (LNG) – Production, Storage, and Handling
- 5 **CSA Z276 ANNEX D**  
Liquefied Natural Gas (LNG) – Fueling Station

- 6 **CSA B109**  
Natural Gas for Vehicles Installation Code
- 7 **CSA LNG 1**  
Liquefied Natural Gas Fuel Connection Devices
- 8 **CSA LNG 2**  
Liquefied Natural Gas Vehicle Fuel Containers
- 9 **LNG 3.1 - LNG 3.19 NEW**  
Fuel system Components for Liquefied Natural Gas Powered Vehicles
- 10 **CSA LNG 4.1 NEW**  
Liquefied Natural Gas (LNG) Dispensing Systems

- 11 **CSA B108**  
Natural Gas Refuelling Stations Installation Code
- 12 **CSA LNG 4.2 PENDING**  
Hoses for Natural Gas Vehicles and Dispensing Systems
- 13 **CSA LNG 4.3 PENDING**  
Temperature Compensation Devices for Liquefied Natural Gas Dispensing Systems
- 14 **CSA LNG 4.4 PENDING**  
Breakaway Devices for Liquefied Natural Gas Dispensing
- 15 **CSA LNG 4.6 PENDING**  
Manually Operated Valves for Liquefied Natural Gas Dispensing Systems

- 16 **CSA LNG 4.7 PENDING**  
Automatic Operated Valves for Liquefied Natural Gas Dispensing Systems
  - 17 **CSA LNG 4.11 PENDING**  
Odorizer for Liquefied Natural Gas Dispensing Systems
  - 18 **CSA LPRD 1 PENDING**  
Pressure Relief Devices for Liquefied Natural Gas Fuel (LNG) Containers
  - 19 **CSA LPRD 2 PENDING**  
Pressure Relief Valves for Natural Gas Dispensing Systems
- B401**  
Vehicle Maintenance Facilities Code