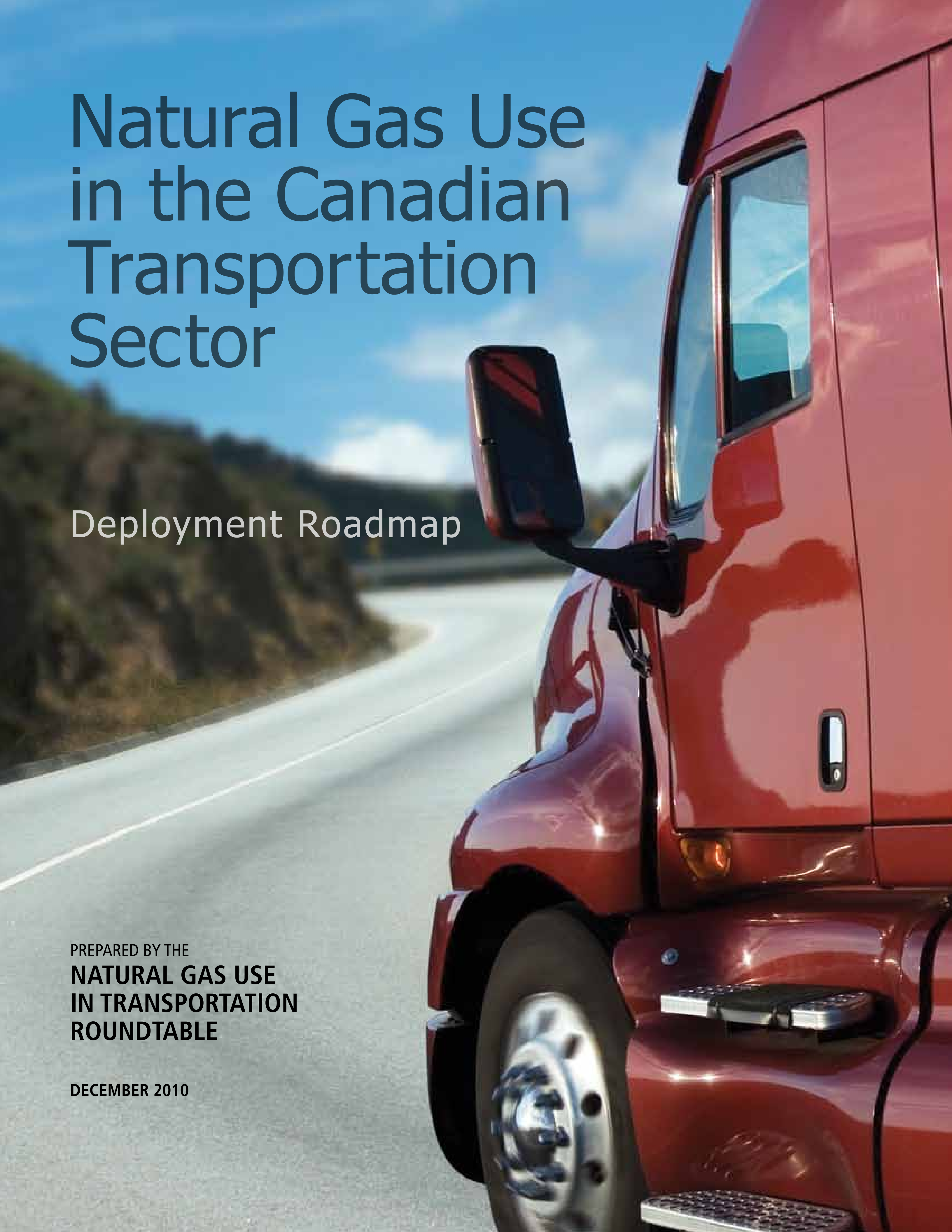

Natural Gas Use in the Canadian Transportation Sector

Deployment Roadmap

PREPARED BY THE
NATURAL GAS USE IN TRANSPORTATION ROUNDTABLE

DECEMBER 2010

Disclaimer

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

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Foreword by the Deputy Minister

The *Natural Gas Use in the Canadian Transportation Sector Deployment Roadmap* initiative, launched in March 2010, brought together stakeholders from governments, industry — including gas producers, transporters, distributors, vehicle and equipment manufacturers, and end-users — as well as representatives from environmental non-governmental organizations and academia. Facilitated by Natural Resources Canada, this process provided a platform for this broad array of stakeholders to discuss the potential for natural gas use across the medium- and heavy-duty transportation sector, explore strategies for overcoming barriers associated with its use, and develop recommendations for deployment.

As this work was conducted, key stakeholders worked together in an unprecedented manner and pace. Consensus-building played an essential role during the development of the Roadmap's analyses and in the formulation of its recommendations.

This Roadmap focused on expanding the use of natural gas across the transportation sector and represents an important contribution to deliberations toward a broader strategy to reducing greenhouse gas (GHG) emissions. Other efforts in the transportation sector include, for example, a suite of regulations to address GHG emissions from vehicles and minimum requirements for renewable content in fuels. Continued dialogue among governments and market participants will be important to ensure that all opportunities are properly assessed to inform decision-making.

I would like to take this opportunity to thank all of those involved in this process for their dedication in contributing to the delivery of the Roadmap.

Serge P. Dupont, Deputy Minister

Roadmap Participants

Alberta Ministry of Energy

Auto21

British Columbia Ministry of Energy, Mines and Petroleum Resources

Canadian Association of Petroleum Producers

Canadian Gas Association

Canadian Natural Gas Vehicle Alliance

Canadian Trucking Alliance

Canadian Urban Transit Association

Climate Change Central

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Dynetek Industries

Encana Corporation

Gaz Métro

IMW Industries

Ministère des Ressources naturelles et de la Faune du Québec

Natural Resources Canada

Pembina Institute

Pollution Probe

Terasen Gas

TransCanada Pipelines

Westport Innovations Inc.

Glossary

Biogas: Methane produced from the decomposition of biomass in landfills, digesters, and wastewater plants.

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

Compressed natural gas (CNG): One possible form in which natural gas can be used in vehicles. CNG is formed by compressing gas to high pressures in the range of 3,000 to 3,600 pounds per square inch (psi). Compression reduces the volume by a factor of 300 (or more) compared with gas at normal temperature and pressure. It is stored in steel or fibre-wound cylinders at high pressures (3,000 to 3,600 psi). Onboard a natural gas vehicle, the gas travels through a pressure regulator and into a spark-ignited or compression ignition engine.

End-user: The person or organization that is the actual user of a product.

Fuel Value Index (FVI): A measure that allows all costs associated with natural gas use to be consolidated and reflected as a cost-per-diesel-litre equivalent, as used in the business modelling. For those vehicle applications with FVI values greater than 1, the value proposition for natural gas 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 — in other words, the level of payback that an investor can expect to receive over the life of the asset.

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): One possible form in which natural gas can be used in vehicles. LNG is made by cooling the gas temperature to -162°C. The liquefaction process reduces the volume by a factor of 600 compared with gas at normal temperature and pressure. The LNG is stored on vehicles in a double-walled stainless steel tank and vaporized before injection into the engine.

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 or LNG as a clean alternative to conventional liquid fuels.

Original Equipment Manufacturer (OEM): The company that originally manufactures the products.

Shale gas: Natural gas that is trapped in fine-grained sedimentary rock that can be accessed through advanced drilling techniques including horizontal drilling and multi-stage fracturing.

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Executive Summary

The Context

Canada's transportation sector is characterized by high energy use and significant greenhouse gas (GHG) emissions. In 2007, transportation accounted for 29 percent of secondary energy use, making it Canada's second-largest sector in terms of energy consumption.[1] Unlike most other sectors of the Canadian economy, though, transportation relies on a single energy source (crude oil-based fuels) to meet the vast majority of its energy needs. Energy demand for transportation is increasing, and vehicle energy use is projected to increase by 31 percent between 2004 and 2020.[2] GHG emissions from transportation sources are also rising. More than one-third of the increase in Canada's GHG emissions between 1990 and 2008 was attributable to transportation sources.[3] To address the transportation sector's increasing energy demand and GHG emissions, a comprehensive strategy is needed to improve vehicle efficiency, increase the use of lower-carbon fuels, and enhance system efficiencies. The increased use of natural gas in the transportation sector is one component of the overall solution.

Canada's natural gas supplies have grown substantially in recent years due to the advent of new drilling technology. Canada's transportation sector could benefit from expanding the use of lower-emission technologies and fuels such as natural gas. For medium- and heavy-duty vehicles that operate in return-to-base and corridor fleets, natural gas offers some important potential benefits, such as the ability to:

- Diversify energy use in the transportation sector and meet increasing energy demand;
- Reduce carbon emissions from the transportation sector;
- Introduce into a new market a cost-effective fuel that has historically traded at a discount to crude oil-based fuels on an energy equivalent basis; and
- Provide an alternative compliance option as carbon-related regulations enter the transportation sector.

Despite these potential benefits, market adoption for medium- and heavy-duty natural gas vehicles (NGVs) in Canada has been very limited to date. There are significant challenges associated with NGV deployment in Canada, including operating risks associated with costs and technology performance, high upfront vehicle costs, a lack of widespread infrastructure, and non-economic issues, including scarce recent experience with NGVs, insufficient information about current technology, and a lack of comfort with NGVs based on past history.

[1] Natural Resources Canada, *Energy Efficiency Trends in Canada 1990 to 2007*, April 2010.
[2] Natural Resources Canada (2006), *Canada's Energy Outlook: Reference Case 2006*.
[3] Natural Resources Canada, *Energy Efficiency Trends in Canada 1990 to 2007*, April 2010.

Natural Gas Use in Transportation Roundtable

To respond to these challenges, the Natural Gas Use in Transportation Roundtable — led by the Deputy Minister of Natural Resources Canada — was formed in March 2010 to identify the optimal use of natural gas in Canada's transportation sector. The Roundtable consisted of federal and provincial officials; industry representatives, such as natural gas producers, transporters, distributors, vehicle makers, equipment manufacturers, and end-users; and representatives from environmental non-governmental organizations and academia.

The *Natural Gas Use in the Canadian Transportation Sector Deployment Roadmap* is the result of the Roundtable's work. This Deployment Roadmap is innovative in nature and distinguishes itself from technology roadmaps in three fundamental ways: 1) the detailed business modelling work that was performed to assess, analyze, and rank potential end-use applications in the medium- and heavy-duty portion of the transportation sector, 2) the consultations that were undertaken with various end-users that might adopt this technology, and 3) the significant contributions made by the Roundtable member organizations, which were fully engaged in the Roadmap development from the outset. The Roadmap's framework for assessing the true potential of NGV adoption could also be used by those considering other fuel or technology pathways.

Roadmap Process

As an initial step in developing the Roadmap, working groups assessed opportunities for new natural gas markets in the on-road transportation sector (including light-, medium-, and heavy-duty vehicles), as well as marine and rail applications. In the near term, medium- and heavy-duty vehicles were found to offer the greatest opportunities for increased natural gas use. The prospects for natural gas use in other applications, including light-duty vehicles, marine vessels, and locomotives, were also found to be promising. However, due to more substantial barriers, which may include supply chain, technological, and market issues, these vehicle applications will likely require a longer time frame to achieve widespread natural gas use. Because of this finding, the working groups' subsequent work — which included conducting business case modelling, developing an education and outreach strategy, and examining research and development (R&D) requirements — focused primarily on medium- and heavy-duty applications.

The resulting Roadmap aims to:

- Address fundamental knowledge gaps regarding stakeholder interest, capacity, and economic and environmental impacts;
- Inform public and private sector decision-makers;
- Assist stakeholders in determining long-term investment requirements; and
- Outline key steps for implementation by defining future government programming needs and industry's role.

Recommendations

The following set of recommendations was developed in consultation with stakeholders representing all Roadmap working groups as well as Roundtable members. These recommendations reflect findings related to business modelling work; capacity-building needs; and research, development, and demonstration (RD&D) requirements. Recommendations have been proposed in four key areas: 1) De-risking Investment and Early Adoption, 2) Addressing Information Gaps, 3) Increasing Capacity to Sustain Markets, and 4) Ensuring Ongoing Competitiveness.

De-risking Investment and Early Adoption

1. Analysis has demonstrated that investment in medium- and heavy-duty NGVs can provide environmental and over-vehicle-life economic benefits, but the upfront capital cost vehicle premium and the risks associated with operation costs and achieving ongoing fuel savings are barriers to adoption. Fiscal measures implemented on a temporary basis could address these barriers and de-risk decision-making for early fleet adopters.
2. To introduce natural gas into the new market of over-the-road trucking, coordinated investments are needed to ensure that the development of key corridor infrastructure is consistent with projected demand, strategically located to support end-users, and installed in a timely manner across jurisdictions.
3. Existing industry players could provide access to private onsite refuelling stations. Fleets could further improve the business case for natural gas adoption by allowing other fleets to use these stations via cardlock and other arrangements. However, there are implementation details (e.g. liability issues) that would need to be addressed by the parties involved.
4. Demonstration of the use of natural gas is needed to address technical barriers, develop standards, and conduct feasibility studies and business cases.

Rationale

Temporary fiscal measures would help de-risk adoption and lower economic barriers to market entry. End-users perceive early adoption as risky and, in particular, they attach uncertainty and risk to 1) the residual value of an NGV after the initial ownership period (e.g. four to five years for highway tractors), 2) the potential for ongoing fuel savings, and 3) the lack of refuelling infrastructure relative to diesel fuel infrastructure. Temporary fiscal measures would encourage early adoption of NGVs in larger quantities, which in turn would help the NGV industry achieve the economies of scale required to reduce the cost of vehicle systems. While there is a positive internal rate of return for several end-use applications, temporary fiscal measures would also be necessary to overcome the barriers to adoption if they are determined to be the result of market failure within the medium- and heavy-duty portion of Canada's transportation sector. While there are many precedents for market intervention by governments to assist in developing scale and removing barriers to entry, over the longer term it will be important for natural gas as a transportation fuel to be able to compete on a level playing field with other fuels — based on its own merits. This principle should be considered by policy-makers in terms of the design and duration of any policies moving forward.

Addressing Information Gaps

5. An education and outreach strategy would be needed to target end-users as well as market influencers and other key stakeholders. This strategy should consist of both a "top-down" and a "bottom-up" approach. A top-down approach would include a central website for all target audiences with local content tailored to specific jurisdictions. A bottom-up approach would feature a local support network for end-users and provide access to resources including workshops and case studies of local fleets.

Rationale

End-users identified gaps in their knowledge and awareness of NGVs as an option that could serve their needs. In addition, end-users with past experience using natural gas had additional information requirements related to recent NGV developments, particularly technological innovations. It would provide momentum if governments and other players were to provide essential information to enable markets to function efficiently, especially since there is no single private sector actor that operates across the entire spectrum of the NGV value chain. Governments are regarded as unbiased providers of information in the vehicle and fuel market arenas, and this neutrality is important to end-users. Benefits of this measure include the development of a broader understanding and increased awareness of the applicability of NGVs, which would facilitate adoption of these vehicles in greater numbers.

Increasing Capacity to Sustain Markets

6. A "safety codes and standards" working group should be established to collaborate with existing Canadian Standards Association technical committees to address gaps and issues in existing codes and standards identified during the Roadmap process. Separate committees for liquefied natural gas (LNG) and compressed natural gas (CNG) may need to be formed to review existing codes and revise or develop new codes and standards. An umbrella committee is needed to ensure that codes and standards for CNG, LNG, liquefied compressed natural gas, and biomethane are coordinated and comprehensive.
7. Appropriate training materials for stations, vehicle repairs, and NGV fleet operations, as well as for cylinder inspection, need to be developed and delivered.
8. An NGV implementation body — consisting of Roundtable members and other key stakeholders — should be established to:
   - Support the implementation of the Roadmap's recommendations and assess progress against key milestones;
   - Provide recommendations to stakeholders regarding how the natural gas community could respond to future developments, such as changes in market conditions and technological innovations;
   - Act as an umbrella organization for the local support network for end-users; and
   - Serve as a forum for stakeholders to discuss issues pertinent to the natural gas community.

Rationale

To encourage NGV adoption, end-users need to be supported during their purchasing decisions, and adequate codes and standards need to be in place to ensure a successful technology rollout. Over the past decade, very little work has been done in Canada to update CNG codes and standards, while LNG codes and standards require even more fundamental development. As NGV technology becomes increasingly available, fleets will require support, since this technology features specific maintenance and safety requirements that will necessitate training of operators and mechanics. An NGV implementation body is recommended as a way to coordinate the work of governments and stakeholders along the NGV value chain to ensure the successful deployment of this technology and mitigate the risks borne by end-users or by any individual player.

Ensuring Ongoing Competitiveness

9. The NGV industry funds R&D activities at present. Further investment by others, including governments, has the potential to enhance the competitive position of the industry through targeted R&D investment. Priorities for future R&D include reducing or eliminating the cost differential between natural gas and diesel vehicles over the long term and maximizing NGVs' operational and environmental benefits.
10. Potential for natural gas use in other transportation applications should continue to be explored.

Rationale

While NGV technology is already mainstream and commercially proven, support for NGV R&D is needed to further reduce the incremental cost of NGV-related technologies. In addition, assistance is needed to sustain market development through the expansion of the number of NGV offerings for end-users. NGV technologies would also benefit from R&D investments to reduce the incremental cost of these vehicles, which

TABLE 1 Natural Gas Use in Transportation: Roles and Responsibilities

		GOVERNMENTS	NG PRODUCERS, TRANSPORTERS, AND DISTRIBUTORS	INFRASTRUCTURE AND VEHICLE SUPPLY STREAM	END-USERS
De-risking Investment and Early Adoption	Vehicle Premium	■	■		■
	Corridor Infrastructure	■	■	■	
	Return-to-Base Infrastructure		■	■	■
	Demonstrations	■		■	■
Addressing Information Gaps	Education and Outreach	■	■	■	
Increasing Capacity to Sustain Markets	Codes and Standards	■	■	■	
	Training	■	■	■	
	Implementation Committee	■	■	■	■
Ensuring Ongoing Competitiveness	R&D	■		■	
	Use of NG in Other Applications	■	■	■	■

would ensure ongoing competitiveness for innovative low-emission Canadian technologies. By continuing to explore the potential for natural gas use in other transportation applications, the natural gas community will help expand the benefits of natural gas as a fuel and potentially leverage infrastructure and R&D investments made for the medium- and heavy-duty vehicle market.

Roles and Responsibilities

The stakeholders in Table 1 were identified as parties who could take on roles and responsibilities as they relate to moving the recommendations of this Roadmap forward. For many of these activities, numerous stakeholders could play a role; however, the table aims to provide a general overview of the roles that key stakeholders could play during the early stages of NGV market development.

Moving Forward

For governments and industry alike, the changing supply story for natural gas, projected high oil prices, and the need to reduce GHG emissions and criteria air contaminants have all contributed to renewed interest in natural gas as a transportation fuel. Now that market conditions are more favourable, Canada's natural gas community is well positioned to take a significant leap forward in deploying these vehicles in greater numbers. While natural gas is not the only solution for reducing GHG emissions produced by medium- and heavy-duty vehicles, it provides a particularly good set of benefits for return-to-base and corridor fleets. As a result of past research assistance from governments, several Canadian companies are now technology leaders in the areas of natural gas vehicles and fuelling infrastructure. There is also a sound base of codes and standards that the natural gas community can build upon. But perhaps the most important advantage for Canada's natural gas community is the new collaborative environment that has developed as a result of the Roadmap process. Such collaboration, which was essential during the Roadmap's development, will again be critical as Canada's natural gas community turns its focus to implementing the recommendations set out in this report.

BACKGROUND

BACKGROUND

Chapter 1

Introduction

Natural Gas: An Energy "Game Changer"

Not long ago, energy analysts projected that natural gas production in North America would decline steadily for the foreseeable future. However, recent advances in drilling technology have enabled cost-effective extraction of natural gas from unconventional reservoirs, such as shale formations, which are in abundant supply. In response to this development, North American energy market analysts now describe natural gas as a potential energy game changer, and governments and industry are exploring new and expanded opportunities for this resource.

Roadmap Approach

In response to this opportunity, a Roundtable — led by the Deputy Minister of Natural Resources Canada — was formed in March 2010. It consisted of senior officials in federal and provincial governments, end-users, executives from industry (including gas producers, transporters, distributors, and vehicle and equipment manufacturers) and representatives from environmental non-governmental organizations and academia. During the Roundtable's inaugural meeting, working groups were formed to focus on the following issues:

- Natural gas fundamentals;
- Vehicle readiness and R&D;
- Infrastructure readiness and R&D;
- End-user needs;
- Codes and standards; and
- Market transformation and policy analysis.

Co-leaders from Natural Resources Canada and private sector organizations were assigned to each working group, which consisted of staff from the Roundtable member organizations. These working groups conducted research and analysis in their respective subject areas, and met periodically by teleconference to assess progress and determine next steps.

As an initial step in developing the Roadmap, working groups assessed opportunities for new natural gas markets in the on-road transportation sector (including light-, medium-, and heavy-duty vehicles), as well as marine and rail applications. During its second meeting, which took place in June 2010, the Roundtable determined that medium- and heavy-duty vehicles offered the greatest opportunities for increased natural gas use in this sector in the near term. The prospects for natural gas use in other applications, including light-duty vehicles, marine vessels, and locomotives, were also found to be promising. However, due to more substantial supply chain and technological barriers, these vehicle applications were identified as likely requiring a longer time frame to achieve widespread natural gas use in Canada.

The Roadmap's purpose is to identify the optimal use of natural gas in Canada's transportation sector.

As a result of this decision, the working groups' subsequent analytical work primarily dealt with medium- and heavy-duty applications. During the analytical stage of the Roadmap's development, work focused on three key areas:

- Conducting business case modelling to determine the optimal use of natural gas in specific medium- and heavy-duty vehicle applications;
- Developing an education and outreach strategy to ensure that end-users and other key stakeholders have the information they need to facilitate NGV deployment; and
- Identifying R&D requirements to ensure that the NGV industry becomes self-sustaining over the long term.

During its final meeting in September 2010, the Roundtable reviewed drafts of the Roadmap report and recommendations and provided a final set of revisions. Once these revisions were complete, Roundtable members provided their final concurrence to the report.

The Final Product

The *Natural Gas Use in the Canadian Transportation Sector Deployment Roadmap* is the culmination of the work led by Roundtable members and the working groups from March to October 2010. The Roadmap's purpose is to identify the optimal use of natural gas in Canada's transportation sector. It also aims to:

- Address fundamental knowledge gaps regarding stakeholder interest, capacity, and economic and environmental impacts;
- Inform public and private sector decision-makers;
- Assist in determining long-term investment requirements by stakeholders; and
- Outline key steps for implementation and define future government programming needs and industry's role.

This report is unique in nature and distinguishes itself from technology roadmaps in three fundamental ways: 1) the detailed business modelling work that was performed to assess, analyze, and rank potential end-use vehicle applications, 2) the consultations that were undertaken to identify opportunities and challenges within the end-user community, and 3) the significant contributions made by the Roundtable member organizations, which were fully engaged in the Roadmap's development from the outset. Because of its emphasis in these areas, the Roadmap's framework could potentially be used by others who are assessing other fuel and technology pathways.

B A C K G R O U N D

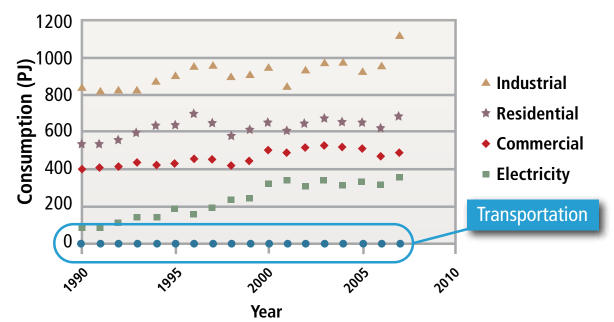
Chapter 2

Drivers of Interest and Market Opportunities

Participants involved in the Roadmap's development focused on addressing two fundamental questions pertaining to scope. The first question was, "Recognizing that natural gas use could be expanded in several key sectors, why should governments and industry consider natural gas in the transportation sector at this time?" In other words, what factors are driving interest among stakeholders to consider natural gas use specifically in the transportation sector? The second question was, "Within the transportation sector, which vehicle applications have the greatest potential for natural gas use?" This chapter provides the Roundtable's responses to these questions.

Why Should Governments and Industry Consider Natural Gas Use in the Transportation Sector?

Canada's abundant natural gas resources can be used in any of the nation's major economic sectors, including commercial, residential, industrial, electricity, and transportation. As Figure 1 indicates, natural gas use in the various sectors of the economy increased from 1990 to 2007. The transportation sector is unique in that it currently uses significantly less natural gas relative to the other sectors. Even if demand for natural gas use in the transportation sector increased significantly over the coming decade, the effect on natural gas prices would likely be minimal.



Source: Natural Resources Canada (2010), "Energy Use Data Handbook Tables (Canada)." Accessed February 2010.

FIGURE 1 Natural Gas Consumption in Canada by Sector (1990–2007)

There are a number of benefits that can be derived from expanded natural gas use in the transportation sector. First, it will diversify the sector's potential energy sources. Unlike all other sectors of the Canadian economy, transportation relies on a single energy source (crude oil-based fuels) to meet nearly all of its energy demands. In 2007, crude oil-based fuels supplied 99 percent of transportation energy demands, compared with propane (0.5 percent), electricity (0.1 percent), and natural gas (0.1 percent).[1] And while Canada is a net exporter of crude oil, more than half of the oil processed in Canadian refineries is imported from Europe, the Organization of Petroleum Exporting Countries (OPEC), and the northeastern United States.[2]

[1] Natural Resources Canada, "National Energy Use Database," http://www.oee.nrcan.gc.ca/corporate/statistics/neud/dpa/trends_tran_ca.cfm.

[2] EcoRessources Consultants, *Cost-Benefit Analysis of the Proposed Regulations to Require Renewable Fuels Content in Canadian Fuels – the 2% Requirement*. A report prepared for Environment Canada. Page 11.

TABLE 1 Drivers for Key Stakeholders

STAKEHOLDER	DRIVERS
Governments	▪ Enhance energy diversification ▪ Develop clean energy solutions ▪ Meet GHG reduction targets / build a low-carbon economy / encourage growth of green industries ▪ Foster strong markets for Canada's energy resources ▪ Support economic recovery and sustainable growth ▪ Support the economic competitiveness of Canadian industries and technology
Fuel Supply Stream (Natural Gas Producers)	▪ Take the opportunity to provide abundant, Canadian, low-cost natural gas resources ▪ Stimulate demand and expand markets ▪ Retain and attract investment in Canada ▪ Strategically invest in anticipation of climate change regulations
Fuel Supply Stream (Natural Gas Transmission and Distribution)	▪ Use the significant infrastructure already in place ▪ Increase throughput to reduce tolls and improve competitiveness ▪ Diversify markets ▪ Build demand beyond traditional end-use markets
Vehicle and Equipment Suppliers	▪ Supply consumers with lower-carbon fuel options ▪ Position Canadian companies to compete more effectively when heavy-duty vehicle carbon regulations are implemented ▪ Build on the competitiveness of Canada's world-leading industry: ▪ Develop a strong technology and manufacturing base nationally ▪ Encourage wider use of technologies to achieve economies of scale in production ▪ Provide local economic benefits through jobs and accessing local supplier networks

End-Users	▪ Invest strategically in expectation of heavy-duty GHG emissions regulations
	▪ Demonstrate commitment to customers/shareholders:
	  ▪ Significant GHG reduction benefits associated with renewable natural gas
	  ▪ Ability to measure and quantify GHG reductions
	  ▪ Opportunity to reduce noise in urban settings
	▪ Take advantage of expectations that natural gas will remain competitively priced:
	  ▪ Natural gas use may reduce fuel price volatility risks
	▪ Take into account the increasing cost and complexity of 2010 diesel engine emission control technology

Second, natural gas can provide important benefits as a low-carbon transportation fuel. In 2007, Canada's transportation sector accounted for approximately 29 percent of total energy demand, making it the second-largest energy consumer in the nation.[3] As a result of such significant energy demand, this sector also accounted for 36 percent of Canada's GHG emissions, making it the second-largest source of emissions in the country.[4] Moreover, total energy demand in the transportation sector is expected to grow by 31 percent between 2004 and 2020.[5] The major source of energy use and emissions is on-road vehicles.

Third, natural gas is a cost-effective fuel that has historically traded at a discount to crude oil-based fuels on an energy equivalent basis. Furthermore, recent growth in the Canadian natural gas supply lends confidence that this discount will continue for the foreseeable future. This benefit is potentially critical for operators of medium- and heavy-duty vehicle fleets, who may be able to use natural gas to substantially lower their fuel costs on a per kilometre basis. With the growing availability of factory-built natural gas medium- and heavy-duty vehicles, there is an opportunity to ensure that lower-emission NGVs are seen as a viable option for the normal replacement of vehicle fleets over time. In addition to these benefits, there are also numerous other factors driving interest in the use of natural gas in the transportation sector. These drivers — which can be unique to specific stakeholders — are provided in Table 1.

[3] Natural Resources Canada, *Energy Efficiency Trends in Canada 1990 to 2007*, April 2010.
[4] Natural Resources Canada (2010), *Canada's Secondary Energy Use by Sector, End-Use and Sub-Sector.*
[5] Natural Resources Canada (2006), *Canada's Energy Outlook: Reference Case 2006*.

Within the transportation sector, which vehicle applications have the greatest potential for natural gas use?

With interest in potentially increasing natural gas use in the transportation sector identified, the Roundtable turned its focus to determining the specific vehicle applications that have the greatest potential for increased natural gas use in the near term. To address this issue, the Roundtable assessed the potential for increased natural gas use in various vehicle segments, including light-, medium-, and heavy-duty vehicles, as well as marine vessels and locomotives. The following criteria were used to evaluate these segments: technology availability, market potential, environmental benefits, energy use, and economic impact. In the near term, medium and heavy-duty vehicles were found to have the greatest potential for widespread deployment as a result of the following factors:

- The availability of mature, certified vehicle engine and storage technologies;
- The growing energy demand for which these vehicles, particularly heavy-duty vehicles, account;
- The potential for significant fuel savings and a good rate of return for fleet owners; and
- Significant market potential given the focus on return-to-base and corridor fleets.

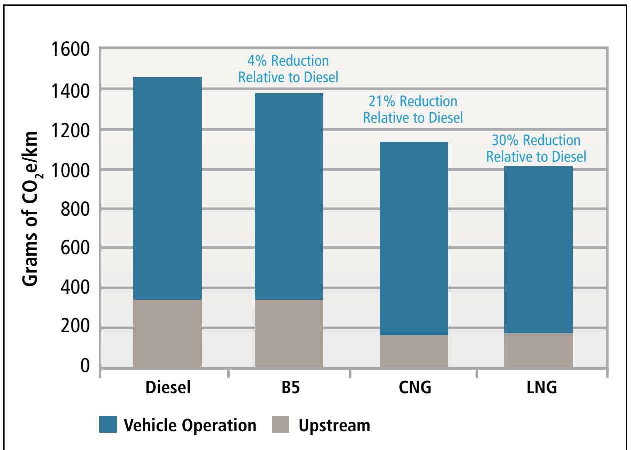
In addition, natural gas may have a role to play in the light-duty marketplace in the medium term, particularly for fleet applications used by taxi companies, municipalities, construction businesses, and utilities. For large fleets that already have a private onsite CNG station, there is an opportunity to further improve the economics of infrastructure investment for the fleet owners by extending natural gas use to their light-duty vehicles. Similar synergies may also exist for corridor as well as marine and rail applications. See Appendix A for additional details regarding the results of the scoping analysis.

Options for Reducing GHG Emissions from Medium- and Heavy-Duty Vehicles

In addition to these benefits, Roundtable members emphasized the important role that natural gas can play in helping various entities comply with environmental regulations that aim to reduce GHG emissions from medium- and heavy-duty vehicles. Figure 2 compares diesel fuel GHG emissions with emissions produced by biodiesel (5 percent blend), compressed natural gas (CNG), and liquefied natural gas (LNG). For each fuel, the figure includes upstream emissions (i.e. emissions produced during resource recovery, refining, and shipping) and vehicle operation emissions (i.e. emissions produced at the tailpipe). As the figure indicates, natural gas produces between 21 to 30 percent fewer GHG emissions on a well-to-wheels lifecycle basis compared with diesel.

Due to the low carbon content of natural gas relative to gasoline and diesel, the production of NGVs could help truck and bus manufacturers meet yet-to-be-developed fleet average GHG standards. The Government of Canada recently announced its intention to implement GHG fleet average standards, which will come into effect in 2014; however, the structure of the medium- and heavy-duty standards is unknown at this time.

In addition to the incoming GHG vehicle standards, there are other environmental regulations for which natural gas could receive favourable treatment. Natural gas use in vehicle fleets could provide an important



Source: GHGenius version 3.16b (2010)

FIGURE 2 Alternative Fuel Options to Reduce GHG Emissions from Heavy-Duty Trucks

Why GHG Emissions Are Lower from Natural Gas than Diesel

As Figure 2 indicates, the upstream extraction and processing of natural gas, as well as combustion of it in a vehicle (as either CNG or LNG), produces fewer GHG emissions compared with diesel. With regard to **upstream emissions**, natural gas is typically processed only to remove impurities, a process that is less energy-intensive than the refining that is necessary to produce diesel.

Natural gas also produces fewer **vehicle operation emissions** than diesel, for two reasons. First, natural gas consists primarily of methane, which has the lowest carbon content of any fossil fuel. By comparison, diesel contains long chain hydrocarbons and a high level of carbon-content aromatics. Second, natural gas also has a higher energy content by mass than diesel. As a result of these two factors, natural gas produces fewer vehicle operation emissions than diesel: 13.68 grams of carbon per megajoule (g-C/MJ) and 18.79 g-C/MJ respectively, although there may be engine efficiency differences compared with diesel, depending on the type of natural gas engine technology.

Source: GHGenius version 3.16b (2010)

contribution to reaching climate change policy goals in Canada at a reasonable cost. For example, if one out of every 10 new medium and heavy-duty vehicles sold in Canada over the next 10 years were natural gas-powered (36,000 vehicles), carbon emissions could be reduced by an estimated 1.99 megatonnes annually by 2020.[6] Similarly, fuel providers are already preparing to meet new regulations for low-carbon fuels in British Columbia, as well as forthcoming regulations being developed in some other provinces. The inclusion of natural gas for transportation in the mix of fuels sold by fuel suppliers could help them meet standards where the regulations permit.

It is worth noting that in addition to using alternative fuels such as natural gas, further GHG emission reductions can be achieved through the use of supplemental options that improve the fuel efficiency of end-use applications, such as aerodynamic devices and design, fuel-efficient tires, and driver training. The U.S. Environmental Protection Agency has estimated the benefits of some of these options. For example, aerodynamic devices such as trailer end fairings can provide an estimated 5 percent or greater reduction in fuel use. Low rolling resistance tires can lead to fuel savings of approximately 3 percent or greater. The application of these technologies, coupled with driver training, can lead to additional fuel-saving benefits.[7]

[6] Calculated value based on GHGenius (version 3.16b) and historical vehicle sales data from the Canadian Vehicle Manufacturers Association.

[7] U.S. Environmental Protection Agency (2010), *Verified Technologies.* Available online: http://epa.gov/smartway/transport/what-smartway/verified-technologies.htm.

Conclusion

Within the transportation sector, medium- and heavy-duty vehicles were found to have the greatest potential for increased natural gas use in the near term. There a number of reasons why the transportation sector would benefit from expanded natural gas use, such as:

- Diversifying energy use and responding to increasing energy demand;
- Reducing carbon emissions;
- Introducing a cost-effective Canadian-sourced fuel that has historically traded at a discount to crude oil-based fuels on an energy equivalent basis into a new market (this issue is discussed in detail in Chapter 4); and
- Providing an alternative compliance option as carbon-related regulations enter the transportation sector.

In addition to these benefits, the list of drivers leading stakeholders to expand natural gas use in the transportation sector is compelling. Individual stakeholders can realize benefits, but only if the other stakeholders agree to participate in developing the market. The likely extent and strength of such cooperation will depend on the needed investments, perceived risks and economic returns — issues that are explored in Chapter 5. The next chapter reviews the current state of natural gas in transportation technology and policy in Canada, and provides valuable contextual information that will lay the foundation for the Roadmap's subsequent analysis and recommendations.

BACKGROUND

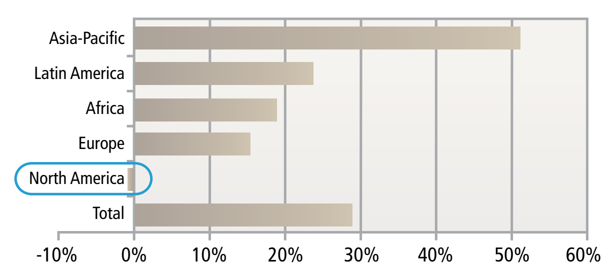
Chapter 3

The State of Natural Gas Use in Transportation

This chapter provides an overview of the current state of natural gas use in the transportation sector from a global perspective — then more specifically from a Canadian and U.S. market perspective — with emphasis on existing NGV policies and programs. The latter part of the chapter describes the current state of natural gas vehicle and infrastructure technology, as well as codes and standards.

Global Market for NGVs

As of December 2009, there were more than 11 million natural gas vehicles in operation globally.[1] The use of natural gas as a road transport fuel currently accounts for 1 percent of total vehicle fuel consumption worldwide. The average growth rate in the number of NGVs between 2000 and 2009 was 28.7 percent, with Asia-Pacific ranking highest at +50.9 percent and North America ranking lowest at -0.1 percent (see Figure 1). This trend is expected to continue at an average rate of 3.7 percent per year to 2030, with most of the growth coming from non-OECD countries that already account for most natural gas use for on-road transportation. See Appendix B for a cross-jurisdictional analysis of NGV policies and programs.



Source: International Association for Natural Gas Vehicles (2010), "NGV by Region." Accessed June 2010.

FIGURE 1 Average NGV Growth by Region Since 2000

Canadian Context

With assistance from federal and provincial research programs, demonstration projects, and NGV market deployment programs during the 1980s and 1990s, the population of light-duty NGVs grew to over 35,000 by the early 1990s. This assistance resulted in a significant adoption of natural gas transit buses as well. The NGV market started to decline after 1995, eventually reaching today's vehicle population of about 12,000.[2] This figure includes 150 urban transit buses, 45 school buses, 9,450 light-duty cars and trucks, and 2,400 forklifts and ice-resurfacers. The total fuel use in all NGV markets in Canada was 1.9 petajoules (PJs) in 2007 (or 54.6 million litres of gasoline litres equivalent), down from 2.6 PJs in 1997. Public CNG refuelling stations have declined in quantity from 134 in 1997 to 72 today. There are 22 in British Columbia, 12 in Alberta, 10 in Saskatchewan, 27 in Ontario, and 1 in Québec. There are only 12 private fleet stations.[3]

[1] International Association for Natural Gas Vehicles (2010), "Natural Gas Vehicles Statistics," http://www.iangv.org/tools-resources/statistics.html.

[2] International Association for Natural Gas Vehicles (2010), "Natural Gas Vehicles Statistics," http://www.iangv.org/tools-resources/statistics.html.

[3] Marbek (March 2010), "Study of Opportunities for Natural Gas in the Transportation Sector."

Several factors have led to the decline of the Canadian NGV market since the 1990s:

- The price advantage of natural gas over gasoline and diesel in Canada eroded after world oil prices collapsed;
- Vehicle costs increased as vehicle modifiers added technology to meet tighter vehicle exhaust emission requirements;
- R&D support to NGVs diminished in the 1990s;
- Public refuelling station use declined as the number of new NGVs decreased, which led to a deterioration of refuelling station revenues and station closings;
- There was a limited choice of factory-made NGV models available; and
- The restrictive regulation of the natural gas distribution industry limited non-core business activities, including NGV business development activities, following industry deregulation.

Current Support in Canada

There is little remaining federal support for natural gas in transportation, apart from the continuing exemption from the excise tax on fuels (10¢/litre on gasoline and 4¢/litre on diesel). However, as the fuel tax chart (Figure 7) in Chapter 4 indicates, the combination of the exemptions from excise and provincial fuel taxes for natural gas constitutes a substantial price advantage.

Québec's 2010 budget increased the capital cost allowance rate for freight hauling trucks and tractors, with additional deductions for LNG-fuelled trucks. British Columbia's *Clean Energy Act,* introduced in May 2010, includes a provision that could be used to support NGVs. Within the private sector, natural gas distribution utilities continue to provide a range of services and, in some cases, financial support that is recovered through gas sales to fleet end-users. However, these utilities are now limited in terms of the activities they can undertake due to the restrictions within the regulated business model under which they operate.

U.S. Market for NGVs

Similar to Canada, the United States has implemented various NGV initiatives and programs since 1980 but has had limited success in sustaining the market. There were 105,000 NGVs in operation in 2000; this figure peaked at 121,000 in 2004, and decreased to 110,000 in 2009.[4] At the federal level, vehicle tax credit and fuel incentive policies have provided assistance over the past five years, and the NGV industry is currently working to secure extensions of these measures. In California, a lead state in NGV deployment, LNG and CNG use in heavy-duty trucks and buses has grown in response to the state's aggressive clean air policies.

Current Support in the United States

The U.S. federal government and some state governments continue to support NGVs through vehicle and station incentives and tax credits. The need to reduce dependency on oil imports is an important policy driver in the United States. The recent expansion in domestic natural gas production is one of the reasons that Congress is currently considering renewing and strengthening NGV incentives.

[4] International Association for Natural Gas Vehicles (2010), "Natural Gas Vehicles Statistics," http://www.iangv.org/tools-resources/statistics.html.

At the federal level, several key incentives have either recently expired or are about to expire. These include an excise tax credit for CNG and LNG; tax credits for the purchase of a new, dedicated, repowered, or converted alternative fuel vehicle; and an income tax credit for refuelling equipment. Additional programs at the federal level include:

- The Department of Energy's Clean Cities Program, a government-industry partnership that announced 23 cost-share grants (10 related to natural gas), which totalled $13.6 million in 2009.
- The National Renewable Energy Laboratory's April 2010 request for proposals regarding the development of natural gas engines and vehicles. The solicitation includes the potential for $14.5 million in funding for engine development, chassis integration, and demonstration of on-road products.

Infrastructure Technology Readiness

Canada has one of the most extensive natural gas pipeline distribution networks in the world, delivering this resource from Western Canada and the East Coast offshore to markets in the United States and across Canada. The expansion of this pipeline network over the past 30 years has led to increased use of natural gas in North America. The reach of the network, the attractive price of natural gas, and its emission reduction benefits provide an opportunity for the transportation sector to increase its use of this fuel.

In some major transportation corridors, natural gas trunk pipelines coincide with major highways, rail lines and even waterways. Natural gas refuelling stations can be located along these corridors to serve the trucking industry, and in some cases could use high-pressure pipeline gas to reduce the cost of providing CNG. In urban areas such as Toronto and Vancouver, there are already approximately 50 CNG public stations serving light- and medium-duty vehicles, as well as a smaller number of private fleet refuelling facilities.

Currently there are no fuelling facilities that provide LNG to vehicles on a regular basis. LNG is available at three locations in Canada where there are peak-shaving plants operated by natural gas utilities. It appears that these facilities may have some excess LNG capacity that can be diverted to transportation markets; two of the utilities[5] are in the process of securing approvals from regulators to allow this use. If the demand for LNG in specific vehicle applications develops as envisioned in this Roadmap, this fuel could be manufactured from pipeline gas or sourced from LNG import terminals such as Canaport in Saint John, New Brunswick. It could then be transported in LNG tanker trucks, rail cars or marine vessels to be distributed to refuelling facilities. LNG can also be vaporized (gasified) and pressurized at a refuelling facility to provide CNG.

Natural gas, for use as a transportation fuel in either CNG or LNG form, is typically sold to the end-user in one of three ways:

- **"Do-It-Yourself"** — End-users can purchase natural gas from a utility or gas marketer (delivered by a utility) and source the fuelling station equipment separately. The end-users invest their own capital to install a refuelling station and access a service provider to maintain the station equipment on a contract or fee basis. However, the customers are expected to develop specifications, build, and operate the CNG or LNG fuelling station equipment themselves.
- **"Utility Package"** — Gas utility companies deliver and sell natural gas and may also provide fuelling infrastructure. Under this model, normal distribution services can be expanded to make the product usable as a vehicle fuel. The utility provides compression/dispensing systems for CNG or storage/dispensing systems for LNG. It may also provide support in developing specifications or building/operating the system in return for natural gas at special rates.
- **"Third-Party Service Provider"** — Companies such as Clean Energy build, operate, and maintain end-user fuelling stations and facilitate the purchase of natural gas on a long-term contract basis.

[5] Terasen Gas has obtained approval to sell LNG into the transportation market from its plant in the port area of Vancouver. Gaz Métro is in the process of obtaining similar approvals for its Montreal peak-shaving LNG plant. A third peak-shaving LNG facility in Northern Ontario is owned by Union Gas. If, in the future, LNG plants are built to export natural gas to overseas markets, LNG could also be sourced from those plants.

Several Canadian companies are suppliers of natural gas fuel delivery, compression, storage, and dispensing equipment.

Vehicle Technology Readiness

There are two types of NGVs available to end-users: 1) retrofitted vehicles (also called conversions), and 2) those developed specifically by original equipment manufacturers (OEMs), and delivered to customers as factory-built vehicles. Aftermarket vehicle conversions fall under provincial jurisdiction in Canada. Industry must take care to ensure that only high-quality and low-polluting vehicle conversion technologies are offered to the market. OEM vehicles must comply with Transport Canada regulations.

Dedicated NGVs are designed to run only on natural gas, while bi-fuel NGVs have two separate fuelling systems that enable the vehicle to use either natural gas or a conventional fuel (gasoline or diesel), but not both fuels at the same time. In general, dedicated NGVs demonstrate better performance and have lower emissions than bi-fuel vehicles because their engines are optimized to run on natural gas. In addition, the vehicle does not have to carry two types of fuel, thus reducing weight and allowing increased cargo capacity.

There are two engine technologies that can be used to power natural gas vehicles: spark-ignited (SI) engines use the same combustion cycle as gasoline engines, while compression ignition (CI) engines are based on the diesel cycle. While CI engines tend to have a higher overall efficiency than SI engines, their higher acquisition costs tend to make them more suited for large fuel consumption applications.

For cars and light-duty trucks, there are no factory-produced (OEM) products available in Canada, although GM is now offering two cargo vans with dedicated natural gas fuel systems installed by a third-party converter. Ford has announced that it will make at least one natural gas “prepped” engine available to upfitters in the near future. A number of small- and medium-capacity vehicle upfitters serve the U.S. market by converting mostly new gasoline light-duty vehicles to natural gas at an incremental price in the range of $12,000 to $15,000.

The natural gas vehicle industry in Canada includes a number of companies whose natural gas vehicle- and station-related products and services are exported to NGV markets around the world. These include:

- Alternative Fuel Systems (alternative fuel automotive components)
- Cummins Westport (CNG/LNG engines)
- Dynetek Industries (lightweight CNG storage vessels)
- ECO Fuel Systems (CNG vehicle conversion systems)
- Enviromech Industries (modular vehicle fuel storage systems)
- FTI International Group (CNG dispensers and stations)
- IMW Industries (oil-free CNG compressors, dispensers and stations)
- Kraus Global (CNG dispensers)
- Powertech Labs (cylinder testing and certification)
- Saskatchewan Research Council (neural control and dual-fuel technologies)
- Viridis Technologies (CNG dispensers and RFID systems)
- Westport Innovations (LNG engine systems)
- Xebec Adsorption (natural gas dryers and biogas upgrading equipment)

Medium- and heavy-duty natural gas engines are available as options from an estimated 15 North American truck and transit bus manufacturers at an incremental cost of $35,000 to upwards of $60,000. However, there are currently a limited number of models available to end-users, which include:

- SI engines that are fuelled purely by natural gas and can serve the medium- and heavy-duty engine market; and
- Higher-horsepower heavy-duty engines that use dual-fuel injectors to initiate combustion with a small amount of diesel fuel, followed by the main injection of natural gas — these engines typically use 95 percent or more natural gas.

To maximize driving range for heavy-duty trucks, the preferred way to store natural gas onboard is in its denser liquid form (LNG) in cryogenic stainless steel tanks. These tanks are costly to manufacture and account for a significant share of the incremental cost of natural gas trucks. CNG can also be used as a fuel for heavy trucks, depending on the fleet's range requirements and duty cycle. Transit buses typically use several roof-mounted fibre-wound tanks to store compressed gas (CNG), while medium-duty trucks use one or more chassis-mounted tanks (CNG). The main reason for using natural gas in its compressed form is that it is widely available by installing compression equipment wherever there is pipe in the ground based on Canada's gas distribution system. In addition, there are some operational differences between CNG and LNG as vehicle fuels that may determine which form of the fuel is selected for use by a fleet.

LNG has been used successfully in trucking demonstrations in Canada, but general commercial uptake has not yet occurred, even though the main suppliers of the engine technologies are based here. However, there has been some uptake in markets such as California and parts of Australia and China. Significant LNG use by the trucking industry would require an expansion of existing fuelling facilities and construction of new LNG plants specifically to serve this market.

Codes and Standards

As new technologies are developed, there is a need for concurrent development of related design/ safety codes and standards. During the 1990s, significant work was done to develop codes, standards and regulations for CNG storage for use onboard vehicles, as well as those pertaining to dispensing and refuelling infrastructure.[6] Over the last decade, however, due to a decrease in demand for NGVs, the relevant codes and standards committees have grown dormant. There are currently no codes, standards or regulations in place in Canada that specifically address LNG vehicles, refuelling stations, and fuel supply. The lack of harmonized codes and standards across Canadian jurisdictions, as well as in the United States, is an additional barrier to NGV market penetration.

What are CNG and LNG?

In transportation applications, natural gas is used as either CNG or LNG. The goal of creating CNG or LNG is to increase the density of the fuel to get more energy onboard the vehicle, which increases its driving range.

CNG is formed by compressing natural gas to high pressures in the range of 3,000 to 3,600 pounds per square inch (psi). Compression reduces the volume by a factor of 300 (or more) compared with gas at normal temperature and pressure. It is stored in steel or fibre-wound cylinders at high pressures (3,000 to 3,600 psi). Onboard an NGV, the gas travels through a pressure regulator and into a spark-ignited or compression ignition engine.

LNG is made by cooling the natural gas temperature to -162°C. The liquefaction process reduces the volume by a factor of 600 compared with gas at normal temperature and pressure. The LNG is stored on vehicles in a double-walled stainless steel tank and vaporized before injection into the engine.

Conclusion

Mature, cost-effective, market-leading natural gas technologies are available from Canadian suppliers for fuel delivery, compression, storage, dispensing, and medium- and heavy-duty engine applications. These technologies are exported to many countries, but sales in Canada have been limited in recent years. Natural gas refuelling infrastructure is available in some major urban markets but overall is limited in quantity. LNG supply for vehicles is limited and will need to be expanded if the market potential in heavy-duty vehicles is to grow beyond a few demonstration projects. While a number of codes and standards are available to cover CNG fuelling stations and vehicle conversions, LNG codes and standards for transportation applications have yet to be fully developed.

[6] As part of this Roadmap, a complete listing of codes and standards was assembled.

ANALYSIS

A N A L Y S I S

Chapter 4

Natural Gas Fundamentals

Canada is the world's third-largest producer and exporter of natural gas. As part of a fully integrated and continental natural gas market, Canada moves its natural gas resources seamlessly across provincial and national borders, from supply basins to demand centres. Regional prices reflecting market forces, including transmission costs, are established within this market. This chapter provides further detail on natural gas supply and demand outlooks, as well as taxation and environmental implications related to the extraction process.

Natural Gas Supply Outlook

The North American natural gas supply portfolio is shifting from one dominated by conventional reservoirs in sandstone or carbonate rock to one dominated by unconventional resources, particularly natural gas from shale, or shale gas. Shale deposits holding significant amounts of natural gas are widely spread across North America. Until recently, this natural gas was difficult to extract, since the gas does not readily flow into wells drilled by conventional methods. Technological advancements in areas such as horizontal drilling and multi-stage hydraulic fracturing now permit economic extraction of this resource in many areas. See Figure 1 for an explanation of shale gas extraction technology.

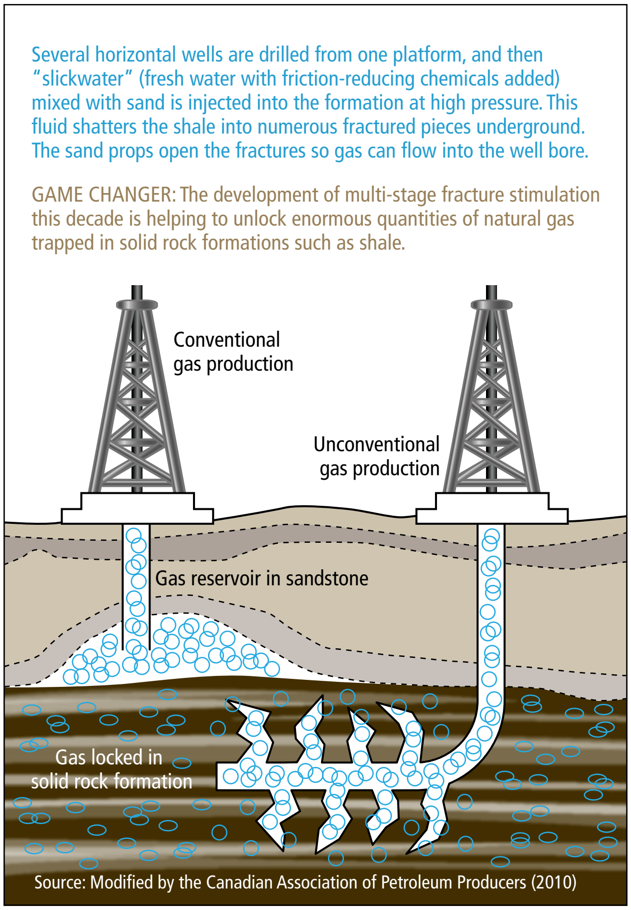


FIGURE 1 Shale Gas Extraction Technology

Technological advancements in areas such as horizontal drilling and multi-stage hydraulic fracturing now permit economic extraction of this resource in many areas.

FIGURE 2 Shale Gas Deposits in North America

Only a few years ago, natural gas production in North America was forecast to decline steadily as conventional reservoirs were being depleted. More recent forecasts, taking into account shale gas and coal-bed methane, have changed the outlook to increasing North American natural gas production for the foreseeable future. Shale gas development began in Texas with the Barnett shale and quickly spread throughout the United States and more recently into Canada.

Shale deposits cover much of the Western Canadian Sedimentary Basin and are also present in Ontario, Québec, New Brunswick, and Nova Scotia. Commercial development in Canada is currently focused in the Horn River Basin and Montney formation in north-eastern British Columbia. Figure 2 shows some of the other shale gas deposits that are spread across the continent; each area has unique geological and geographical characteristics that affect extraction costs. Even at today's low natural gas prices, production is already economically sustainable in many locations. Incremental improvements in drilling techniques, such as longer horizontal wells and increases in the number of fracturing stages, should bring other fields into economic range in the future. Figure 3, which presents one view of North American natural gas supply costs, shows that there is a large amount of supply available, even at today's relatively low natural gas prices.

Natural Gas Price Outlook

The rate at which natural gas is developed depends not only on extraction technology and cost, but also on anticipated market prices for natural gas. Higher market prices encourage more natural gas development, but if prices rise too high, they dampen demand from industrial and commercial gas users, some of whom have fuel-switching capability. Current natural gas prices are attractive to users given the relatively higher prices of oil products and electricity and the robust natural gas supply picture. Figure 4 highlights the substantial forecasted price differential between crude oil and natural gas on a barrel-of-oil equivalent (BOE) basis for the years 2011 to 2015. The price differential between natural

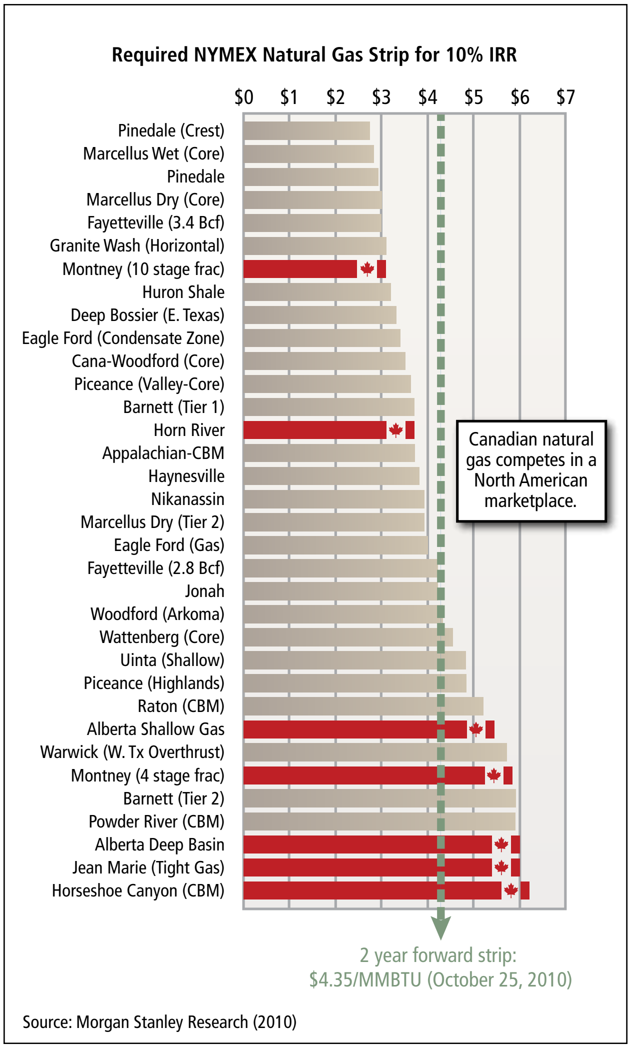


FIGURE 3 North American Natural Gas Supply Costs

gas and crude oil is expected to remain steady, according to industry estimates based on go-forward natural gas pricing contracts through 2015. This trend should go a long way towards satisfying end-user concerns about the future price of natural gas versus crude-derived fuels. Increases in natural gas demand in the transportation sector could have some inflationary effect on natural gas prices; however, this effect is likely to be minor, since gas volumes going into transportation will be relatively small in comparison with the main markets for natural gas in the industrial, power generation, commercial, and residential sectors, and given the robust supply context.

The final price of natural gas for transportation end-users is the sum of the unregulated producer price, regulated pipeline tariffs, certain taxes (in Canada, either Goods and Services Tax/Harmonized Sales Tax or Québec Sales Tax, depending on the province), local distribution charges, liquefaction and/or compression costs, plus retail margin if infrastructure is not owned by the end-user. The natural gas value chain is summarized in Figure 5. For transportation users, the charges for storage and dispensing of compressed and liquefied gas at transport terminals and fleet yards can be a significant component of the final gas price. The respective roles of producers, brokers, and marketers in serving large road transport fleets, as well as rail or marine markets, have yet to be determined and may differ by province. Depending on the availability of services, the end-user may pay a price for natural gas that includes certain 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. Whatever the arrangement, it appears that there is scope for attractive prices for fleets and other bulk users.

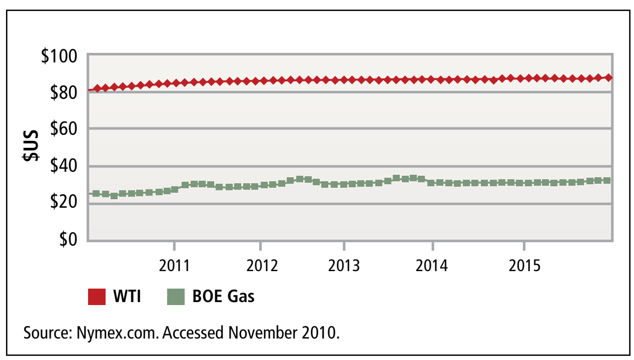
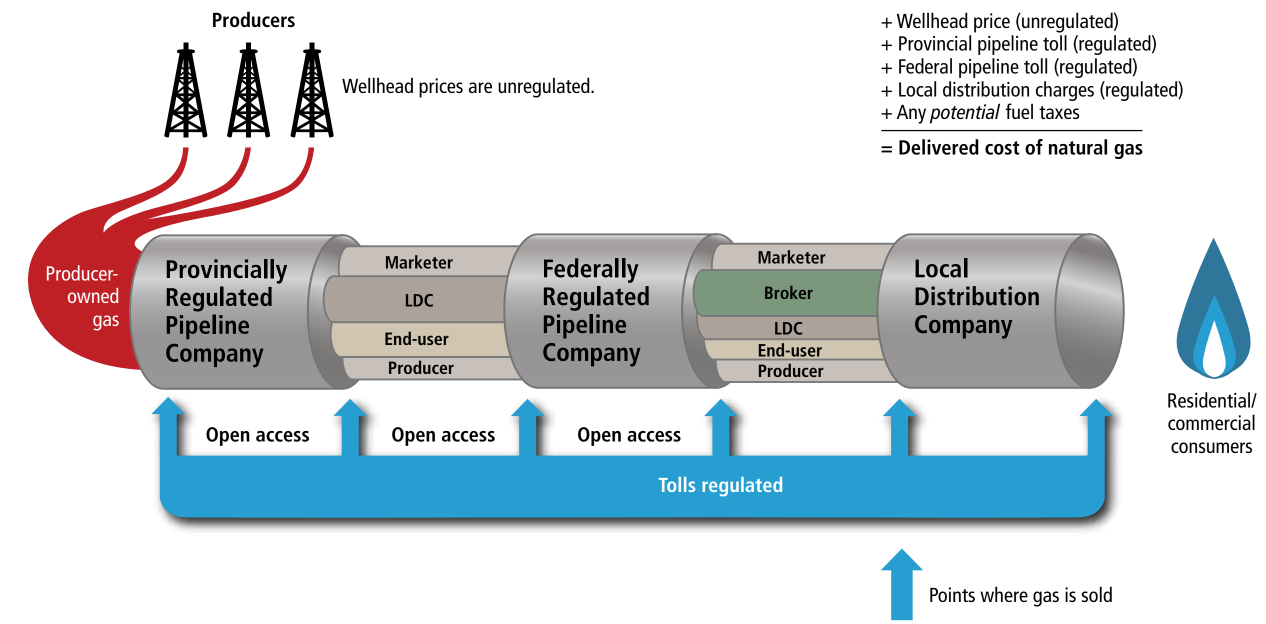


FIGURE 4 NYMEX Futures Prices: WTI vs. Natural Gas (Barrel-of-Oil Equivalent)



Source: Natural Resources Canada (2010)

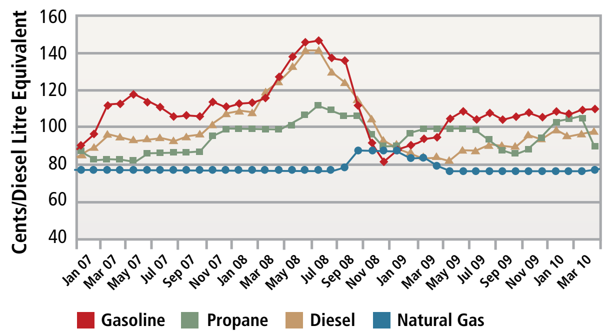
FIGURE 5 Natural Gas Value Chain

For transportation users, particularly truck fleets, the cost of fuel is a major concern. The prospect of a significant or growing natural gas-to-diesel price differential is attractive to all stakeholders. To justify initial investments in new equipment, end-users would like some assurance that compressed or liquefied natural gas prices will be predictable and stable. Figure 6 shows recent fuel prices, based on a survey at retail filling stations in Toronto. While natural gas prices appear to be relatively low and stable, this could be a consequence of how few retail filling stations exist. If the natural gas for vehicles market were to grow significantly, increased competition among a greater number of retail filling stations could result in more price movement.

Contract gas prices for in-yard fleet fuel deliveries can be lower than those in the chart. Since truck fleet and other large end-users are accustomed to delivery and storage prices for diesel amounting to just a few cents per litre, there is likely to be pressure on natural gas suppliers to reduce the gap between wholesale and delivered compressed and liquefied natural gas. While there are good reasons for higher prices for delivered natural gas, based on the different fuelling equipment, storage tanks, and code requirements, there should be some room for cost and margin reductions as natural gas volumes grow.

Role of Taxation

Part of the price advantage of natural gas for transportation is that it is taxed at a lower rate than diesel and gasoline. While this tax treatment gives an advantage to natural gas as a transportation fuel in the short term, if natural gas usage grows to the point that it significantly constrains fuel tax revenues, there could eventually be pressure for natural gas to be taxed by provinces and the federal government at similar rates to diesel fuel. However, preferential tax treatment would help further develop this market.



Source: Natural Resources Canada (2010)

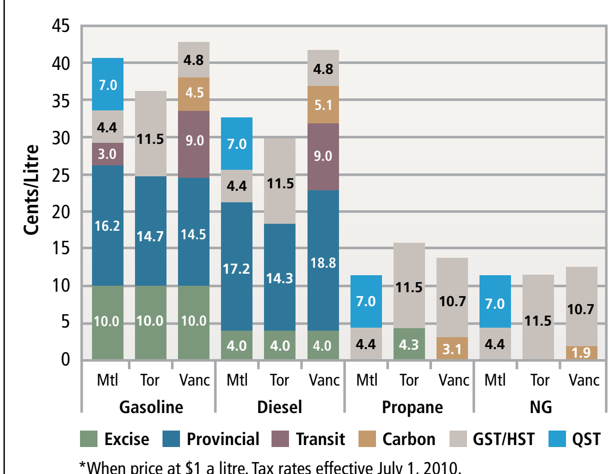
FIGURE 6 Toronto Fuel Prices Including Taxes

Environmental Outlook

Natural gas can provide an advantage for companies that are investing in GHG emission reductions, as conventional natural gas vehicles emit about 20 to 30 percent less carbon on a well-to-wheels basis compared with diesel or gasoline. Both conventional and unconventional raw natural gas require processing to remove impurities, including CO_2. The CO_2 content of shale gas, for example, varies considerably by deposit. In Canada, the approximate range of CO_2 content of shale gas is anywhere from less than 1 to 12 percent. Since some shale gas contains more CO_2 than conventional gas, mitigation methods will need to be developed for high-CO_2 shale formations.

When considered along with the GHG impact of the final combustion of natural gas, the upstream contributions are relatively small, and differences between conventional and unconventional natural gas represent, at most, 3 percent of the total GHG footprint. Further analysis in this area is warranted, but such work is beyond the scope of this Roadmap.

Concerns have been raised surrounding the environmental impact of shale gas development, particularly with respect to water usage and potential impact on water quality. These issues have received more attention in the United States than in Canada, as shale gas development is further advanced and takes place on a larger scale there. In Canada, most aspects of shale gas development fall under provincial jurisdiction and are subject to stringent regulation and enforcement specifically designed to protect Canada's environment and water resources. Evolving drilling technology improvements and improvements in water treatment and recycling continue to help reduce the overall impacts of shale gas development.



Source: Natural Resources Canada (2010)

FIGURE 7 Fuel Tax Comparison by City

Biogas and Biomethane

Biogas is readily available and is derived from landfills and sewage treatment, and through the anaerobic digestion of waste from municipal and agricultural sources. Established technology exists that can be used to upgrade biogas to pipeline-specification renewable natural gas, which is also known as "biomethane." Biomethane is a renewable fuel that provides significant GHG reduction benefits.[1] The displacement of a carbon-positive fuel such as natural gas through the use of this fuel results in a net reduction of GHG emissions. Biomethane is considered carbon-neutral, since it is derived from methane that would otherwise be released into the atmosphere. Biomethane is already being used in vehicles in North America, such as in fleets of garbage compactors that can conveniently refuel at landfill sites. In locations close to natural gas pipelines, biomethane can be injected into the pipeline for distribution. This renewable gas can then be managed and marketed to end-users anywhere on the distribution grid and sold in a blend with fossil gas to meet end-user needs.

Conclusion

The outlook for natural gas has changed significantly, from gradually declining natural gas production to rapidly growing production, enabled by drilling technology advances that allow producers to tap into huge unconventional resources distributed across Canada and North America more broadly. The production of much of this natural gas is economically sustainable at prevailing natural gas prices and at expected future prices, and therefore the outlook is for fairly stable or slow growth in market prices. It is anticipated that the price differential between natural gas and petroleum fuels will grow in future years, allowing natural gas to enter new markets. Biogas and biomethane are becoming increasingly available and can be used directly in stationary and transportation applications to achieve significant GHG benefits.

[1] Lifecycle GHG emissions from the production and use in heavy-duty vehicles of biomethane from landfills or anaerobic digestion are approximately 90 percent lower than GHG emissions from the use of diesel fuel. Source: "The Addition of Biomethane to GHGenius," (S&T) Consultants Inc, March 2009.

A N A L Y S I S

Chapter 5

Business Case Modelling

The objective of the business case analysis task was to examine the value proposition for natural gas as a fuel in various fleet applications to identify which applications have the strongest value proposition and greatest likelihood of being developed in an economically sustainable fashion, and demonstrate for the most promising applications that there is a strong underlying business case capable of generating a significant internal rate of return (IRR). The analysis focused on medium- and heavy-duty vehicles, since they were identified, through the working group's scoping analysis described in Chapter 2, as offering the greatest opportunities for increased natural gas use.

Value Proposition Analysis

1) Model Description

Change Energy Incorporated conducted the value proposition analysis using its proprietary lifecycle costing model, which was used to calculate costs over a 10-year period for NGVs, with diesel vehicles as a comparative baseline. The results of the analysis are summarized by a measure known as a Fuel Value Index (FVI), which combines all incremental operating and capital costs, as well as any differences associated with engine efficiencies and operating practices. The model allows all costs associated with natural gas use to be consolidated and reflected in a cost-per-diesel-litre equivalent (DLE). This comprehensive approach to total cost of ownership allows for a direct, all-in comparison with diesel fleet ownership costs on an energy equivalent basis and goes beyond simple payback measures to consider all operational costs.

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

2) Model Inputs – Jurisdictions and End-Use Applications

To conduct this work, a steering group with representation from each of the Roadmap working groups was formed to develop the statement of work, provide advice to the consultant regarding model inputs and assumptions, and review the results. As a first step, four provinces (British Columbia, Alberta, Ontario, and Québec) were chosen for the modelling based on the likelihood that they could support market launch and early development. The selection was based on a weighted evaluation of the following parameters:

- Existence of natural gas distribution infrastructure (e.g. local and transmission);
- Existence of LNG infrastructure and proximity to potential market;
- Existence of natural gas refuelling stations (public and private);
- Transportation fuel demand for medium- and heavy-vehicles in local area; and
- Identification of supportive policies and programs.

To ensure the integrity of the modelling results, a separate sensitivity analysis was conducted to assess the impact of a range of projected fuel price differentials on the business case.

Based on input from the End-User Working Group, 13 vehicle end-use applications were modelled. An end-use application was defined not only as a type of vehicle (e.g. tractor versus truck), but also by the way in which the vehicle is refuelled (e.g. public corridor versus private onsite station) and how the vehicle is used (e.g. highway goods movement versus urban distribution of goods). Only vehicles operating in return-to-base and regional corridor fleets were considered for the analysis, since the business case for natural gas hinges on amortizing the cost of the refuelling station over projected fuel volumes. It was assumed that all LNG applications used the Westport system, and all CNG applications used the Cummins Westport engine. This arbitrary distinction was made to simplify the number of modelling scenarios. In addition, the low-mileage applications were assumed to be CNG applications. In reality, a fleet's selection of a CNG or LNG vehicle would depend on a number of factors.

3) Model Inputs – Commodity Price Forecasts

Projected commodity pricing for natural gas and diesel fuel were key inputs for the modelling. While only a single set of forecasted values for each fuel could be incorporated in the analysis, it was recognized that there are a range of credible third-party fuel price forecasts. To ensure the integrity of the modelling results, a separate sensitivity analysis was conducted to assess the impact of a range of projected fuel price differentials on the business case. Further details regarding the results of this sensitivity analysis are included later in this chapter.

Two publicly available forecasts of long-term oil and natural gas pricing (GLJ and Sproule) were considered for the model. When plotted against each other, the forecasts were reasonably similar in expectations about future energy prices. For both oil and gas, the difference in 2020 prices

TABLE 1 Data from Sproule Forecast

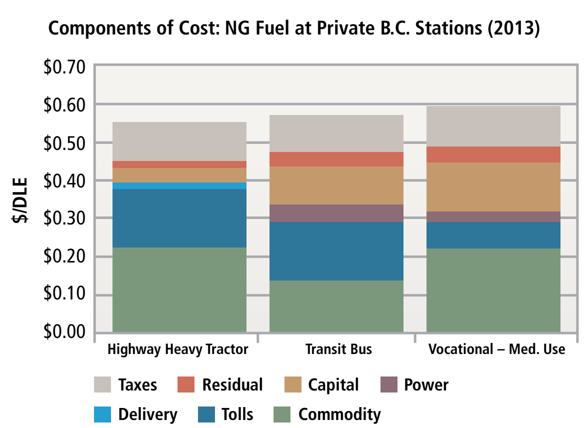
YEAR	OIL 40° AMERICAN PETROLEUM INSTITUTE $/Bbl EDMONTON PAR	INFERRED DIESEL PRICE BY JURISDICTION ($/Litre) B.C.	ALBERTA	ONTARIO	QUÉBEC	NATURAL GAS $/mmbtu AB – AECO
2010	79.12	1.082	0.849	1.022	1.042	4.32
2011	86.34	1.181	0.926	1.115	1.137	4.50
2012	88.57	1.211	0.950	1.144	1.166	4.98
2013	90.69	1.240	0.973	1.171	1.194	6.00
2014	94.67	1.294	1.015	1.222	1.246	7.75
2015	96.1	1.314	1.031	1.241	1.265	7.88
2016	97.55	1.334	1.046	1.260	1.284	8.01
2017	99.02	1.354	1.062	1.279	1.304	8.14
2018	100.52	1.374	1.078	1.298	1.323	8.27
2019	102.03	1.395	1.094	1.317	1.343	8.41
2020	103.57	1.416	1.111	1.337	1.364	8.55
2021 (extrapolated)	104.95	1.435	1.126	1.355	1.382	8.68

Source: Change Energy Inc. (2010)

between the two forecasts was significantly less than 10 percent. These two forecasts were also compared to and found to be quite similar to forecasts produced by other consulting firms. Based on a review of the various forecasts, members of the Natural Gas Fundamentals Working Group, which included representatives of the upstream natural gas industry and Natural Resources Canada, recommended the Sproule forecast for natural gas pricing. Similarly, it was recommended that the Sproule forecast be used for diesel forecasting to provide information on projected crude oil pricing. Based on the historic relationship between diesel prices and crude oil prices, a factor was derived for each jurisdiction to develop projected diesel prices. Values incorporated in the model are shown in Table 1.

Inputs to the Modelling – Vehicle, Station, Fuel, and Operating Costs

The elements of cost that are incorporated in the FVI are: 1) delivered cost of natural gas via pipe, 2) cost to liquefy or compress gas, 3) truck delivery of LNG, 4) applicable taxes, 5) incremental capital cost for vehicles, 6) incremental operating and maintenance cost for vehicles, 7) capital cost for station sized to meet total fleet fuel demand, 8) incremental operating and maintenance cost for station, 9) cost of training personnel, 10) opportunity cost associated with additional fuelling time where applicable, and 11) residual value impact. These various cost elements can be broadly categorized into fuel-related costs and vehicle-related costs. Figure 1 provides a comparison of fuel-related costs for three return-to-base end-use applications.



Source: Change Energy Inc. (2010)

FIGURE 1 Components of Cost: Natural Gas Fuel at Private B.C. Stations

TABLE 2 Comparison of Fuel and Vehicle-Related Costs

	HIGHWAY HEAVY TRACTOR	TRANSIT BUS	VOCATIONAL – MEDIUM USE
Station capital cost	$0.820 million	$1.6 million	$0.545 million
Fleet size	Small – 30	Small – 35	Small – 25
Annual mileage per vehicle	200,000 km	55,000 km	30,000 km
Annual fuel use	2,220,000 DLE	1,160,000 DLE	325,000 DLE
Vehicle-related costs ($/DLE)	$.235/DLE	$.538/DLE	$1.404/DLE
FVI for given year	1.58	1.02	0.56

Source: Change Energy Inc. (2010)

Assumptions

- LNG for highway heavy tractor; CNG for all other.
- Assumed 1 diesel litre (DLE) = .969 m^3 natural gas on an energy equivalency basis.
- Tolls include transmission and local delivery charges plus cost to liquefy for LNG.
- “Delivery” refers to delivery via tanker truck, which applies to LNG only.

Fuel-related costs are driven by fleet size, fuel consumption, and station scale assumptions. Medium-use vocational trucks have the highest capital component in their fuel-related costs, as station capital is amortized over a relatively few number of vehicles (25) that travel only 30,000 km per year per vehicle. For vehicle-related costs, vehicle incremental and operating costs have been aggregated and calculated on a DLE basis. By adding the fuel-related costs per DLE to the vehicle-related costs per DLE, the total cost of ownership for natural gas can be calculated and compared with projected diesel pricing. This information is then used to determine the FVI value for that application (see Table 2).

TABLE 3 Application Ranking Table

APPLICATION	FLEET SIZE	MILEAGE (km/YEAR)	RANK	COMMENTS (FVI RANGE)
LNG Highway Heavy Tractor RTB	Large – 200	200,000	1	Very Good 1.01–1.63
LNG Urban Heavy Tractor RTB	Large – 200	140,000	2	Very Good 0.90–1.45
LNG Highway Heavy Tractor COR	Large – 200	200,000	3	Very Good 0.89–1.43
CNG Transit Bus RTB	Large – 150	55,000	4	Very Good 0.84–1.29
CNG Refuse – Private RTB	Large – 100	30,000	5	Good 0.70–1.04
CNG Urban Heavy Tractor RTB	Large – 200	60,000	6	Good 0.70–1.03
CNG Vocational – High-Use RTB	Large – 100	50,000	7	Fair 0.65–1.01
LNG Port Drayage RTB	Large – 200	60,000	8	Fair 0.63–1.03
CNG Refuse – Public RTB	Large – 100	20,000	9	Weak 0.48–0.85
CNG Vocational – Medium-Use RTB	Large – 100	30,000	10	Weak 0.45–0.74
CNG School Bus RTB	Large – 100	15,000	11	Very Weak 0.31–0.61
CNG Port Drayage RTB	Large – 200	20,000	12	Very Weak 0.31–0.57
CNG Vocational – Low-Use RTB	Large – 100	15,000	13	Very Weak 0.23–0.46

Ranking categories relative to average FVI values:

FVI > 1.05 Very Good
FVI > 0.85 but < 1.05 Good
FVI > 0.75 but < 0.85 Fair
FVI > 0.60 but < 0.75 Weak
FVI > 0.60 Very Weak

The fleet sizes and mileage assumed for the above applications were used for modelling purposes and may vary among fleets.

Source: Change Energy Inc. (2010)

Modelling Results

Of the applications modelled, four applications were found to have average FVI results that were equal to or better than 1, which suggests that the value proposition for natural gas is equivalent to or better than that for a comparable diesel fleet over the 10-year time frame considered. Rankings for all applications modelled are shown in Table 3. The top four end-use applications in order of ranking were:

1. LNG highway tractors refuelling at a private onsite station (return-to-base);
2. LNG return-to-base urban tractors;
3. LNG highway tractors refuelling at public stations on highway corridors; and
4. CNG return-to-base transit buses.

An additional four applications reached an FVI greater than 1 by the end of the 10-year period, which suggests that there is a business case, but that the time frame for payback may be quite lengthy.

5. CNG return-to-base refuse haulers — private ownership;
6. CNG return-to-base urban tractor;
7. CNG return-to-base vocational trucks; and
8. LNG return-to-base port drayage trucks.

The FVI results are significant, since they indicate that there are medium- and heavy-duty NGVs that have strong value propositions and can be economically self-sustaining if the barriers to market adoption are addressed. Other applications were less attractive on the basis of economics alone, as indicated by FVI values below 1 for the 10-year time frame modelled.

Natural gas use in heavy trucks is a particularly interesting opportunity, since there are some key regional trucking corridors in Canada where infrastructure could be well used by an existing high-demand market. Over the past decade, the structure of the trucking industry has swung increasingly towards return-to-base operations as opposed to long-distance hauling. In addition, CNG in transit buses had a very strong FVI. Although the economic case for buses is very good, the past negative experience of some transit properties with CNG buses must be overcome for this application to succeed. This issue was noted by transit end-users through the consultations described in Chapter 6.

Modelling Detail

The degree to which the FVI is greater than 1 indicates the degree that a natural gas option will offer greater economic value compared with a diesel fleet.[1] An FVI of less than 1 indicates that the value proposition is not as great for natural gas as it is for the diesel fuel baseline. Since costs of inputs can vary over the 10-year forecast period, the FVI changes in value over time. Thus, if the price differential between natural gas and diesel increases over 10 years, the FVI will also increase. Figure 2 illustrates the evolution of FVI values over time.

FVI values may also differ between provinces due to jurisdictional differences in key inputs such as diesel fuel pricing and the cost of electricity. For example, Alberta has lower diesel fuel prices than the other three provinces. The impact of this difference on the FVI is shown in Figure 2. FVI results for LNG applications are strongest in Québec and British Columbia, where LNG production infrastructure is already established, with utility-owned and -depreciated facilities. FVIs for LNG applications in Ontario and Alberta are relatively low, partly because of the additional costs associated with delivering LNG from the existing points of supply.[2] The model does not take into account the effect of new liquefaction facilities and the fuel supply capacity requirements that might eventually be required to support growing market demand. Incremental LNG supply from a new facility would have higher capital recovery costs, perhaps as much as $0.10 to $0.15/DLE higher[3] than current prices. However, higher capital costs may be partly offset if revenue is derived from other markets such as rail and marine freight, off-grid gas supply, "portable main" applications, and gas utility supply reinforcements. Both Alberta and Ontario have strong chemical industry capacity that could accommodate the establishment, operation, and use of LNG facilities.

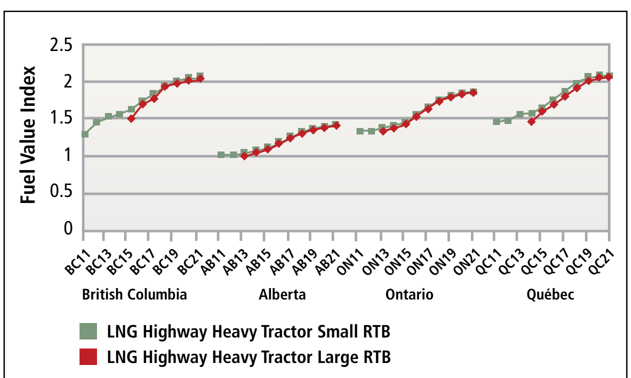


FIGURE 2 FVI Results for LNG Highway Heavy Tractors by Jurisdiction (2011–2021)

[1] There are other non-economic factors, such as environmental or social goals, that may encourage a fleet to use natural gas even if the FVI is 1 or less.

[2] There is a liquefaction facility in Northern Ontario owned by Union Gas, but it was not included as a potential supply source for the Ontario market based on utility input.

[3] Based on analysis conducted by Encana Corporation.

> The IRR values demonstrate that there is a strong business case, particularly for high-mileage applications that operate along corridors or in return-to-base fleets.

Business Case Analysis

As an alternative fuel, natural gas is relatively complex, since end-users must consider not only the costs and issues related to vehicles, but also refuelling infrastructure. The FVI modelling provided a way to incorporate all costs of ownership and compare the value propositions for a range of end-use applications.

The next step involved an analysis of the business case for each of the four most promising end-use applications. Given that the modelling demonstrated that these applications had a lower all-in cost of ownership than that of a comparable diesel fleet, the following questions needed to be addressed:

1. How significant was the business case, and could the most promising end-use applications compete for market capital based on their projected internal rate of return (IRR)?
2. For end-users, what was the payback on vehicle capital cost based on fuel savings, and would this payback fall within an acceptable range in term of tolerable levels of risk?

Table 4 provides both IRR values and payback estimates for the four highest-ranked end-use applications. Both five- and 10-year IRR values are shown to demonstrate savings that were not realized if the fleet chose to dispose of the vehicles after five years, which was identified as a common practice in major for-hire trucking fleets.

The IRR values demonstrate that there is a strong business case, particularly for high-mileage applications that operate along corridors or in return-to-base fleets. Capital investments can earn an attractive rate of return. Payback ranges varied depending on the scenario modelled, but in each case, payback values demonstrate that the incremental cost for natural gas would be recovered well within the vehicle's life.

TABLE 4 IRR Summary for "Very Good" Ranked End-Use Applications (British Columbia, 2011)

FVI RANKING	APPLICATION	FLEET SIZE	CAPITAL INVESTMENT	5-YEAR	10-YEAR	PAYBACK (YEARS)
1	LNG Highway Heavy Tractor (return-to-base) ($0.80 million station; $2.05 million vehicle increment)	30	$2.85 million	48%	58%	1.77
2	LNG Urban Heavy Tractor (return-to-base) ($4.13 million station; $13.66 million vehicle increment)	200	$17.79 million	18%	30%	3.10
3	LNG Highway Heavy Tractor (corridor) ($5.78 million station; $13.66 million vehicle increment)	200	$19.44 million	19%	32%	2.98
4	CNG Transit Bus (return-to-base) ($3.06 million station; $6.75 million vehicle increment)	150	$9.81 million	0%	13%	7.32

Source: Change Energy Inc. (2010)

Sensitivity Analysis

Sensitivity of the FVI results to key assumptions was tested by modelling 1) the effect of carbon credits, 2) the impact of a fiscal measure that reduced incremental vehicle cost by 50 percent, and 3) the potential for a lower projected differential in natural gas pricing compared with diesel pricing. Findings of this analysis are as follows:

- A carbon credit based on British Columbia's approach to carbon taxation had little benefit for low-mileage vehicles (typically driven less than 30,000 km/year), but high-mileage applications (typically greater driven more than 100,000 km/year) showed a 6 percent benefit by the end of the 10-year period. These findings indicate that the economic case for natural gas in the transportation sector is not dependent on pricing carbon, but would be further enhanced by the monetization of carbon.
- Measures that reduced the capital cost premium of a truck or bus by 50 percent had a significant impact on FVI values, increasing them from 6 to 20 percent, depending on the end-use application.
- The base modelling incorporated separate forecasts for each of natural gas and diesel fuel. The differential between these projected fuel costs varied from a range of approximately 45 percent in 2011 to 54 percent in 2021. To test the robustness of the business case against a range of potential fuel price scenarios, four scenarios were modelled using 40 percent, 30 percent, 20 percent, and 10 percent differentials between diesel fuel and LNG pricing. Key findings were that a minimum 20 percent fuel price differential would be needed for high-use vehicles such as LNG return-to-base tractors to be economic, while low-use vehicles would need a 30 to 40 percent fuel price differential. As Figure 3 indicates, LNG tractors that refuel at a private station had FVI values greater than 1 for all modelled scenarios except the 10 percent differential scenario.

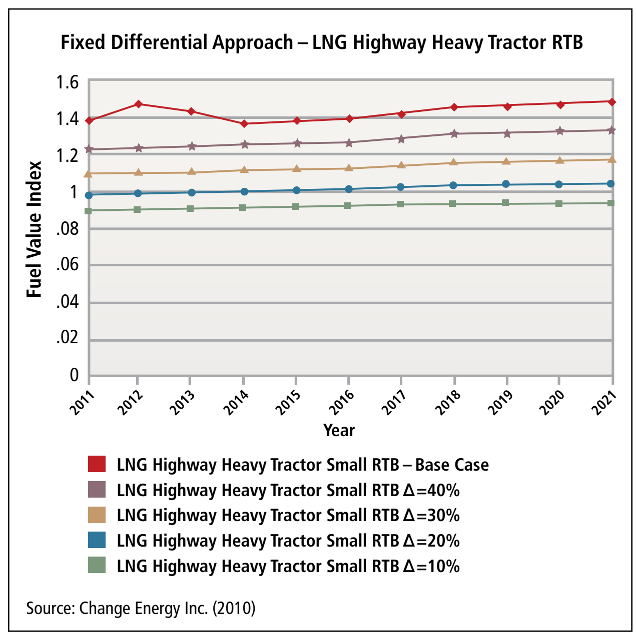


FIGURE 3 Impact of Varying Differential in Natural Gas and Diesel Pricing on FVI

The impact of factoring a range of projected differentials between natural gas and diesel pricing was also assessed for the IRR calculations for the four top-ranked end-use applications. Table 5 summarizes these findings.

Assumptions

- Base case for LNG applications assumed 45 percent differential with diesel in 2011 and 54 percent differential in 2021.
- Base case for CNG applications assumed less-than-optimal station utilization in early years, so differential values with diesel much less favourable.

Conclusion

The modelling results are intended for illustrative purposes only, and this work was undertaken to identify whether medium- and heavy-duty NGVs have positive value propositions, as well as the potential to be economically self-sustaining. In addition, the IRR analysis demonstrated that capital invested in the top-ranking end-use applications will generate an attractive rate of return. The potential for good rates of return stands up under a range of projected price differentials between natural gas and diesel fuel. Given the robustness of the overall business case, it is clear that natural gas can be an economically sound alternative for fleets of the right scale and in the right or "optimal" end-use applications.

The demonstrated favourable rates of return, combined with the lack of capital flowing to these opportunities, indicates that there are some underlying barriers that are limiting investment and uptake of medium- and heavy-duty natural gas vehicles. The barriers in the transit industry have already been mentioned, but there are other equally important issues that must be resolved for other markets to succeed:

- Of key importance to trucking operators is the residual value of an NGV at the end of its cycle, which is typically five to seven years. Will the vehicle need to be repowered to diesel before it is sold, or will there be a valuable market for used natural gas trucks?
- Can economies be realized by transferring high-value components such as dual-fuel injectors and cryogenic storage tanks from trucks being retired to new trucks?
- How quickly will the prices of natural gas components decrease as production volumes increase?
- Can the significant capital cost of new natural gas trucks and buses be easily accommodated within the existing financial structure of fleets?
- Can GHG emission reductions from the use of natural gas in vehicles be translated into monetary value for end-users?

These issues have technical and economic aspects that will need to be addressed through comprehensive information and education initiatives in order for the NGV market to develop successfully. Education and outreach is discussed in Chapter 7. Other issues that were not quantified in the economic analysis can be important to end-users. One example is the low noise of natural gas engines compared with diesel, and this issue is important in the transit, port drayage, and refuse hauling markets. Also, some urban fleets may be able to use biomethane produced from local waste sources. A triple bottom line analysis[4] may be conducted to account for such environmental and social factors and their potential benefits to end-users.

TABLE 5 Ten-Year IRR Summary with Sensitivity Analysis (British Columbia, 2011)

FVI RANKING	END-USE APPLICATION	BASE CASE	40%	30%	20%	10%
1	LNG Highway Heavy Tractor (return-to-base)	58%	50%	39%	28%	16%
2	LNG Urban Heavy Tractor (return-to-base)	32%	30%	22%	14%	4%
3	LNG Highway Heavy Tractor (corridor)	32%	29%	22%	14%	5%
4	CNG Transit Bus (return-to-base)	13%	26%	18%	8%	0%

Source: Change Energy Inc. (2010)

[4] A triple bottom line analysis, also known as "people-planet-profit," captures an expanded spectrum of values and criteria for measuring organizational and societal success: economic, ecological, and social.

A N A L Y S I S

Chapter 6

End-User Needs

As part of the Roadmap's development, consultations were conducted with the following end-user groups that operate medium- and heavy-duty fleet vehicles: 1) highway trucking, 2) municipal, 3) transit, 4) vocational truck, and 5) school bus. The objective of these consultations was to identify barriers to NGV adoption and deployment and to determine the conditions that would be needed for end-users to partake in market transformation. Information regarding past experience with natural gas vehicles was also gathered from three of the groups (municipal, transit, school bus).

End-User Consultations: Key Findings

During the consultation process, end-users provided the following perspectives regarding NGV deployment:

1. Vehicle incremental cost must be addressed. Payback requirements varied considerably, but end-users were unanimous in identifying incremental vehicle cost as a barrier to adoption. Some public sector fleets also noted fixed budget constraints.
2. Existing fuel tax exemptions need to be maintained in the near to medium term. However, end-users recognize that there could be pressure to eliminate the exemption in the long term as natural gas usage grows and begins to displace diesel consumption. This point was most clearly articulated by highway trucking end-users, who also had the most aggressive payback requirements. Environmental benefits related to GHG reduction were cited as a rationale.
3. Credit for using a lower-carbon fuel needs to accrue to fleets. Natural gas use should benefit fleets through carbon credit generation and compliance with regulations. Mandates requiring low-carbon fuels for public contracts were also suggested.
4. Aligned federal and provincial measures are needed. Suggestions included support for vehicle trials, programs that are accessible to both public and private sector fleets, and aligned measures that help ensure that GHG reductions are achieved.
5. Assistance is needed related to regulations and approval processes. End-users noted that refuelling facilities represent a challenge in terms of approvals. It was suggested that government could play a role in facilitating refuelling station approvals. Governments could also assist in addressing the regulations governing vehicle weights and dimensions to allow some overweight margins for LNG-fuelled trucks.
6. Past and current challenges are significant and must be addressed. Inadequate support for stations, parts, and vehicles was noted. Also highlighted were slow refuelling times relative to liquid fuels, and unreliable, maintenance-intensive early-generation engines.
7. Available NGV models may not suit all end-users' needs. School bus end-users noted the lack of natural gas Class C-type school buses as a barrier.
8. Natural gas use must mesh with fleet operational practices. Transit and vocational truck users both noted that other vehicle maintenance tasks are carried out in conjunction with refuelling. Maintaining operational efficiencies is a key driver for end-users.

End-User Consultation Results

It was evident from the consultations that there are significant differences in end-user awareness regarding the current availability, capabilities, and benefits of medium- and heavy-duty NGVs. In addition, while the consultation process was not intended to gauge intent, it was clear from these discussions that natural gas has the potential to be a viable option for medium- and heavy-duty vehicles in Canada if end-user needs can be addressed. The following charts summarize verbatim comments made by end-users within the group consultation process.

HIGHWAY TRUCKING	
Overall Business Case	It is critical that the trucking industry be able to take advantage of a carbon credit system and get credits if truckers use natural gas as fuel. The cost of premium, green technology cannot be passed on, so truckers need other direct benefits to support investment.
Fuel Costs	There will eventually be a tax on natural gas, but the social good of lower GHG emissions should relate to the level of tax on this fuel. Government needs to take advantage of our huge domestic natural gas reserves.
Vehicle Capital Costs and Financing	Québec offers incentives for trucks hauling freight to switch to LNG vehicles, but this is only for the Québec portion of corporate income taxes. The federal and provincial governments need to get onboard. There also need to be more than just road tax exemptions. Industry is making investments, and it needs governments to open doors and take away roadblocks.
Operational Issues	With the size of the fuel tanks, and changes in technology using more "real estate" on the frames, consideration must be given to weight allowances or increased wheel bases – vehicles are running out of room.
Refuelling Requirements	Refuelling facilities and infrastructure are one of the biggest challenges. Government needs to take the initiative in development of refuelling facilities. Also, a facilitator is needed to get through all the permits and legislation.
Training	It takes training to get technicians up to speed, but this is not a huge issue. It is part of doing business.
MUNICIPAL	
Overall Business Case	There is a generally held belief that new technologies are so clean (100 new vehicles = 1 old vehicle) that there is no sense of the advantage of natural gas or other alternative fuels. Diesel tends to beat LNG or CNG on a strict business case basis.
Fuel Costs	With some station financing models, end-users must commit to buying a minimum amount of natural gas. This creates an unacceptable risk, especially if government support changes, the technology is inadequate, or the business case changes.
Operational Issues	Perception that equipment downtime is still a common issue, since natural gas systems are not very durable. Also, fuelling infrastructure does not exist in large quantities.
Training	Training for mechanics is an issue.
Facilities and Refuelling Stations	Maintenance and safety infrastructure needs to be upgraded when introducing CNG/LNG to a garage. Maintenance infrastructure upgrades were costly ($80,000 for methane detectors in garages). Hamilton found CNG quite costly to maintain, specifically the fuelling stations.
Perspective on Roles	Mandates and incentives must be realistic, long-term, and helpful. In the 1980s, vehicles had to be produced by OEMs, which was good but also limiting. The business case changes dramatically when new fuel taxes are imposed and incentives are withdrawn. There is a need for a solid, long-term commitment that at least matches vehicle life (10 years).
TRANSIT	
Vehicle Refuelling	Estimated fill times ranged from three to nine minutes, with an average of 4.4 minutes. The reported fuelling time of nine minutes was specifically attributed to CNG, and that transit provider also reported a fill-time of three minutes for diesel.
Experience with Natural Gas Refuelling Stations	Fuelling station reliability was reported to be good for one operator and below expectations for another. A third operator reported problems with winter use, including the need to adjust compressor regulators to compensate for fuel flow. Support from the fuelling station operator was rated as poor but improving by one current operator. The former operator indicated that service was helpful but not timely. Parts availability was rated as poor but improving by one current operator and good by another. A third operator indicated that it carried additional stock, which was expensive.

Operational Issues	Infrastructure to fuel and park buses indoors is expensive; Technical Standards and Safety Authority(TSSA) required numerous inspections; and pressure relief valves required annual testing at a cost of $500 per test.
Training	Specialized training was required for fuelling. Also, a licensed TSSA compressor operator needed to be on duty even when the station was not running.
Experience with Natural Gas Transit Buses	One current operator reported average reliability. The other two were not so positive: "Natural gas is nowhere near as reliable as diesel. Runs very hot and multiple problems during the summer months. Required increasing bus spare ration due to multiple problems and long lead times for parts." Warranty issues were cited a significant by all three operators: "Huge problems historically." "Yes, poor engine life." "Numerous meetings with manufacturer to attempt to resolve issues."
VOCATIONAL TRUCKS	
Acceptable Payback Period	Due to the increased risk associated with new fuel-efficient technologies, a payback period of 12 years (average life of a vehicle) is not practical, as the durability of the technology is unknown. Three years is the preferred payback period for new technology. The Ontario Government ended an incentive program that offered up to 33 percent of the price differential between an NGV and diesel. With the rebate, the payback period is four years. Without this incentive, the implementation of NGV would be risky.
Vehicle Performance and Refuelling	Have driven new trucks and the technology is much better. After driving, knew they had to have these trucks; however, there is difficulty finding the appropriate model.
Implementation Challenges	Fuel capacity. Will the vehicle be able to conduct a full day's work without refuelling? Will it be able to make longer journeys? Related to this is the issue of refuelling; currently, the infrastructure is not sufficiently widespread to ensure easy access. Pricing, availability, refuelling infrastructure, no crash test information, and the question of who does maintenance and repair work on NGVs. Other challenges include costs, the competitive nature of the industry, and the need to bid against other firms for contracts. The only way to get NGVs regularly used is to mandate their use for residential (collection) contracts.
Government Role	There is a lingering sentiment that NGVs are "pieces of junk." The government needs to help educate people about the improvement in the technology to get past this stigma. Follow the lead of the U.S., which offers incentives, rebates, and tax breaks.
Additional Comments	There is a green initiative throughout the economy, and NGVs are a good way to market a company to companies and municipalities that are interested in being more environmentally friendly.
SCHOOL BUS	
Acceptable Payback Period	School bus fleets have fixed purchasing allowances. They replace 6 percent of their fleet per year but have fixed budgets to purchase new vehicles, which are dictated by the province. There is little leeway to purchase high-cost vehicles such as NGVs.
Implementation Challenges	The lack of a Class C NGV school bus is the biggest hurdle. NGVs are not made in a model that they use, and the model that is available (Class D) has higher operating costs by 37 percent. CNG vehicles are only available in pusher buses, and these vehicles are unpopular with drivers. There needs to be more variety in vehicle options. If conversion to natural gas were more accessible and easier, it would facilitate increased NGV use.
Experience with Natural Gas	One fleet had a CNG bus for two or three years and may buy 11 more. Relative to diesel, the NGV is slower to refuel by roughly six minutes, and drivers don't like that. However, the NGV's performance and power are good, and operators enjoy driving the 84-seaters.
Government Role	Incentives, tax breaks and grants. Federal incentive programs generally seem to be inaccessible to school bus operators. Governments should pay for trial adoption of the vehicles. The school board is currently working with Nova Scotia on driver monitoring and training to reduce fuel consumption. It is willing to experiment with NGVs, but it is not in the budget to do so.
Operational Issues	Vehicle cleaning and light maintenance are performed in conjunction with refuelling, including vehicle washing, light service, fluids, and repairs to sticky doors.
Information Needs	There is insufficient information or knowledge (on natural gas school buses) available.

End-User Decision-Making Process

Heavy-duty trucking fleets are looking for a two- to three-year payback on their investment, in addition to the inclusion of strategies that will reduce risk and uncertainty associated with NGVs. Relative to the other end-user groups, the transit industry has a longer payback period, and the economic calculations for new buses include other considerations that are not typically within the transit property's control. A comprehensive education and outreach initiative is essential to provide end-users with the economic, operational, and technical information they need to calculate payback and reduce risks and uncertainty. Table 1 describes the "5A Approach,"[1] which can be used to distinguish key questions in the end-user decision-making process, as well as the broader approach to market transformation.

Conclusion

Understanding and addressing end-user needs is fundamental to increasing the use of natural gas in transportation and ensuring successful deployment. Medium- and heavy-duty vehicle fleets tend to be conservative when considering the adoption of new technology, and natural gas (particularly LNG) is unfamiliar and unavailable for most end-users. The uncertainty about fuel availability and prices, combined with the high incremental vehicle prices, limited marketing, and lack of financial incentives for natural gas trucks, helps explain the low NGV uptake to date. The potential for market growth for natural gas vehicles will not be realized unless the attitudes, knowledge, and key concerns of end-users are addressed.

It was evident from the consultation process that an extensive amount of information is needed to support end-users who are considering deployment of medium- and heavy-duty natural gas vehicles. Of the information needs identified, some requirements are common to all end-users, while others are unique and applicable only to certain groups. In addition, end-users with past experience using natural gas in their fleets require additional information that identifies how natural gas vehicle and refuelling technologies have improved in recent years. The next chapter discusses NGV education and outreach issues in greater detail.

TABLE 1 5A Approach

AVAILABILITY	
Does the technology/fuel exist?	▪ Are benefits documented? ▪ Does policy support markets? ▪ What market intelligence is available?
AWARENESS	
Are end-users aware of this technology?	▪ What is the degree of awareness along the value chain with respect to the key elements – benefits, policy, and market intelligence?
ACCESSIBILITY	
Is there something preventing interested consumers from getting access to the product?	▪ Where in the distribution network are there barriers preventing goods from reaching the hands of interested customers?
AFFORDABILITY	
Does the higher purchase price present a large market barrier?	▪ What is the relationship between production volumes, costs, and price compared with perceived benefits (e.g. energy savings)? ▪ What level of price reduction is necessary to affect this barrier? ▪ What financing structures can help break down this barrier? ▪ How can manufacturing costs be reduced? ▪ How do we improve the value proposition to consumers?
ACCEPTANCE	
If it meets the previous four A's, why are people still not buying? Is it providing an acceptable service to the end-user?	▪ Does it meet customer requirements? ▪ Is it reliable? ▪ Will it readily fit into existing fleets?

[1] 5A Approach adapted from material developed by Natural Resources Canada and Navigant Consulting.

ANALYSIS

Chapter 7

Education and Outreach

As discussed in previous chapters, medium- and heavy-duty NGVs have potential to offer economic and environmental benefits to end-users and society. However, to enable Canada's NGV market to develop, various stakeholders have important information and knowledge requirements that must be met, and these stakeholders influence vehicle purchase decisions in direct or indirect ways. This chapter reviews what information needs to be provided to stakeholders, or target audiences (TAs) as they are called here, to inform their decisions, and how best to provide it. Following a background section that provides the rationale for NGV education and outreach, this chapter highlights the key components of this strategy, including the objective, target audiences, and approach. To obtain the information for this section, a teleconference involving all working groups took place in July 2010. The purpose of this call was to identify key target audiences, key messages, and potential dissemination strategies.

Background

Past efforts to encourage NGV adoption have included education and outreach elements, with the federal government partnering with industry to implement programs targeting fleet owners. For example, in the past, information brochures were developed and distributed at trade shows targeting municipal fleet contacts. While activities of this nature were undoubtedly helpful, on their own they are insufficient to effect meaningful change. In addition, several aspects of the natural gas vehicle story have changed recently, and these changes need to be communicated:

- The turnaround in the outlook for natural gas means that supply is no longer a barrier to considering natural gas use in transportation.
- Technologies for medium- and heavy-duty natural gas vehicles have improved significantly in terms of reliability, power, fuel efficiency, and availability from OEMs. Canadian suppliers have developed leading engine, storage and compression, and dispensing technologies that are sold around the world.
- There is renewed interest from industry in the potential for natural gas as a transportation fuel. This interest is aligned with government priorities in terms of carbon reduction as a public policy priority.
- The full natural gas value chain is interested and engaged, with producers (e.g. Encana), transmission companies (e.g. TransCanada), and local distribution companies (e.g. Gaz Métro, Terasen Gas, ATCO Gas, Enbridge) all actively involved in the Roadmap process.

In particular, the changes in natural gas supply and vehicle technology are not necessarily well known to end-users or to the wide range of stakeholders that influence the market. Similarly, natural gas as a fuel is not as well understood as conventional liquid fuels in terms of its properties, differences from other fuels, delivered cost, lower-carbon nature, and renewable form. Finally, some stakeholders may request information pertaining to upstream issues, such as the impact of shale gas development, since this topic has received significant media attention of late.

Key Components of a Natural Gas Vehicle Education and Outreach Strategy

To address these knowledge gaps, a comprehensive and sustained education and outreach strategy focused on key target audiences is essential in order to effect change and begin to transform the vehicle market.

Objective

The objective of this strategy would be to:
"Educate and inform stakeholders to ensure that they have the necessary information and tools at their disposal to make informed decisions that will support the deployment of natural gas vehicles in Canada."

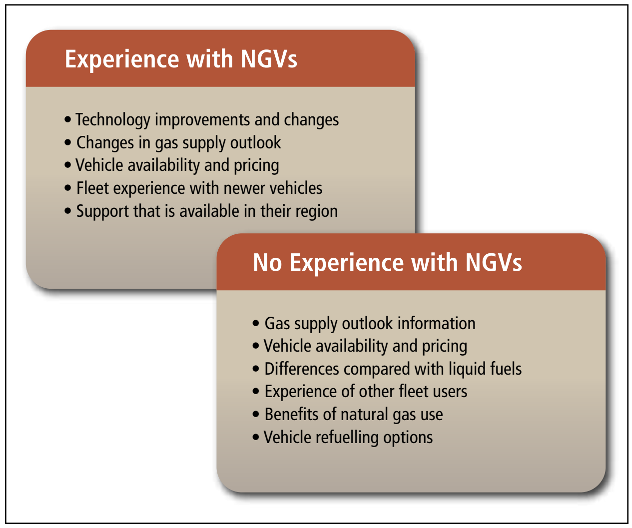


FIGURE 1 How the Degree of End-User Experience with NGVs Affects Outreach

Target Audiences

The education and outreach matrix identifies 14 key target audiences that can be organized into the following five categories: 1) end-users, 2) vehicle supply chain, 3) authorities and regulatory bodies, 4) industry, and 5) general interest.

1) End-Users

This category includes public and private sector fleets such as municipal transit, short-distance delivery, long-distance delivery, industrial, school bus, and vocational. Education and outreach efforts for this category would need to focus on basic education and outreach needs in the context of both knowledge gaps and past experiences with NGVs (see Figure 1). The former group would include those fleet managers who have little, or out-of-date, information about NGVs. These individuals need information to assist them with investment decisions related to NGV fuelling, including information about natural gas resources and prices, vehicle technology availability and price, operating experiences of other users, applicable codes and standards in their region, equipment and fuel suppliers, and environmental and other benefits of natural gas as a vehicle fuel.

The latter group includes those who have had previous negative experiences with NGVs and remain skeptical about the potential benefits associated with using this fuel. These individuals would likely require information regarding the experience of contemporary fleets that use natural gas, as well as details about technological advancements, current vehicle and infrastructure offerings, and opportunities to receive support for transition in their region.

2) Vehicle Supply Chain

This category includes OEM dealers, many of whom have limited experience with NGVs. Therefore, these target audiences require information that would enable them to address the needs and concerns of potential purchasers of these vehicles. Examples include information about the potential environmental and economic benefits associated with natural gas vehicle use, impact on vehicle range, and weight and dimensions, as well as other details that would help individuals make informed decisions about vehicle purchases.

3) Authorities and Regulatory Bodies

This category includes authorities with jurisdiction, regulators, governments, the Canada Border Services Agency, and emergency response providers. These target audiences may not have a major role in the market for natural gas for vehicles once the market has been developed. However, they are important target audiences, as their involvement in the initial stages of market development is crucial; the standards for which they are responsible must be met during the approval, construction, and operational phases of a project such a refuelling station.

4) Industry

This category includes companies active in the upstream, midstream, and downstream portions of the natural gas industry. It also includes equipment manufacturers, consultants, and research organizations. This target audience works with end-users to assess and deploy natural gas vehicles, so it needs to understand its role in the decision-making and deployment process, working to ensure that implementation is coordinated and that it effectively meets end-user needs.

5) General Interest

This category includes the public, media, and environmental groups. The target audiences in this category, especially the media, play a role in forming the opinions of others, so they need to have accurate information at their disposal.

Figure 2 describes the process continuum for end-users, such as fleet managers, who are considering the purchase of a medium- and or heavy-duty vehicle. When going through the process of purchasing such a vehicle, these end-users receive information from a variety of target audiences. If this information is insufficient or inaccurate, a communication breakdown will occur that may undermine the end-user's decision to purchase an NGV.

STEP 1

The first step in the continuum is for the end-user to gather information. All TAs are involved at this stage because each channel is a possible source of information that can be used to inform and influence the end-user.

STEP 2

There must be a supportive environment for the use of the NGVs. Regulations need to be in place and the possible incentives or programs identified. Positive references to NGV use in the media help generate awareness and interest.

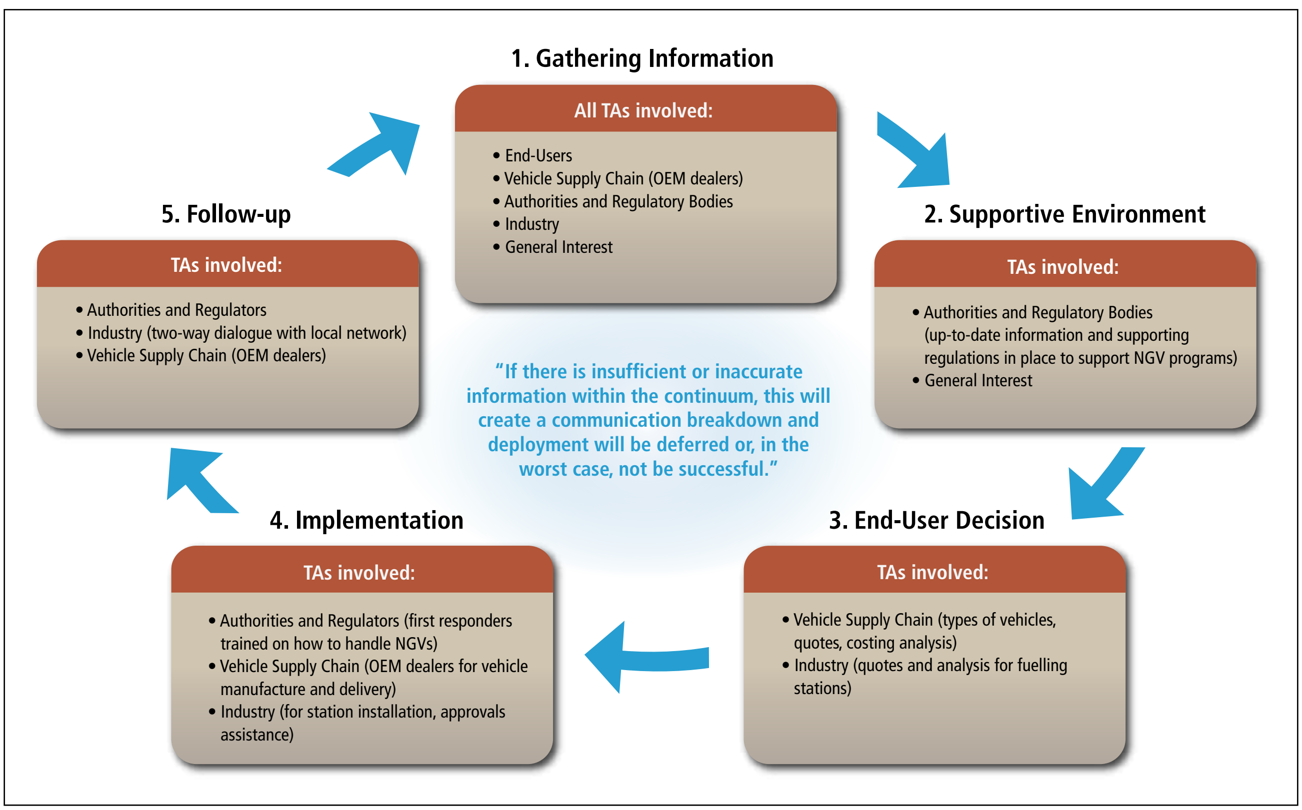


FIGURE 2 Process Continuum for Deploying a Medium- or Heavy-Duty NGV in Canada

STEP 3

End-users need to have costing and analysis done that incorporates vehicles, fuel, and possibly a refuelling station. Payback scenarios must be developed. Benefits must be weighed against costs and perceived risks in order to make a decision.

STEP 4

Dealers must deliver vehicles and industry needs to work with end-users to ensure that required approvals are secured for vehicles and station. Proper support for emergencies must be in place. First responders need to be trained to recognize and handle an emergency involving an NGV.

STEP 5

There needs to be continued follow-up involving industry, the vehicle supply chain, and end-users with respect to vehicle and station performance, maintenance, warranty issues, and product updates. There must also be follow-up involving authorities and regulators, depending on inspection and certification requirements in local regulations.

Approach

A holistic education and outreach strategy that targets end-users as well as market influencers and other key stakeholders should be developed. The strategy should have two main elements:

- A "top-down" approach that includes a central website for all target audiences with local content tailored to specific jurisdictions. This website should focus on basic education and outreach needs in the context of both knowledge gaps and past experiences with NGVs. It would serve as a central access point for all information related to NGVs (properties, benefits, suppliers, case studies, reports, news, refuelling stations, etc.) and provide real-time information on events such as announcements or upcoming workshops. The website could house brief videos (five or six minutes) that are educational and focused on "101" types of topics.

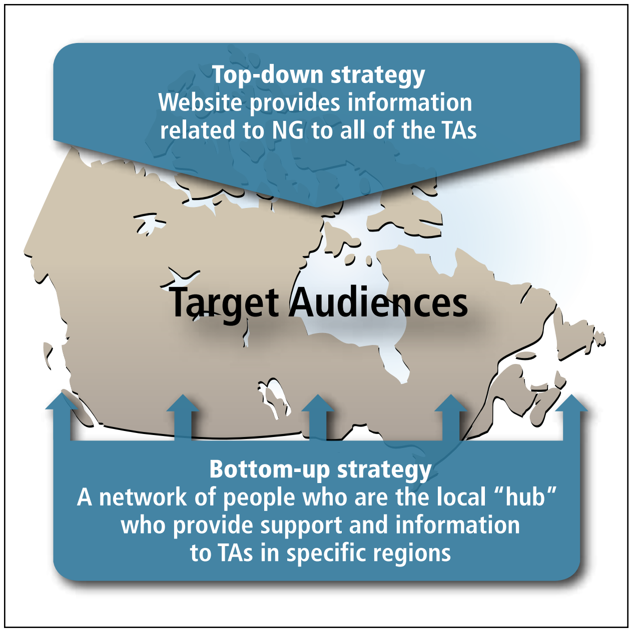


FIGURE 3 Information Dissemination: Top-Down and Bottom-Up Approach

- A "bottom-up" approach, which features a national support network that will provide access to resources at the local level for end-users, including workshops and meetings. This network — which could be similar to that of the Clean Cities Program in the United States — would be overseen by an umbrella organization. The network would have provincial coordinators who would provide customized support to users of NGVs. The coordinators would pool information and collect data that would be relevant for end-users, host workshops and meetings, disseminate education and outreach information, and provide technical assistance and other resources. See Figure 3.

Conclusion

To avoid competing messaging, there should be a branding exercise to ensure that all elements and tools have a common and unique look and feel. Branding would help TAs differentiate new and outdated information. Delivery of the education and outreach programs, including website hosting, would ideally involve an objective third party with resources and overall management provided by industry and government on a collaborative basis.

ANALYSIS

Chapter 8

Technology Research and Development Needs

During the 1970s, governments in Canada began funding R&D on alternative fuels — such as propane, hydrogen, and natural gas — to reduce dependency on petroleum resources. Since that time, governments in Canada and the United States have funded R&D on NGVs to achieve environmental benefits, as this technology was viewed as a means to improve air quality in urban areas. Initial R&D on gaseous fuels focused on developing codes and standards that would govern vehicle conversions, station design, and siting. These efforts also focused on addressing several shortcomings for natural gas as a vehicle fuel, including:

- Power loss;
- Incomplete combustion of methane;
- Limitations associated with natural gas conversions of diesel engines; and
- Heavy gas storage tanks.

Other R&D work funded by federal and provincial governments — in some cases with participation from U.S. agencies, engine manufacturers, and universities — resulted in large natural gas-diesel bi-fuel engines, lightweight fibre-wound CNG tanks, high-capacity fuelling facilities for transit buses, and other important innovations. Despite this progress, NGV R&D in Canada and the United States declined to very low levels beginning in 2000 due to the declining outlook for natural gas resources. With the turnaround in the gas resource outlook over the past two years, U.S. governments have begun to increase funding support for NGV R&D. Although public sector support in this area in Canada remains minimal, Canadian companies are world-leading producers of NGV technology because of past R&D investments.

Current Status of NGV Technology and Codes and Standards

Natural Gas Engines and Infrastructure

Current NGV refuelling station technology, as well as light- medium-, and heavy-duty vehicle technologies, is available, reliable, and economical. NGV refuelling station technology is mature and is in use worldwide for both CNG and LNG applications. Similarly, NGV technology has reached maturity. Vehicles with modern NGV technology have horsepower, acceleration, and cruise speeds that are equivalent to conventional fuel vehicles. Natural gas engines have been certified to exhaust emission standards established by the U.S. Environmental Protection Agency and Environment Canada, which are among the most stringent in the world. And recent innovations such as Westport Innovations' High Pressure Direct Injection (HPDI) have addressed fuel efficiency limitations associated with older natural gas engines.

Moreover, OEMs have increased the number of NGV options that are currently on the market. Examples include highway tractors from Freightliner, Kenworth,

and Peterbilt; refuse trucks from Autocar and Mack; school buses from Thomas Built and Bluebird, and specialty vehicles from Capacity. Westport Innovations has also recently entered into an agreement with Volvo to develop heavy natural gas engine systems for Volvo.

Natural gas engines and LNG technologies are also available for LNG short-sea shipping through multi-fuel compression-ignition engines (diesel-HFO-gas) and dedicated lean burn spark-ignited engines, as well as for rail applications through diesel dual-fuel and gas turbines. However, these technologies still need to be integrated into platforms that are primarily custom-built.

Codes and Standards

Due to the significant efforts undertaken by Natural Resources Canada and other stakeholders in the early 1990s, a number of codes and standards for natural gas vehicles and CNG refuelling stations were developed. A list of existing codes, standards, and regulations for CNG vehicles, CNG refuelling infrastructure, and fuel quality has been compiled as part of this Roadmap process. These codes represent a mature state of development; however, limited market adoption for natural gas vehicles in Canada in the past five to seven years has led to a decline in committee activity for natural gas vehicle, refuelling station, and fuel codes and standards. In some instances, formerly active codes and standards committees have become dormant. In other instances, there are no existing committees whose scope of work explicitly includes emerging areas of interest such as codes and standards for LNG vehicles and refuelling stations. In addition, known issue areas, such as impact loading requirements, have gone unaddressed in the absence of committee activity.

The Need for Ongoing Technology Support

Engines and Infrastructure

Environmental standards pertaining to the transportation sector continue to evolve, as evidenced by the recent announcements related to the development of GHG regulations for medium- and heavy-duty vehicles in both Canada and the United States. While NGV technologies are currently-market ready, they would benefit from R&D investments to reduce their incremental cost. Assistance is also needed to sustain market development through the expansion of the number of NGV offerings for end-users.

These issues were taken into account by the California Energy Commission (CEC) as it developed its Natural Gas Vehicle Research Roadmap[1] in 2009. The CEC roadmap describes the strategic research, development, demonstration, and deployment (RDD&D) needed to enhance the viability of the NGV market in California. Results from the CEC roadmap's research suggests that there is a lack of heavy-duty and off-road engine size and capacity, and that vehicle integration of new engines is a significant hurdle to greater natural gas vehicle availability and market penetration. Specific research topics include engine development and vehicle integration, fuelling infrastructure, and storage, technical, and strategic studies.

[1] Prepared for the California Energy Commission, Public Interest Energy Research Program, August 2009, CEC-500-2008-044-F.

TABLE 1 Canada's NGV-Related R&D Needs

	SHORT-TERM (0–5 YEARS)	LONGER-TERM (5–10 YEARS)
Engine Development and Vehicle Integration	▪ Develop engines and NGVs with improved economics, efficiency, and emissions ▪ Integrate available natural gas technologies (e.g. Westport HPDI, Cummins Westport ISL G, Emission Solutions technologies) into a broader range of NGV engine sizes and applications of OEMs ▪ Develop NGV high-efficiency clean combustion (HECC) engine technology	▪ Develop NGV versions for off-road applications, particularly large-engine solutions for the rail and marine sectors ▪ Develop a variety of hybrid natural gas HDVs
Fuelling Infrastructure and Storage	▪ Develop fuelling infrastructure upgrades to accommodate fuel variability ▪ Develop improved CNG storage designs that integrate superior safety features and improved handling (with concurrent cost reduction) ▪ Develop higher-efficiency NG compression technology, with recovery of energy in compression ▪ Develop improved efficiency, handling, reliability, and durability of LNG dispensing and onboard storage	▪ Develop small-scale liquefaction technology that uses the waste energy from the pressure differential in natural gas transmission pipelines to liquefy pipeline gas ▪ Commercialize low-energy station technologies that minimize energy inputs for CNG and LNG refuelling stations

Although the Canadian market opportunities for NGVs are different from those in the United States, many of the findings of the CEC roadmap are applicable to Canada's efforts to increase the use of natural gas in its transportation sector (see Table 1).

These R&D opportunities are of great interest to the Canadian NGV industry, which has historically shown leadership in this area, but is now experiencing pressure to export much of its expertise abroad since the markets for Canadian NGV companies are primarily located in China, India, the United States, and Europe. The United States and Europe have well-developed RD&D programs that Canadian products may be able to access; however, continued access to them often involves relocating (in at least some capacity) to the country funding the work.

Codes and Standards

There is a strong link between codes and standards committee activity and R&D efforts. R&D generates the necessary data on issues like safe distances and component failure, from which the committee members can adapt existing codes and develop new ones. As new technologies are developed, there is also a need for concurrent development of related safety codes and standards to ensure that possible gaps in regulations do not impede new products from coming to market. The symbiotic and iterative relationship between the R&D community and the codes and standards committees is essential for the creation of pertinent regulations.

Next Steps

Moving forward, it will be important for industry, government, and universities to collaborate to achieve the RD&D priorities described in this chapter. One way to achieve such collaboration would be through the formation of a technical advisory group, which is a proven vehicle to help establish priorities and provide guidance to a federal R&D effort on the needs of industry.[2]

With regard to codes and standards, focused effort at the committee level will be required to address and resolve codes and standards issues and gaps related to natural gas vehicles and refuelling stations. Having an active and appropriate committee structure that is properly resourced will be an important prerequisite to achieving progress.

[2] Examples in the transportation and energy field are the Rail Research Advisory Board and the Hydrogen Technical Advisory Group (HYTAG).

DEPLOYMENT

DEPLOYMENT

Chapter 9

Market Transformation

Markets are dynamic and characterized by new products, changing end-user demands and fluctuating prices. Generally, markets move toward technologies that provide a net increase in social welfare, but occasionally, market dynamics are insufficient to achieve a desired objective that is projected to be in the greater social interest. In these cases, barriers and/or failures prevent the market from achieving the societal objective. Governments may choose to intervene in the market when it is evident that there is a market failure and that market transformation will have a lasting impact and serve the greater societal interest. This chapter aims to determine whether there is a rationale for government involvement to assist industry in transforming the portion of the transportation market that involves medium- and heavy-duty vehicles operating in corridors and return-to-base fleet applications.

Is There a Market Failure in Canada's Transportation Sector?

Market failure is a concept in economic theory where the allocation of goods and services by a free market is inefficient. Market failures have been identified in the vehicle efficiency and alternative fuels area in academic literature.[1] In many of these cases, the market failure is associated with one or any combination of the following factors:

1. Perceived risk associated with early adoption — where there is potential for a positive return on investment, but the market does not act to achieve this return because of the perceived risks;
2. Imperfect information — this can occur where an entity lacks the relevant information to judge returns on a specific investment;
3. Lack of choice — where the demand for a good or service is supplied by a market with limited options; and
4. Externalities — where there are impacts on society, such as climate change, that are not considered in the price of the good being sold and that may be an advantage or disadvantage to society more broadly.

With regard to natural gas use in transportation, other jurisdictions have identified a need for intervention to address market failure and secure societal benefits, so they have introduced various policies to support NGV deployment, ranging from mandates to incentives. For example, the U.S. *Energy Policy Act* of 2005 introduced alternative fuel motor vehicle tax

[1] See, for example, Chapter 11 of *Reducing Climate Impacts in the Transportation Sector*, by Daniel Sperling, James S. Cannon, 2009.

In summary, the business modelling work showed that over a reasonable range of credible price forecasts, the overall business case for use of natural gas in specific transportation applications is robust relative to other fuels.

credits to de-risk the early adoption of a range of lower-emission vehicle technologies, including natural gas technologies. Analysis included in this report points to a range of potential benefits associated with natural gas use for medium- and heavy-duty vehicles, including energy diversification, energy supply, emission reductions, and regional economic benefits. In addition, the business case modelling shows that there are end-use applications that have a favourable IRR, yet the market is not moving to adopt these applications. Altogether, these findings suggest that there is evidence of market failure, or at least evidence of significant market barriers to NGV adoption, within the medium- and heavy-duty vehicle portion of Canada's transportation sector.

Putting the Business Modelling in Context

If one concludes that the transportation sector demonstrates a failure with regard to fleet adoption of medium- and heavy-duty NGVs, the focus then turns to identifying those markets that have the strongest business case and the greatest potential to become self-sustaining in the long term. The business case modelling summarized earlier in this report aimed to identify the medium- and heavy-duty end-use applications with the greatest likelihood of being economically self-sustaining.

The modelling generated a value, the FVI, that captures the all-in economic costs of natural gas fleet ownership relative to diesel fleet ownership. In the case of this study the FVI was, by necessity, limited to providing an indication of the economic value proposition only. In this context, applications that are not achieving market uptake despite having FVI values greater than 1 and favourable IRRs may be impeded by market failure. Conversely, if a market is developing in spite of having a FVI of less than 1, it would be worthwhile to examine market conditions to determine what factors are driving it.

The business modelling work determined the IRR for the top four end-use applications. The IRR values demonstrated that there is a strong business case, particularly for high-mileage applications that operate along corridors or in return-to-base fleets. Capital investments can earn attractive rates of return. Payback ranges varied depending on the scenario modelled, but in each case, payback values demonstrated that the incremental cost for natural gas would be recovered well within the vehicle's life.

In summary, the business modelling work showed that over a reasonable range of credible price forecasts, the overall business case for use of natural gas in specific

transportation applications is robust relative to other fuels. The economic case for the application of natural gas in the transportation sector is not dependent on pricing carbon, but this would further enhance the business case. Notwithstanding the above, attitudinal barriers and upfront capital risk exposure are such that obstacles to broader deployment remain. Market intervention should then focus on targeted measures to mitigate upfront risks, rather than to support the overall business case, with potential public and private sector responses to address this issue. This assistance would be of broader economic benefit to Canadians.

Moving Beyond Market Failure: Addressing Barriers and Building a Competitive NGV Industry

To facilitate widespread NGV deployment in Canada, policy tools are needed not only to address market barriers, but also to ensure that this industry becomes self-sustaining and competitive over the long term. Options for consideration by governments are described in Table 1. For example, as a first step towards market transformation, temporary fiscal measures could be implemented to de-risk NGV investment and encourage early adoption of these vehicles in greater numbers. In doing so, these temporary measures would help industry achieve the economies of scale required to reduce the cost of vehicles. Another example would be measures to address information gaps and non-market barriers to NGV adoption. These information-related measures would help ensure that end-users have the information necessary for the NGV market to function properly.

As the NGV industry continues to evolve, additional measures will be needed to increase this market's capacity to become self-sustaining. For example, end-users will need to feel supported in their purchasing decision, and all of the required codes and standards will need to be in place. Finally, measures will be needed to ensure that the NGV industry remains competitive on an ongoing basis. RD&D is required to ensure that NGV technology remains competitive relative to diesel and to expand the number of NGV offerings.

Details regarding potential policy tools — which include fiscal measures, regulation, information, and research, development and demonstration — are included in Table 1.

If implemented individually, each of these measures could help support NGV deployment, albeit on a limited scale. To maximize deployment potential,

TABLE 1 Potential Policy Tools to Support NGV Market Development

TOOL	DESCRIPTION/ROLE/RATIONALE	EXAMPLES

Fiscal Measures	▪ Fiscal measures reduce the main economic barrier to market entry by reducing financial risk.
	▪ End-users perceive early adoption as being risky and, in particular, they attach uncertainty and high risk to:
	  ▪ The residual value of an NGV after the initial ownership period of, for instance, four to five years for highway tractors; and
	  ▪ The lack of refuelling infrastructure relative to diesel fuel infrastructure.
	▪ Fiscal measures may lower upfront vehicle cost, guarantee residual vehicle values, assist with access to refuelling infrastructure, or ensure fuel savings relative to incumbent fuels.
	▪ Increased early adoption of NGVs in larger quantities would help industry achieve the economies of scale required to bring down the cost of vehicle systems.
		▪ Tax measures (e.g. accelerated capital cost allowances and investment tax credits) and cash rebates that may apply to the vehicle, refuelling infrastructure, or fuel price differential.
		▪ In its 2010 budget, the Province of Québec announced adjustments to its accelerated capital cost allowances in support of LNG Class 8 trucks. The capital cost allowance measure allows for asset write-down within a significantly reduced time frame compared with a conventional truck, with the goal of de-risking upfront capital investment for the fleet.
		▪ Cash rebates have been provided in the past to reduce the incremental cost of the vehicle.

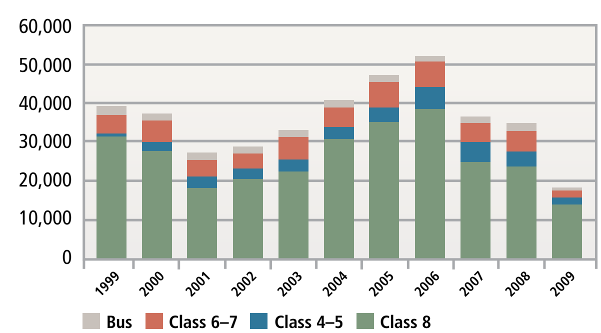
Regulation	▪ Regulation for GHG reduction is being developed for medium- and heavy-duty vehicles in the 2014 period. With careful design, these regulations could recognize and include the GHG benefits of natural gas vehicles. ▪ The rationale for regulating these vehicles is similar to that for light-duty vehicle regulation – most major governments have intervened with fuel economy or GHG standards to overcome the market failure of consumers not valuing fuel savings beyond the three-year period. ▪ Benefits of regulation include market certainty in terms of acceptable levels of environmental performance and equal treatment of technologies, as all must meet the same standard. ▪ With regard to another regulatory issue, governments could provide assistance by addressing regulations governing vehicle weights and dimensions to allow some overweight margin for LNG-fuelled trucks.	▪ Fuel economy and GHG regulations for light-duty vehicles. ▪ Low-carbon fuel standards as implemented in California and British Columbia and under consideration in Ontario.
Information	▪ End-users identified gaps in terms of information and awareness concerning NGVs as an option that could serve their needs. ▪ It is also the responsibility of governments to provide essential information to enable markets to function efficiently, especially where there is the absence of a single private sector actor that operates across the entire spectrum of the natural gas vehicle value chain. ▪ Governments are regarded as unbiased providers of information in the vehicle and fuels market arena, and this is important to end-users. ▪ Benefits of these measures include the development of a broader understanding of the benefits and commercial applicability – and therefore a greater consideration/adoption of – NGVs.	▪ Websites and fleet information hubs. ▪ Examples of these initiatives already in progress include the Clean Cities Program in the United States.
RD&D	▪ RD&D assistance for NGVs can leverage existing private sector spending and help position Canadian technologies to be more competitive and, ultimately, generate regional economic benefits. ▪ Diesel technologies have been assisted by substantial R&D funding over the past decade to meet more stringent tailpipe standards; R&D assistance for natural gas technologies would extend similar treatment and help level the playing field. ▪ End-users have identified the need for a greater range of natural gas products from which to choose, and targeted R&D investment can assist market development by increasing model availability. Production-oriented R&D investments could reduce the incremental cost of NGVs and break through the low volume/high upfront cost barrier faced by innovative lower-emission technologies trying to enter the market.	▪ The National Renewable Energy Laboratory's Natural Gas Engine Research and Development Program.

a coordinated and holistic approach is needed. For example, the regulation of the medium- and heavy-duty vehicle sector will take significant time to implement, so market opportunities may be missed in the interim. Given the likely time frame for regulation, temporary fiscal measures, for example, could assist early market entry for several years and a regulatory GHG framework could be examined for long-term market encouragement based on GHG reduction potential. These measures would also need to be supported by capacity-building measures such as codes and standards development, as well as training and outreach and education activities. While there are many precedents for market intervention by governments to assist in developing scale and removing barriers to entry, there are potentially market-based solutions that should also be given consideration going forward. One such example would include arrangements between end-users and fuel suppliers that would lock in the fuel price differential over a given volume of fuel.

Over the longer term, it will be important for natural gas as a transportation fuel to compete on a level playing field with other fuels — based on its own merits. This principle should be considered by policy-makers in terms of the design and duration of any policies moving forward.

Market Potential

In 2009, Canada had an estimated 830,000 registered medium- and heavy-duty vehicles, which represented 4 percent of on-road vehicles.[2] More than 80 percent of these vehicles were in use in one of four provinces: Alberta, British Columbia, Ontario, or Québec. As the primary technology focus for natural gas use in medium- and heavy-duty vehicles is on new factory-produced vehicles, market potential for natural gas must be considered in the context of the medium and heavy vehicle replacement cycle. The sale of medium- and heavy-duty vehicles varies considerably by year, as shown in Figure 1. Based on the past 10 years of sales, an average of 36,000 medium- and heavy-duty vehicles are sold in Canada each year.[3]



Source: Historical vehicle sales data per Canadian Vehicle Manufacturers Association

FIGURE 1 Medium- and Heavy-Duty Vehicle Sales in Canada (1999–2009)

[2] Statistics Canada, Canadian Vehicle Survey – Annual 2009.
[3] Historical vehicle sales data per Canadian Vehicle Manufacturers Association.

As previously noted, natural gas works well in return-to-base and corridor applications. There is no data available that identifies what portion of Canada's medium- and heavy-duty vehicle population operates in return-to-base mode or along regional corridors. Nonetheless, it is evident that the potential for NGV sales can best be described as a subset of total vehicle sales, given that many applications will not be suitable for natural gas (such as long-haul trucking).

Given these considerations, a range of potential penetration rates for natural gas vehicles, as a percentage of total medium- and heavy-duty vehicle sales, are shown in Table 2. The resulting energy use and carbon emission reductions are also noted. At a 15 percent penetration rate, natural gas use would be 122.5 billion cubic feet per year, which represents about 6 percent of Canada's 2009 domestic natural gas consumption.[4] The projected carbon reduction benefit is material in the context of Canada's 2020 GHG emission reduction goals. GHG emissions from heavy diesel vehicles in 2005 were 39 megatonnes of CO_2e.[5] To achieve a 17 percent reduction in GHG emissions from this portion of the economy by 2020, an estimated 6.6 megatonne reduction is needed. Approximately one-third of this goal could be achieved if one out of every 10 new medium- and heavy-duty vehicles sold in Canada over the next 10 years were an NGV (see Table 2).

Natural gas is one of several potential solutions to reducing emissions from medium- and heavy-duty vehicles in Canada. This domestic fuel offers a niche opportunity for return-to-base and corridor fleets.

TABLE 2 Estimated NGV Market Potential in Canada

ANNUAL NG TRUCK SALES AS % OF TOTAL SALES	TOTAL NG VEHICLES OVER 10 YEARS	ENERGY USE (THOUSANDS DLE)	ENERGY USE (Bcf)	ANNUAL GHG BENEFIT (Mt CO_2e)
1%	3,599	238,668	8.2	0.1997
3%	10,796	716,003	24.5	0.5992
5%	17,994	1,193,338	40.8	0.9986
7%	25,191	1,670,673	57.2	1.3981
10%	35,987	2,386,676	81.7	1.9973
15%	53,981	3,580,014	122.5	2.9959

1. Assumed 70 percent Class 8; 30 percent Class 3–7 based on historical split in sales.
2. Fuel use for Class 8 estimated at 78,800 diesel litres/year @39.4 DLE/100 km.
3. Fuel use for all other estimated at 37,300 diesel litres/year @ 62 DLE/100 km.
4. Carbon benefit based on GHGenius values of 25 percent for Westport LNG system and 18 percent for Cummins Westport engine.
5. Class 8 estimated 200,000 km/year and 72-tonne GHG reduction.
6. All other medium-and heavy-duty vehicles estimated at 60,000 km/year and 17-tonne GHG reduction.

Source: Calculated based on data from Canadian Vehicle Manufacturers Association and GHGenius (version 3.16b)

The actual market potential for natural gas could be higher or lower depending on what policy measures are employed, and their strength and duration, as well as the relative prices of natural gas versus diesel fuel over the decade.

Conclusion

As discussed, there are a number of reasons why deploying NGVs in Canada will require market intervention by a range of stakeholders, including governments, industry, and other key organizations. To facilitate NGV deployment in Canada, the following chapter contains key recommendations, as well as roles and responsibilities for key stakeholders.

[4] Canadian Gas Association.
[5] Environment Canada, Canada's National GHG Inventory.

DEPLOYMENT

Chapter 10

Recommendations

The following set of recommendations was developed in consultation with stakeholders representing all Roadmap working groups as well as Roundtable members. These recommendations reflect findings related to business modelling work; capacity-building needs; and research, development, and demonstration (RD&D) requirements. Recommendations have been proposed in four key areas: 1) De-risking Investment and Early Adoption, 2) Addressing Information Gaps, 3) Increasing Capacity to Sustain Markets, and 4) Ensuring Ongoing Competitiveness.

De-risking Investment and Early Adoption

1. Analysis has demonstrated that investment in medium- and heavy-duty NGVs can provide environmental and over-vehicle-life economic benefits, but the upfront capital cost vehicle premium and the risks associated with operating costs and achieving ongoing fuel savings are barriers to adoption. Fiscal measures implemented on a temporary basis could address these barriers and de-risk decision-making for early fleet adopters.
2. To introduce natural gas into the new market of over-the-road trucking, coordinated investments are needed to ensure that the development of key corridor infrastructure is consistent with projected demand, strategically located to support end-users, and installed in a timely manner across jurisdictions.
3. Existing industry players could provide private onsite refuelling stations. Fleets could further improve the business case for natural gas adoption by allowing other fleets to use these stations via cardlock and other arrangements. However, there are implementation details (e.g. liability issues) that would need to be addressed by the parties involved.
4. Demonstration of the use of natural gas is needed to address technical barriers, develop standards, and conduct feasibility studies and business cases.

Rationale

Temporary fiscal measures would help de-risk adoption and lower economic barriers to market entry. End-users perceive early adoption as risky and, in particular, they attach uncertainty and risk to 1) the residual value of an NGV after the initial ownership period (e.g. four to five years for highway tractors), 2) the potential for ongoing fuel savings, and 3) the lack of refuelling infrastructure relative to diesel fuel infrastructure. Temporary fiscal measures would encourage early adoption of NGVs in larger quantities, which in turn would help the NGV industry achieve the economies of scale required to reduce the cost of vehicle systems. While there is a positive internal rate of return for several end-use applications, temporary fiscal measures would also be necessary to surmount the barriers to adoption if they are determined to be

Recommendations have been proposed in four key areas: 1) De-risking Investment and Early Adoption, 2) Addressing Information Gaps, 3) Increasing Capacity to Sustain Markets, and 4) Ensuring Ongoing Competitiveness.

the result of market failure within the medium- and heavy-duty portion of Canada's transportation sector. While there are many precedents for market intervention by governments to assist in developing scale and removing barriers to entry, over the longer term, it will be important for natural gas as a transportation fuel to be able to compete on a level playing field with other fuels — based on its own merits. This principle should be considered by policy-makers in terms of the design and duration of any policies moving forward.

Addressing Information Gaps

5. An education and outreach strategy would be needed to target end-users as well as market influencers and other key stakeholders. This strategy should consist of both a "top-down" and a "bottom-up" approach. A top-down approach would include a central website for all target audiences with local content tailored to specific jurisdictions. A bottom-up approach would feature a local support network for end-users and provide access to resources including workshops and case studies of local fleets.

Rationale

End-users identified gaps in their knowledge and awareness concerning NGVs as an option that could serve their needs. In addition, end-users with past experience using natural gas had additional information requirements related to recent NGV developments, particularly technological innovations. It would provide momentum if governments and other players were to provide essential information to enable markets to function efficiently, especially since there is no single private sector actor that operates across the entire spectrum of the NGV value chain. Governments are regarded as unbiased providers of information in the vehicle and fuel market arenas, and this neutrality is important to end-users. Benefits of this measure include the development of a broader understanding and increased awareness of the applicability of NGVs, which would facilitate adoption of these vehicles in greater numbers.

Increasing Capacity to Sustain Markets

6. A "safety codes and standards" working group should be established to collaborate with existing Canadian Standards Association technical committees to address gaps and issues in existing codes and standards identified during the Roadmap process. Separate committees for liquefied natural gas (LNG) and compressed natural gas (CNG) may need to be formed to review existing codes and revise or develop new codes and standards. An umbrella committee is needed to ensure that codes and standards for CNG, LNG, liquefied compressed natural gas, and biomethane are coordinated and comprehensive.
7. Appropriate training materials for stations, vehicle repairs, and NGV fleet operations, as well as for cylinder inspection, need to be developed and delivered.

8. An NGV implementation body — consisting of Roundtable members and other key stakeholders — should be established to:
   - Support the implementation of the Roadmap's recommendations and assess progress against key milestones;
   - Provide recommendations to stakeholders regarding how the natural gas community could respond to future developments, such as changes in market conditions and technological innovations;
   - Act as an umbrella organization for the local support network for end-users; and
   - Serve as a forum for stakeholders to discuss issues pertinent to the natural gas community.

Rationale

To encourage NGV adoption, end-users need to be supported during their purchasing decisions, and adequate codes and standards need to be in place to ensure a successful technology rollout. Over the past decade, very little work has been done in Canada to update CNG codes and standards, while LNG codes and standards require even more fundamental development. As NGV technology becomes increasingly available, fleets will require support, since this technology features specific maintenance and safety requirements that will necessitate training of operators and mechanics. An NGV implementation body is recommended as a way to coordinate the work of governments and stakeholders along the NGV value chain to ensure the successful deployment of this technology and mitigate the risks borne by end-users or by any individual player.

Ensuring Ongoing Competitiveness

9. The NGV industry funds R&D activities at present. Further investment by others including governments has the potential to enhance the competitive position of the industry through targeted R&D investment. Priorities for future R&D include reducing/eliminating the cost differential between natural gas and diesel vehicles over the long term and maximizing NGVs' operational and environmental benefits.
10. Potential for natural gas use in other transportation applications should continue to be explored.

Rationale

While NGV technology is already mainstream and commercially proven, support for NGV R&D is needed to further reduce the incremental cost of NGV-related technologies. In addition, assistance is needed to sustain market development through the expansion of the number of NGV offerings for end-users. NGV technologies would also benefit from R&D investments to reduce the incremental cost of these vehicles, which would ensure ongoing competitiveness for innovative low-emission Canadian technologies. By continuing to explore the potential for natural gas use in other transportation applications, the natural gas community will help expand the benefits of natural gas as a fuel and potentially leverage infrastructure and R&D investments made for the medium- and heavy-duty vehicle market.

TABLE 1 Natural Gas Use in Transportation: Roles and Responsibilities

		GOVERNMENTS	NG PRODUCERS, TRANSPORTERS, AND DISTRIBUTORS	INFRASTRUCTURE AND VEHICLE SUPPLY STREAM	END-USERS
De-risking Investment and Early Adoption	Vehicle Premium	■	■		■
	Corridor Infrastructure	■	■	■	
	Return-to-Base Infrastructure		■	■	■
	Demonstrations	■		■	■
Addressing Information Gaps	Education and Outreach	■	■	■	
Increasing Capacity to Sustain Markets	Codes and Standards	■	■	■	
	Training	■	■	■	
	Implementation Committee	■	■	■	■
Ensuring Ongoing Competitiveness	R&D	■		■	
	Use of NG in Other Applications	■	■	■	■

Roles and Responsibilities

The stakeholders in Table 1 were identified as parties who could take on roles and responsibilities as they relate to moving the recommendations of this Roadmap forward. For many of these activities, numerous stakeholders could play a role; however, the table aims to provide a general overview of the roles that key stakeholders could play during the early stages of NGV market development.

DEPLOYMENT

Chapter 11

Next Steps

As mentioned at the outset of this report, a number of factors have renewed interest in natural gas as a transportation fuel, including the changing supply story for natural gas, projected high oil prices, and the need to reduce GHG emissions and criteria air contaminants. While there are various societal benefits that can be derived by increasing natural gas use in the transportation sector, there are also a number of market and non-market barriers that must be addressed before widespread NGV deployment can be achieved.

The Roadmap analysis found that medium- and heavy-duty vehicles offer the greatest opportunities for increased natural gas use in the immediate term. To optimize natural gas use in these vehicle applications, the Roadmap:

- Provides analysis regarding end-use business modelling, education and outreach, and R&D needs;
- Offers governments and industry recommendations related to de-risking investment and early adoption, addressing information gaps, increasing capacity to sustain markets, and ensuring ongoing competitiveness of the NGV industry; and
- Defines the future roles and responsibilities of major stakeholders.

While Canada has technologies at all stages of the supply chain to build this market, the combined efforts of industry, government, and other stakeholders will be essential to achieve widespread medium- and heavy-duty deployment in the coming years. The NGV Implementation Committee will provide a forum for key stakeholders to meet and carry out other activities that will support the recommendations described in this report. In addition to increasing the deployment of medium- and heavy-duty vehicles, the committee will work to address the technological and market barriers that currently impede widespread adoption of natural gas vehicles in light-duty vehicles, marine vessels, and locomotives.

In the coming years, the prospect for increased NGV deployment in Canada is extremely promising. The Roadmap process has shone a light on the excellent products that Canadian companies build and export for NGVs in other parts of the globe. The task ahead will be for the natural gas community to apply this expertise towards using natural gas in our transportation market for the further benefit of Canadians.

APPENDICES

APPENDICES

Appendix A

Results of the Scoping Analysis

Roadmap working groups assessed the potential for increased natural gas use in various vehicle segments based on the following criteria: technology availability, market potential, environmental benefits, energy use, and economics. The vehicle segments included heavy-, medium-, and light-duty vehicles, marine vessels, and locomotives. The principal findings follow.

Heavy-Duty Vehicles

A growing number of OEMs are offering factory-produced and emissions-certified natural gas heavy-duty vehicles in a variety of power ratings. These vehicles use a significant amount of fuel, so the potential savings from choosing natural gas are substantial, but there are significant perceived risks associated with early adoption for end-users. For these vehicles, the IRR is high, but the initial incremental cost of the vehicle could be a deterrent to fleets that tend to be conservative in their investment decisions. Natural gas fuel tanks are heavier than those used for diesel, and for those trucks that travel close to the weight limit, some tradeoff in cargo weight may be required.[1] The significant volume of heavy-duty vehicles along the Windsor-Québec corridor and the coincident natural gas pipeline network provide the key elements that could support a targeted market transformation initiative that leverages existing natural gas infrastructure to extend use of this lower-carbon fuel into a new market. Return-to-base fleets, such as transit buses, are also a large potential market for natural gas, since buses use significant amounts of fuel, are centrally fuelled, and have longer lifetimes for amortizing the initial investment.

Medium-Duty Vehicles

OEMs that manufacture trucks and buses are also offering a growing number of medium-duty NGVs. In urban areas where public refuelling stations exist (e.g. Vancouver and Toronto), medium-duty vehicles may be able to access existing refuelling stations for demonstrations or early-stage fleet adoption. Many medium-duty vehicles operate in urban areas, where the low emissions of NGVs are most beneficial. In addition, medium-duty vehicles can achieve significant fuel savings, particularly when they are operated over longer distances (e.g. airport buses and some package delivery fleets). Medium-duty vehicles operating in return-to-base fleets are particularly well positioned to take advantage of central refuelling and low natural gas prices.

[1] Some provinces and states are examining this issue and whether to allow some overweight margin for LNG trucks.

Light-Duty Vehicles

Light-duty vehicles for consumers and commercial fleets would need to be converted on an aftermarket basis to natural gas since there are no OEM vehicles sold in Canada. Public refuelling infrastructure is available in urban centres such as Vancouver, Calgary, and Toronto, but is limited elsewhere. Because private vehicles use relatively little fuel, it would be difficult to justify making investments in additional refuelling infrastructure unless large numbers of vehicles were converted or manufactured to use natural gas. In addition to natural gas, consumers have a choice of other technologies to reduce their GHG emissions via their new vehicle purchase decision: hybrid-electric, advanced diesel, and electric vehicles. If OEM NGVs are brought to market in future at a price that is competitive with other choices, there could be some market interest.

Marine – Short-Sea Shipping

Natural gas propulsion technology is commercially available for large marine engines. One ship can use as much fuel as 50 heavy-duty trucks. The fuel savings potential for ships using natural gas is significant, since fuel costs for marine vessels are expected to increase due to compliance requirements associated with new emission regulations. While some expensive emission control equipment can be avoided, this saving must be balanced by additional investment cost in LNG tanks and dual-fuel injection systems. There are good opportunities for LNG in shipping on the Great Lakes with the proximity of natural gas pipelines and the possibility of shared LNG infrastructure with heavy-duty vehicles. Ships have very long lifetimes (25 to 40 years) to amortize the high investment costs ($40 to $50 million). Although LNG is best fitted during ship construction, retrofits are feasible when a major refit is scheduled. However, the additional LNG tank volume could force cargo reductions in some cases.

Rail

The technology for natural gas in locomotives is at the prototype stage. For this market to develop, OEM locomotive manufacturers must become interested in providing integrated technology solutions for storing and using LNG on trains. Fuel injection and metering technologies are similar, but larger, than those used in heavy-duty vehicles. The potential market for LNG use in locomotives is attractive, since one of these vehicles uses as much fuel as 20 heavy-duty vehicles. Also, natural gas locomotives will produce significantly fewer criteria air contaminants than their diesel counterparts. Rail routes parallel to major trucking corridors could share LNG infrastructure to reduce the cost. Even with high investment costs, long locomotive service life and high fuel use should yield attractive rates of return.

APPENDICES

Appendix B

NGV Cross-Jurisdictional Analysis

	NGV STATUS/PENETRATION RATES[1]	POLICIES AND PROGRAMS	OUTCOMES
Argentina	Other than Pakistan, no other country in the world has as many NGVs in operation than Argentina. This country had 462,168 NGVs in use in 2000, and this figure has increased steadily each year, reaching 1,807,186 in 2009. NGVs as % of total vehicle population: 21.7. Number of refuelling stations in 2009: 1,851.	Since the 1980s, the government has kept the price of NG artificially low, facilitated the installation of equipment needed for service stations, and created a program for several thousand taxis in Buenos Aires to convert to NG. Another project, "Blue Corridors," will connect major cities in several South American countries with routes of NG fuelling stations.	The savings realized by taxi drivers was enough to convince car owners to convert their vehicles, which in turn, prompted more service stations to offer NG. Local industry is now working to gradually replace diesel in heavy-duty vehicle fleets.
Brazil	Brazil ranks third in the world in terms of the number of NGVs in use. This country had 60,000 NGVs in use in 2000, and this figure increased on an annual basis, reaching 1,632,101 in 2009. NGVs as % of total vehicle population: 9.6. Number of refuelling stations in 2009: 1,704.	In some large cities (e.g. Sao Paulo and Rio de Janeiro), the government is planning to promote programs to displace diesel with NG in city buses. Strategies are also being developed to make NG attractive to fleet operators by resolving issues such as technology, price differentials to diesel engines and fuel, taxation, and operating and maintenance practices. The Blue Corridors project (see Argentina) will also have an impact on the NGV market in Brazil.	NG was first used in LDVs in 1996; most of the NGVs now are aftermarket converted taxis or commercial medium-duty vehicles.
India	In 2000, India had 10,000 NGVs in operation. By 2009, this figure had increased to 725,000. NGVs as % of total vehicle population: 2.3. Number of refuelling stations in 2009: 520.	In addition to a Supreme Court mandate, government support was provided through further measures such as: ▪ Sales tax exemption on conversion kits; ▪ Concessional custom duty on CNG conversion kits; ▪ Allotment of land for CNG stations and pipelines on priority basis; and ▪ Banned old vehicles from registering in New Delhi.	The mandate resulted in 10,000 CNG buses on New Delhi's roads and has been credited with making significant improvements in the city's air quality. In 2003, another Supreme Court order acknowledged the success of the New Delhi CNG project and issued a directive to introduce clean fuels in 11 additional cities.
Italy	This country had 320,000 NGVs in operation in 2000, and this figure increased to 580,000 by 2009. NGVs as % of total vehicle population: 1.1. Number of refuelling stations in 2009: 730.	The government has adopted several direct funding initiatives to support NGV use, including subsidies for the construction of NG refuelling stations, taxi and commercial vehicle conversions, and replacement of public buses with those filled with NG. Italy has also mandated a tax-based differential between NG and petroleum-based transport fuels that makes NG retail prices approximately 50% of those for diesel.	In Europe, Italy has the greatest number of NGVs in use.

[1] National statistics: International Association for Natural Gas Vehicles: http://www.iangv.org/tools-resources/statistics.html;
State-level statistics: U.S. Energy Information Agency: http://www.eia.doe.gov/;
Number of refuelling stations at the state level: U.S. Department of Energy Alternative Fuels Data Center: http://www.afdc.energy.gov/afdc/fuels/stations_counts.html?print.

Pakistan	Pakistan has the largest number of NGVs in the world. In 2000, Pakistan had 120,000 NGVs in use, and by 2009, this figure had increased to 2,400,000. NGVs as % of total vehicle population: 52.0. Number of refuelling stations in 2009: 3,105.	Among NGV policies in Pakistan are liberal licences for CNG retailing, free market consumer price of CNG, natural gas tariff for CNG linked to petrol, priority of natural gas connection for CNG, and exemption of import duty and sales tax on import of machinery and kits can be enumerated.	Despite being the global leader in NGV use, Pakistan continues to face a number of operational, implementation, and pricing issues. For example, certain stations are unable to deliver gas at adequate pressure, which extends refuelling times and causes queues. Deployment of CNG buses has been delayed due to insufficient funding. The government has also allowed producers to increase wholesale CNG prices to station operators, which has caused the discount of CNG prices to those of gasoline to fall from 50% to approximately 20%.
Peru	In 2006, Peru had 7,823 NGVs in use, and this figure has increased to 81,024 in 2009. NGVs as % of total vehicle population: 0.65. Number of refuelling stations in 2009: 94	The government has fixed the cost of natural gas $1.50 per gallon, compared with about $4.55 per gallon for 90 octane gasoline. Other initiatives that support NGVs include: ▪ Reduced taxis on the import of NGVs to Peru. ▪ Government-sponsored "My Taxi Program" is designed to help drivers convert their engines to natural gas. ▪ Funding is available to individuals who scrap old diesel vehicles.	The number of NGVs in Peru has skyrocketed over the last few years. The My Taxi Program has led 45,509 drivers to convert their engines in only 32 months.
United States	The U.S. had 105,000 NGVs in operation in 2000. This figure peaked at 121, 249 in 2004, and decreased to 110,000 in 2009. NGVs as % of total vehicle population: 0.06. Number of refuelling stations in 2009: 1,300.	Federal Incentives: ▪ *Safe, Accountable, Flexible, Efficient Transportation Equity Act:* includes an excise tax credit of $0.50 per gasoline gallon equivalent of CNG or liquid gallon of LNG for use as a motor vehicle fuel. This credit was introduced in 2006 and expired December 31, 2009. ▪ *Energy Policy Act:* includes a qualified alternative fuel motor vehicle tax credit for the purchase of a new, dedicated, repowered, or converted AFV. It also includes an income tax credit to help cover the cost of NG refuelling stations. These credits will expire December 31, 2010. ▪ *American Recovery & Reinvestment Act (ARRA):* increases the credit value for purchasing equipment used to store and dispense qualified alternative fuels placed in service in 2009–10. Federal Programs: ▪ Clean Cities: government-industry partnership sponsored by the DoE, which strives to reduce dependence on petroleum resources. NGV projects will be featured in 19 of 25 cost-share projects announced in the Clean Cities program that will be funded with approximately $300M from the ARRA. ▪ ARRA provides funding to a variety of other programs that may benefit NGVs. State Programs: ▪ State tax credits for fuels, vehicles, infrastructure, and business development exist in 25 states.	NGV strategy in the U.S. has generally focused on high-fuel-use, return-to-base fleets that operate in urban areas. Numerous programs and initiatives have been introduced at the federal and state levels over the last several decades; however, these efforts have not led to success in fostering a sustainable NGV market.