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An Assessment of Propane as a Transportation Fuel for Light-Duty Fleets in Quebec

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Preamble

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1. Executive summary

The objective of this study is to examine the potential of use of propane as an alternative fuel for light-duty vehicle fleets in Quebec. We thus examine the possibility of using this fuel for vehicles with a weight lower than 5,500 kilograms according to Transport Canada. This category targets in particular police vehicles, light transportation trucks, public and private maintenance vehicles. On the basis of our analyses, we conclude that:

> propane is an optimal solution for fleet operators who look for substantial reductions in operating costs and greenhouse gas emissions (GHG), and by means of an easy to set up, tested, reliable and readily available technology.

This conclusion relies on a comparative analysis of propane in relation to:

• two traditional fossil fuels: gasoline and diesel fuel,

• four alternative fuels: biodiesel, natural gas, E10 ethanol blended gasoline and hydrogen,

• and two types of alternative motorization: electric vehicle and hybrid vehicle.

Our comparison was made on the basis of:

1) economic factors such as the costs of operation and conversion,

2) greenhouse gas emissions levels and other atmospheric contaminants,

3) the availability of the technologies required for these fuels and motorizations,

4) the reliability and the safety of these technologies,

5) and the availability and the installations required for the supply of the selected fuels.

Our analysis allowed us to note that numerous advantages were related to the use of propane:

• Propane allows reductions of the operating costs up to 35 % compared with gasoline, so much for light-duty passenger vehicles, light-duty passenger trucks or light-duty vehicles.

• Propane is the most economic alternative fuel of all when we take into account the costs of conversion, installation and infrastructure.

• Propane reduces the GHG emissions of 25 % compared with gasoline, 20 % compared with diesel, 18 % compared with E10 ethanol blended gasoline and 5 % compared with natural gas.

• Propane is available right now, on a large scale, contrary to the alternative motorizations and hydrogen for which we shall have to wait several years, along with the majority of

alternative fuels which are not available on a large-scale or will have no retail chain midterm.

• Propane is a product widely distributed in Canada and in Quebec. In Quebec, its distribution is assured by more than 80 retailers through the whole province.

• Propane is a reliable and secure technology, easy to install and which has been used for several years in commercial and institutional vehicle fleets in Ontario and in the United States. Among all the alternative fuels, it is the only one that shows reliability and safety equivalent to gasoline and to diesel.

Finally, we noticed the lack of information available on benefits associated with propane. In fact, superficial prejudices not relying on reliable or sincere sources remain. These prejudices underline the lack of information about the subject and the absence so far of efforts to better inform the population, the authorities and the companies concerned by the reduction of GHG emissions and the savings in the operating costs of a vehicle fleet.

2. Introduction

This report was prepared in October 2008 by Professor Louis Hébert, academic director of the HEC/McGill EMBA program at HEC Montreal. The analysis concerns the use of propane as an alternative fuel to gasoline for light-duty vehicle fleets in Quebec. This study deals mainly with the introduction of this fuel within the light commercial fleets (vehicles with a weight lower than 5500 kg). This category targets notably police vehicles, light transportation trucks, public and private maintenance vehicles as well as other similar applications. This study includes the evaluation of alternative fuels intended for fleets of at least six vehicles. Thus, the use of propane for private individuals was not addressed.

The first section of this study consists in describing all the present alternative solutions on the market besides common fuels such as gasoline or diesel. The study of the options available on the Quebecois market allowed to make the distinction between two types of alternative motorization that are the hybrid and electric vehicles and four alternative fuels others than propane. The selected solutions were the following:

- Electric vehicles
- Hybrid vehicles
- Biodiesel
- Ethanol
- Natural gas
- Hydrogen

On the basis of (1) the specificities of the Quebecois market, (2) its tendencies, (3) the availability and the infrastructures of certain solutions and (4) the initial targeting, only three of the seven alternative fuels assessed at first were selected for the second section of this study, namely the comparative analysis of traditional and alternative fuels. Therefore, besides propane, gasoline and diesel, this section will also address the study of biodiesel, natural gas and ethanol.

The analysis and the comparison of these alternative solutions will concern essentially four elements, (1) the economic aspects (prices and costs of conversion), (2) the levels of greenhouse gas emissions (GHG) and other atmospheric contaminants, (3) the reliability of the conversion technology and finally (4) the availability of the fuel and the supply infrastructures.

The study will conclude on the positioning of propane that meets the needs of commercial fleets, public or private, of light-duty vehicles that have for objective to reduce the costs of fuel along with greenhouse gas emissions (GHG).

As leader in environmental politics in Canada, the government of Quebec took the commitment to reduce its GHG emissions by 10 million tons to reach the objectives fixed by Kyoto before 2012[1]. As a consequence, the government of Quebec established a plan including 24 actions which aims at reducing GHG emissions and at adapting itself to the climatic change[2].

In this action plan, a whole section is dedicated to the transportation sector which is mainly accountable for GHG emissions in Quebec with almost 40 % of the total emissions. Of this quantity, 80 % results directly from the road transportation sector[3]. To solve this problem, the government encourages any initiative to reduce emissions in the road transportation sector and proposes the adoption of alternative solutions such as the use of other motorizations or alternative fuels.

Among existing alternative fuels, propane is an underestimated, simple and very easy to use alternative which integrates into most gasoline vehicles and which reduces operating costs along with vehicle emissions.

What is propane?

Propane is a hydrocarbon just like gasoline and is used as fuel for light-duty vehicles. It can be found in gas form and has a low carbon content (C_3H_8)[4]. Its properties confer the advantage to be easily storable and transportable in a liquid state which allows a large variety of usages.

This gas derived of oil productions (oil or gas) serves as fuel in the industrial, agricultural or even domestic sectors. In Canada, the industry uses HD-5 propane which is a cleaner and more effective formulation. It is used in internal combustion engines, boilers and even barbecues.

Propane is non-toxic and, in its natural form, odorless. However, a large concentration in the air can cause an asphyxiation risk through oxygen deprivation. That is why an odorant is added at the point of manufacture to ensure that any leaks are readily detected.

To whom is destined « propane » as an alternative fuel?

The use of propane as alternative fuel is destined to light-duty fleet operators running on gasoline, who want to reduce operating costs, while reducing GHG emissions. These operators have the possibility of converting their vehicles from running all the time on gasoline to running on propane most of the time. The conversion technology is reliable and simple to install on most vehicles. The existence of conversion equipment on the market makes this alternative fuel more and more attractive for light-duty fleet operators such as automobiles, small vans or light-duty vehicles.

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[1] Ministère du Développement durable, de l'Environnement et des Parcs (2008). [http://www.mddep.gouv.qc.ca/changements/kyoto/msg_ministre.htm] Online July 24th, 2008

[2] Gouvernement du Québec (2006). [http://communiques.gouv.qc.ca/gouvqc/communiques/GPQF/Juin2006/15/c9630.html] Online July 14th, 2008

[3] Ministère du Développement durable, de l'Environnement et des Parcs (2008). [http://www.mddep.gouv.qc.ca/changements/ges/2005/inventaire2005.pdf] p.11. Online July 14th, 2008

[4] http://www.propanequebec.com/propane.htm Access September 16th, 2008

The contributions for private and public sectors

Propane as an alternative fuel is an attractive option for companies and organizations as well as institutions of the public sector. According to our analyses and the bibliography, it is clear that propane allows a reduction of GHG emissions and operating costs due to the consumption of fuel.

The public sector adopts more and more strict environmental politics to be able to meet the commitments taken by the government of Quebec to reduce GHG emissions. The light-duty fleet operators have to turn to alternative fuels to reach their objectives.

For example, propane meets the needs of municipalities and allows reducing their costs of operations, reducing emissions and projecting a « green image ». The government of Quebec recognizes the important role of municipalities in the reduction of GHG and operating costs of public fleets. Municipalities, with their population and their industrial activities, are great users of fuel. Propane is destined for cities of small and medium sizes, distant from large municipalities and self-reliable for their fuel supply.

Propane reduces the costs associated with the consumption of public fleets which is profitable for the government of Quebec who still does not take advantage of the price increase of hydrocarbons[5]. Indeed, a study of the ministère des Finances of Quebec demonstrates that revenues resulting essentially from QST tax on gasoline are more than compensated with the increase of the expenses in fuel and heating and by the reduction of the tax on fuels revenues. In 2007, the losses would be estimated to about 6 million dollars a year for any increase of 5 ¢ of the price of hydrocarbons[6]. The government consequently has to reduce its expenses and encourage the use of alternative fuels. Propane positions as the optimal solution, easy and simple to set up and offering to reduce GHG emissions along with operation costs for light-duty fleets in short-term.

Companies, like the public sector, were strongly affected by the rise of the gasoline price in 2008 and operators of private fleets look for solutions to limit their operating costs. The private sector tries to reduce its fuel expenses to remain competitive and the choice of an alternative fuel is now a part of companies' global strategy. Propane, often underestimated by the operators, is an optimal solution which is available right now. Propane is a reliable, flexible alternative solution for vehicle fleets running on gasoline and meets the needs of operators who look for an alternative fuel to reduce significantly their costs of operation along with their GHG emissions, which allows a greener positioning for the companies.

3. Motorizations and alternative fuels

To assure the validity of our study, we selected the alternate solutions of motorization and alternative fuels considered the most relevant in the Quebecois context. Traditional fossil fuels, gasoline and diesel are available everywhere in Quebec and the diesel engine is an internal combustion engine just like the gasoline engine, but of which the ignition is by compression. Therefore, we have considered, besides traditional fossil fuels, two types of motorization: the electric vehicle and the hybrid vehicle. As for alternative fuels, besides propane, we took into account biodiesel, ethanol, natural gas and hydrogen. Propane and hydrogen adapts only to

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[5] Finances Québec, le secteur de la politique budgétaire et de l'économie. Hausse du prix des hydrocarbures *Impact*
sur les équilibres financiers du Québec, Avril 2008

[6] Finances Québec, le secteur de la politique budgétaire et de l'économie. Hausse du prix des hydrocarbures *Impact*
sur les équilibres financiers du Québec, Avril 2008

gasoline engines while natural gas adapts to gasoline and diesel engines. Biodiesel and ethanol are directly used in their respective motorization: diesel engines and gasoline engines.

3.1 Alternative motorization

Motorization can be more or less complex according to the source of energy used to fuel the engine which, consequently, entails a higher initial purchase cost than for a gasoline vehicle.

3.1.1 Electric vehicle

The electric engine is entirely fed by a battery which is recharged on the grid. The advantage of this driveability mode is the cost in electrical energy by kilometer, which is relatively inexpensive in Quebec.

The electric car is part of a dream, especially in Quebec where hydroelectricity is perceived as plentiful. The use of this type of vehicle does not produce harmful emissions and the price of hydroelectricity remains, even at the moment, advantageous. Unfortunately, the electric vehicles available on the market are cars with weak range and performance, working to a maximal speed of 50 kph or luxury vehicles (BMW or *Lightning*[7]). However, major manufacturers announce touring vehicles for 2010.

Recently, Quebec authorized two electric vehicles of low speed (50 kph) to circulate on certain roads of the province for an experimental project of three years[8]. Both vehicles, *Nemo* and *Zenn*, are manufactured north of Montreal and their performance does not allow foreseeing their use other than for very specific needs.
Although no GHG emissions are produced by using electric cars, potential problems linked to the recycling of the batteries are still without answer.

Electric vehicles experimented so far are generally considered as failures[9]. The automotive industry has rather concentrated on the development of hybrid vehicles.

3.1.2 Hybrid vehicle

By definition, hybrids, also called HEV for “Hybrid Electric Vehicle”, are vehicles using two power sources to move the vehicle. Generally, the hybrid has two types of motorization: a conventional internal combustion engine and an electric motor[10]. The electric motor is fed by the battery which is constantly reloaded by an alternator during the use of the internal combustion engine.

Automobiles with hybrid motorization are now part of alternatives of the Quebecois market in the same way as their equivalents in standard motorization. The configuration of these vehicles is generally gasoline/electric and according to *International Energy Agency* (IEA), a hybrid vehicle costs approximately 5 000 $ US more than an equivalent conventional model[11].

Hybrids are interesting to use only in cities where they work on the electric engine and only for a driving which requires only weak accelerations. The economy on the costs of gas consumptions rarely absorbs the difference of cost invested at first and GHG emissions reductions are hard to

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[7] http://www.lightningcarcompany.co.uk/ Access September 18th, 2008.
[8] http://www2.canoe.com/infos/environnement/archives/2008/07/20080716-220015.html, Access September 17th, 2008.
[9] Politique verte du matériel roulant 2007-2011. Ville de Montréal
[10] http://www.nrel.gov/vehiclesandfuels/hev/hevs.html, online July 14th, 2008
[11] http://www.ieahev.org/hybrid.html, access October 22nd, 2008

Hybrids are interesting to use only in cities where they work on the electric engine and only for a driving which requires only weak accelerations. The economy on the costs of gas consumptions rarely absorbs the difference of cost invested at first and GHG emissions reductions are hard to quantify, because they depend on the type of driving and vehicle's use. Therefore, hybrids will not be considered in the comparative degree of alternative solutions for the continuation of the analysis.

3.2 Alternative fuels

Alternative fuels available in Quebec other than propane are biodiesel, ethanol, natural gas and hydrogen.

3.2.1 Biodiesel

Biodiesel is made of several renewable resources including vegetable oil and animal fats. It is obtained by mixing vegetable or animal oil with methanol or ethanol. Biodiesel has a biodegradable, non-toxic and clean combustion. It works in any type of diesel engine without any necessary modification.

Biodiesel is still at the stage of tests with several car fleets in Quebec. For example, B5 with 5 % of concentration of biodiesel mixed with common diesel is presently assessed by the *Société de transport de Montréal* (STM) for city buses to determine its reliability during the periods of cold.

3.2.2 Ethanol

Ethanol is a volatile, flammable and colorless liquid made of oxygen, hydrogen and carbon. It can be produced by the hydration of ethylene or biologically, by fermenting sugar or converted starch contained in grains. In Canada, ethanol is mainly made from corn and wheat[12].

3.2.3 Natural gas

Natural gas is a fuel consisting primarily of methane and can be transported in the compressed state (Compressed Natural Gas - CNG) or in the liquid state (Liquefied Natural Gas - LNG). It can be used as an alternative fuel for the vehicles of medium-duty category and heavy vehicles (taxis, buses, trucks, etc.). The use of natural gas under compressed state has lower storage costs compared with storage under liquid state, considering the necessity of cooling the reservoir permanently (cryogenic reservoir). However, CNG requires a bigger volume to store the same mass as LNG. The technologies using compressed natural gas have consequently much less range for the same volume of reservoir. Most vehicles in Canada use CNG. In Quebec, the distribution network of the LNG is very limited.

3.2.4 Hydrogen

The increasing price of gasoline has gradually presented hydrogen as an interesting alternative fuel for transportation. Hydrogen can be stored under low temperature in the liquid state or under high pressure in the gaseous state. The distribution of hydrogen must be supported by an important infrastructure[13]. Automobile manufacturers, such as *Ford*, *GM* and *BMW*, have already developed hydrogen prototype vehicles and the technology is recognized to be reliable and secure. Hydrogen as an alternative fuel remains at the stage of experiment in Quebec and even if the use of this vehicle produces, in theory, zero emission of CO2, the source of energy used to produce the hydrogen should not be neglected[14]. Furthermore, the distribution network remains the weak point of this fuel and its development for the next years is clearly not foreseen in Quebec. The numerous technical and economic constraints suggest that this technology will not breakthrough the market before several years. For that reason, hydrogen will not be selected for the comparison of alternative solutions.

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[12] http://oee.rncan.gc.ca/transportation/fuels/ethanol/ethanol.cfm?attr=8, online July 15th, 2008
[13] http://www.h2.ca/PDF/HydrogenSystems.pdf, online July 15th, 2008
[14] The car of the perpetual future, Hydrogen cars, From *The Economist* print edition Sep 4th 2008

3.3 The Quebecois context

If alternative solutions to gasoline are possible for light-duty fleets, they are not quite possible for commercial applications in the short term. For example, hydrogen as fuel will not be available commercially in Quebec for several years.

Besides, Quebec intends to favor « green » solutions for transportation. Biofuels (biodiesel and ethanol) offer several environmental advantages. Policies recently adopted on this subject by the government should encourage the use of these biofuels in the next years.

Nevertheless, with the recent debate on ethanol, Quebec could rather prioritize the development of electric motor cars on the long term. These vehicles do not produce GHG emissions. Hydroelectricity is also the main source of electricity in Quebec, which makes the use of electric vehicles clean, with the exception of the recycling of the batteries. Unfortunately, some doubt that the electricity network can support a large-scale load before at least the next five years[15].

In summary, if certain alternative solutions seem to have a promising future in the long term, few of them are valid options in the short term. Some suggest that it will be necessary to wait at least ten years before electric or hydrogen vehicles can represent a real alternative (see figure 1). The fleet operators who wish to reduce their operating costs must then consider other options. Because a regular vehicle cannot be converted to hybrid, the conversion to natural gas or propane represents an opportunity for fleets already in operation with standard vehicles.

[15] Gouvernement du Québec, Ministère des Ressources Naturelles et de la Faunes (2006). L'énergie pour construire le Québec de demain: la stratégie énergétique du Québec 2006-2015.

Figure 1: Window of opportunity

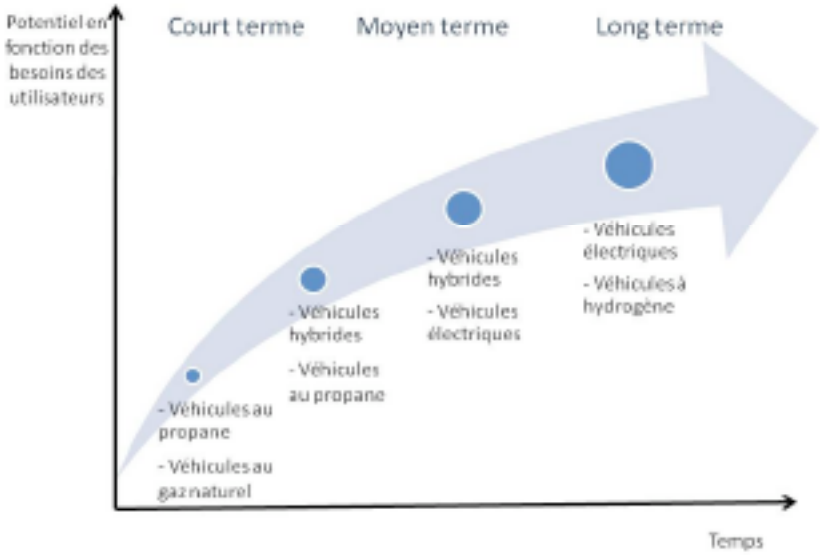


Figure 1 translation
Potentiel en fonction des besoins des utilisateurs = Potential according to users' needs
Court terme = short term
Moyen terme = mid-term
Long terme = long term
Véhicules au propane = propane vehicles
Véhicules au gaz naturel = natural gas vehicles
Véhicules hybrides = hybrid vehicles
Véhicules électricques = electric vehicles
Véhicules à hydrogène = hydrogen vehicles
Temps = time

Natural gas and propane should take advantage of this situation for the next five to seven years, or even more with the introduction of new technologies like hybrid propane/electric vehicles instead of the conventional gasoline/electric model. An increasing demand in the number of vehicle conversions for natural gas or propane is possible in short-term. In mid-term, this demand can maintain until the arrival on the market of electric vehicles more functional and better adapted to the needs of vehicle fleets in terms of range and cost price. Nevertheless, there is definitely, in short term, a window of opportunity for an alternative fuel like propane.

4. Analysis and comparison

In this section, we suggest comparing propane to traditional fuels, gasoline and diesel as well as alternative fuels described previously. This comparison aims at identifying the advantages as well as the disadvantages of propane from an economic and environmental point of view. We will begin by examining more precisely the questions of price and operating costs of propane.

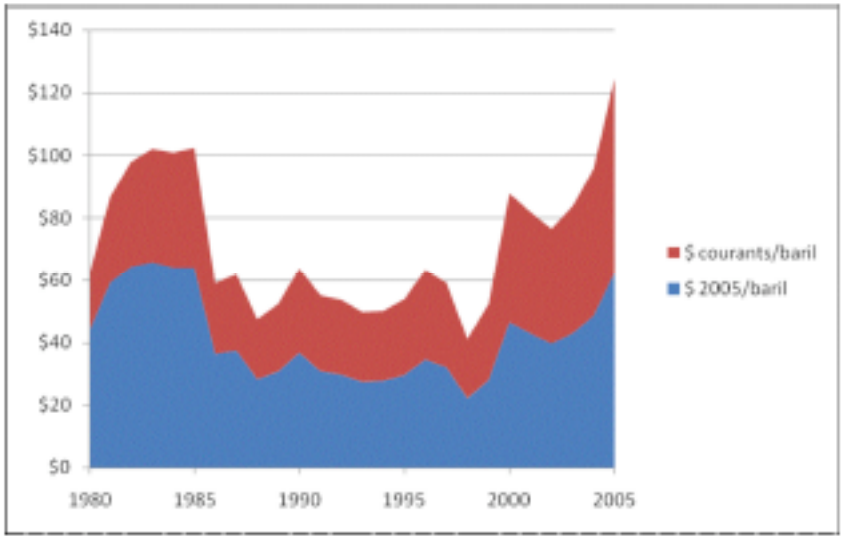
4.1 Economic aspects

Firstly, we would like to assess the economic advantages of the use of propane as fuel for lightduty vehicle fleets. We were able to notice a price increase for traditional fuels since several years. We think that this phenomenon plays in favor of the use of propane.

4.2 The price increase of traditional fuels

As a general rule, the price increase of crude oil is the main reason for the price increase of traditional fuels (see figure 2). This increase is not a recent phenomenon, but has been observed for several years. At the beginning of 2008, the price of the liter of gasoline exceeded 140 cents/liter in gas stations. From 2004 to 2007, the price of gasoline increased of 27 % and diesel increased of 24 %.

Figure 2: Average price of crude oil delivered in Quebec

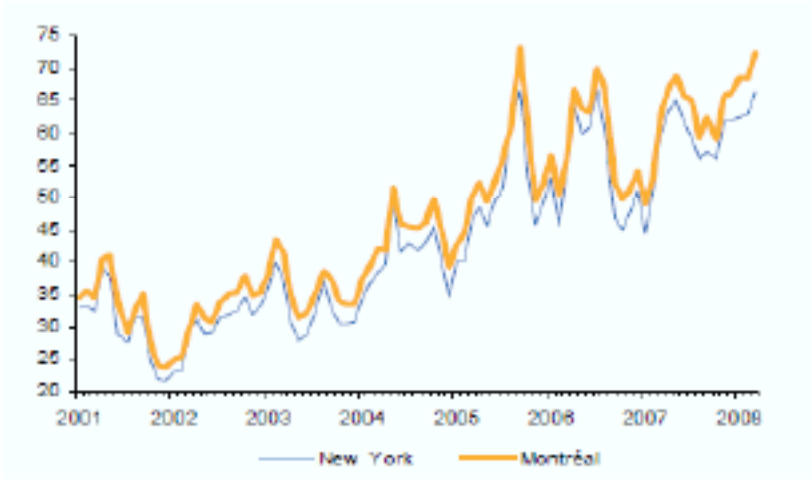


Sources: Ministère des Ressources naturelles et de la Faune du Québec, ministère des Ressources naturelles du Canada et Statistique Canada.

Figure 2 translation
$ courants/baril = current $ / barrel
$ 2005/baril = $ 2005 / barrel

We can also notice that the Quebecois market undergoes the same pressures as the North American market. As shown in figure 3, the gasoline rack price in Quebec is strongly correlated to the rack price of New York. The agreements of free trade between Canada and the United States created a space of integrated market and lead to a very strong competition between the Quebecois and American refineries.

Figure 3: Comparison of the regular gasoline rack price in Montreal and New York



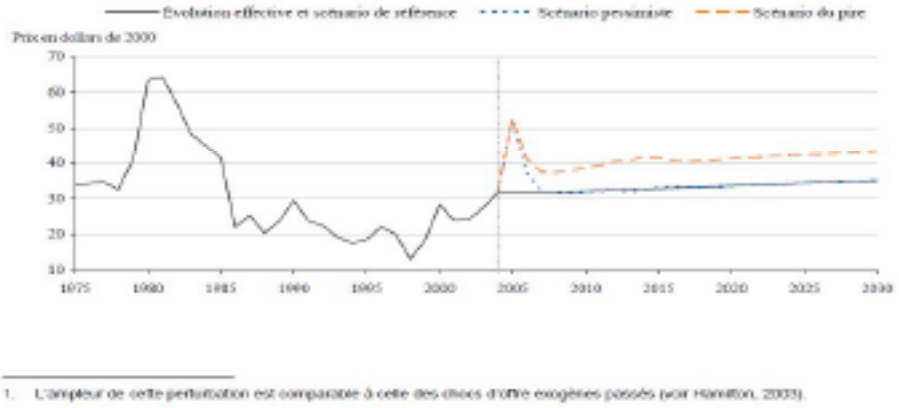
Source : Énergie Information Administration et Régie de l'énergie

A demand which exceeds the global supply, difficult weather conditions as well as unstable geopolitical situation of several producing countries are elements which accentuates the uncertainty as for oil prices and which encourage speculation. Although the prices fell recently, future forecasts remain uncertain.

It is important to note that the demand from emerging countries does not stop increasing and it can have a major effect on available stocks in the years to come. According to the OECD[16], a supply crisis could have an impact on the prices. Simulations were made to determine the impact on the oil price that an oil supply crisis could have. These simulations take it into account only the price increase which would be necessary to balance the demand and the offer considering the reduction of the offer, and do not consider the risks and the uncertainty which would increase the risk premium[17]. Therefore, we could expect an even more significant increase in prices. Figure 4 brings to light these two scenarios.

[16] http://www.oecd.org/dataoecd/39/59/34087712.pdf, online October 29th, 2008.
[17] http://www.oecd.org/dataoecd/39/59/34087712.pdf, p19, online October 29th, 2008.

Figure 4: Scenarios of the real evolution in oil prices



1. L'ampleur de cette perturbation est comparable à celle des chocs d'offre exogènes passés (voir Hamilton, 2003).

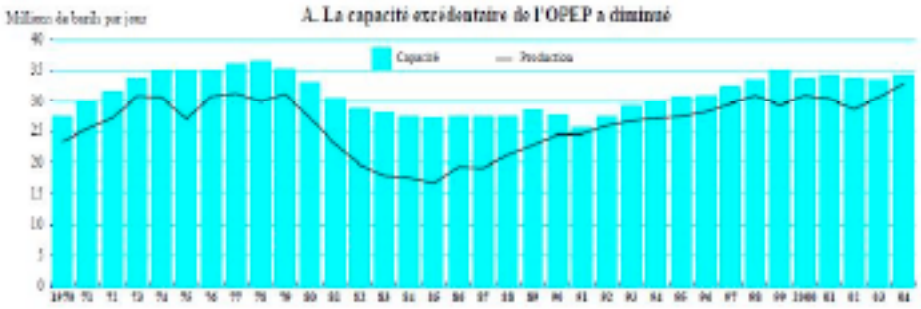
Source: OECD economic outlook no 76

Figure 4 translation
Évolution effective et scénario de référence = real evolution and reference scenario
Scénario pessimiste = pessimist scenario
Scénario du pire = worst scenario
Prix en dollars de 2000 : Price in dollars of 2000
L'ampleur de cette perturbation est comparable à celle des chocs d'offre exogènes passés (voir Hamilton, 2003). = The scale of this disturbance is comparable to that of the past exogenous offer shocks (see Hamilton, 2003).

The decrease of the OPEC's excess capacity, such as illustrated in figure 5[18], is another factor which contributes to the oil price increase.

[18] http://www.oecd.org/dataoecd/39/59/34087712.pdf , p17, online October 29th, 2008.

Figure 5: Short term influence on the oil price



Source: OPEC's no 76 economical perspectives

Figure 5 translation
Millions de barils par jour = millions of barrels per day
A. La capacité excédentaire de l'OPEP a diminué = A. OPEC's excess capacity has been reduced
Capacité = Capacity
Production = production

Fleet operators will face fuel price increases which impact on their costs of operation. Therefore, the search for a less expensive fuel is necessary. In the following section, we can underline that propane, besides producing greenhouse gas (GHG) emissions lower than those produced by gasoline, allows fleets to reduce operating costs associated with the consumption of fuel.

4.2.1 Propane: lower prices

For the past 5 years, propane prices have been 40 % lower than gasoline. However, the correlation between the price of these two sources of energy is similar (see figure 6). Therefore, an increase of the crude oil price has a direct impact on the price of gasoline, which echoes systematically on the price of propane. In Quebec, the price of propane is historically more stable and lower than the price of gasoline as well as diesel[19]. Moreover, figure 6 graphic demonstrates the evolution of the average retail price of propane, gasoline and diesel sold in Montreal for the past 10 years[20]. In October 2008, the price of a liter of propane kept its advantage of about 40 % in comparison with other traditional fuels, both in Montreal and elsewhere in Canada (see table 1).

[19] http://fuelfocus.nrcan.gc.ca/prices_bycity_f.cfm?PriceYear=2008&ProductID=6&LocationID=28#PriceGraph, online October 23rd, 2008.

[20] http://fuelfocus.nrcan.gc.ca/prices_bycity_f.cfm?PriceYear=2008&ProductID=6&LocationID=28#PriceGraph online October 23rd, 2008.

Figure 6: Average retail price for fuel sold in Montreal from 1998 to 2008

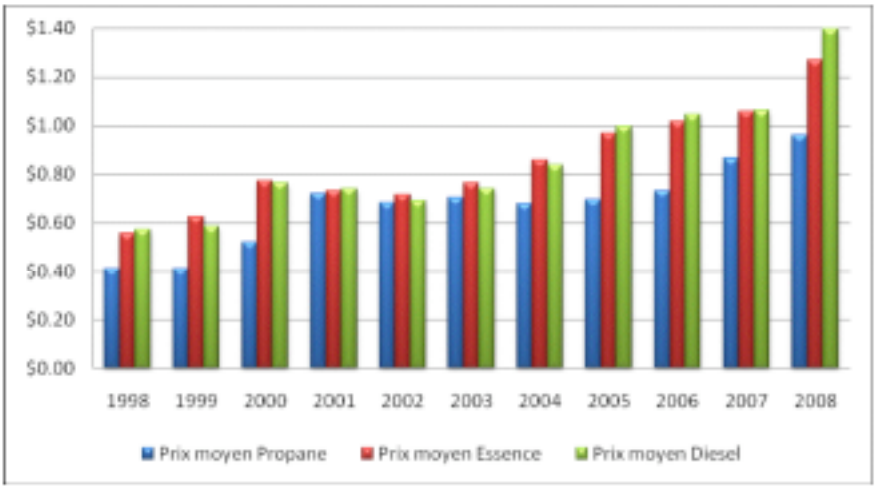


Figure 6 translation
Prix moyen propane = average propane price
Prix moyen essence = average gasoline price
Prix moyen diesel = average diesel price

Figure 6 underlines the average propane and gasoline price for the past 10 years and demonstrates that propane presents a certain advantage from a financial point of view. The propane price sold by a supplier for a fleet of vehicles is lower than the retail propane price.

Table 1 presents the price of propane sold by a supplier in Montreal and in the major cities in Ontario. The price difference is essentially associated with the cost of transportation of propane to these various cities.

Table 1: Propane supplier price on October 21st, 2008 in Montreal[21]

	London	Toronto	Ottawa	Montreal
Propane price for a fleet of vehicles (per liter)	$ 0,508	$ 0,515	$ 0,550	$ 0,557
Average retail gasoline price (per liter)	$ 1,024	$ 1,030	$ 0,992	$ 1,052
Average diesel gasoline price (per liter)	$1,099	$1,109	$1,119	$1,209

[21] http://www.propanefacts.ca/economic/comparisons/, online October 23rd, 2008.

4.2.2 Propane: a lower price volatility

Besides the different propane prices, we examined their volatility. A strong volatility is often an inconvenience which harms the budgetary forecasting efforts. On the contrary, prices less volatile allow adjusting more easily and thus reducing the complexity of the operations budget management. Figure 7 evidences the standard deviation between the average price and the prices registered at the pump in Montreal for propane, gasoline and diesel.

We observed that the propane volatility is the lowest compared to gasoline and diesel. Propane presents an advantage for fleet operators who can make more precise financial forecasts by using this fuel as an alternative fuel.

Figure 7: Price volatility of retail fuel sold in Montreal from 1998 to 2008

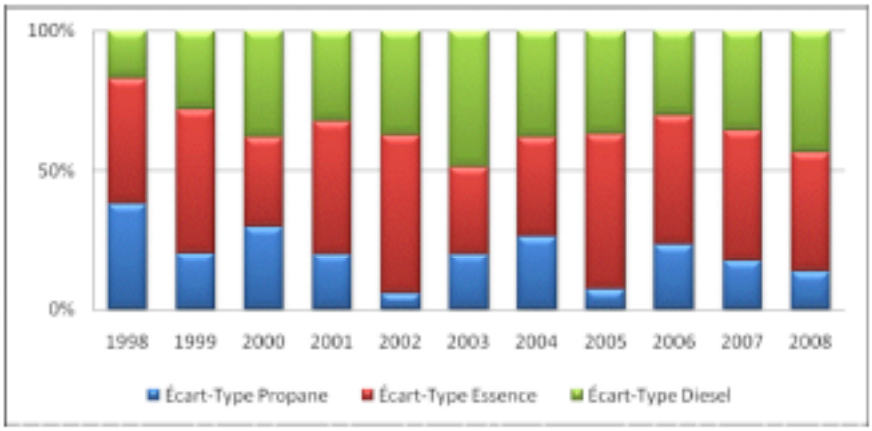


Figure 7 translation
Écart-type propane = propane standard deviation
Écart-type essence = gasoline standard deviation
Écart-type diesel = diesel standard deviation

Usually, the propane stocks level increases summertime because of a lower consumption (the households tends to heat less in summer). However, it is the first time in five years that we notice, both in the United States and in Canada that these stocks are below the usual levels. This accentuates a little more the increasing prices tendency, which remains however slowed down by the decrease in demand in summertime. Furthermore, the levels of stocks should return to normal rather quickly, due to the imports into the US Gulf Coast.

Normally, the propane prices begin to increase around June and July because of the wintry forecasts. This increase is mainly linked to the evaluation of the level of available stocks for the season. However, according to the National Energy Board, the propane stocks have been at a lower level for the last five years.

4.2.3 The diesel engine and conversion costs

To estimate the cost-in-use of propane and alternative fuels, we also have to take into account the vehicle costs of conversion.

Propane and CNG

The use of alternative fuels such as propane or natural gas requires a vehicle conversion. The costs of conversion associated to this transformation are about $4,000 for propane[22] and $6,000 for natural gas (CNG) [23] for all types of light-duty vehicles. The equipment includes the conversion of the engine as well as the installation of a propane tank in the rear of the vehicle. Besides these fixed costs of vehicle conversion, it is also necessary to consider the training of the staff. This training concerns firstly the technical staff (mechanics), so that they are capable of operating on the converted vehicles, but also the employees in charge of the supplying. Indeed, the regulation in Quebec requires that the persons in charge of supplying propane vehicles be certified by Emploi-Québec. The cost for the certification is $250.

Diesel engine

Diesel vehicles are more expensive to buy compared with a vehicle of the same category running on gasoline. The difference in price varies from $1,000 to $2,000 for a light-duty passenger vehicle and can reach up to $5,000 for light-duty commercial vehicles of bigger category[24]. We have considered costs of purchase for light-duty passenger vehicles, light-duty passenger trucks and light-duty diesel vehicles of $2,000, $2,500 and $5,000 respectively.

4.2.4 Alternative fuels' indirect costs and opportunity

The supposed environmental benefits of **biofuels** could be more harmful than the issue they try to solve, according to a report published by the Organization for Economic Cooperation and Development (OECD). Indeed, biofuels anticipated being a new source of income for farmersand a solution against GHG emissions entailed a sharp increase in farm produces prices which is the main cause for the food products price increase. Repercussions are serious for developing countries, among which the economy and sometimes survival depends on food imports.

Every cereal price (including rice) increase of 10 % weights down on the overall cost for cereal imports of developing countries importers of about 4.5 billion dollars[25]. This report concludes that the use of biofuels requires a more in-depth analysis. Even if they have a positive effect of improvement on fuel efficiency and GHG emissions reduction, the food products price increase has more negative repercussions.

Moreover, following these observations, the government of Quebec decided to invest on the cellulosic ethanol research, which is a fuel made from agricultural and ligneous waste. The researches aim at improving the processes of production to make them more effective and especially less polluting. The Enerkem plant in Quebec represents the first experimental plant. Its opening is planned for autumn 2008. Ethanol gasoline is currently sold at the same price or even slightly less than regular gasoline.

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[22] http://www.oee.nrcan.gc.ca/transports/carburants/propane/propane-disponibilite.cfm?attr=16, online October 23 rd, 2008.

[23] http://www.oee.nrcan.gc.ca/transports/carburants/gaz-naturel/gaz-naturel-disponibilite.cfm?attr=8, online October 23rd, 2008.

[24] http://blogs.chron.com/carsandtrucks/2008/05/are_diesel_benefits_worth_the_1.html, online October 22nd, 2008.

[25] http://www.oecd.org/dataoecd/17/51/41403444.pdf, page 6, online October 22nd, 2008.

Natural gas, just like propane, is strongly affected by the price increase of oil, in addition to the level of stocks being relatively low in the United States along with Canada to regulate the demand. Furthermore, the gas installations in the gulf of Mexico are at risk at this time of year because of the hurricanes which could damage the installations and thus affect the prices.

4.2.5 Scenarios

To obtain a global evaluation of the cost advantages associated with propane, we analyzed the fuel costs for three categories of light-duty vehicles. These three categories, light-duty passenger vehicle, light-duty passenger truck (minivan, SUV, light truck) and light-duty commercial vehicle are those used by Transport Canada. These scenarios were based on the fuel prices in effect in Montreal on October 21st 2008 (see table 2).

Table 2: Fuel prices

2008 Fuel prices	Gasoline	Diesel	Propane	Natural Gas	E10
Fuel price in Montreal per liter	$1.05	$1.21	$0.56	$0.83	$1.12

The propane price is the price offered by a propane supplier in Montreal for a fleet of about 6-10 vehicles on October 21st, 2008 (www.propanefacts.com). The price of compressed natural gas (liquefied is only available for heavy vehicles) includes the costs of infrastructures necessary for the supply and the fill-up of vehicles (compressor load). The gasoline price is the average retail price in 2008 – Montreal (October 21st, 2008) [26]. The diesel price is the average retail price in 2008 – Montreal (October 21st, 2008)[27].

Furthermore, our scenarios are conservative and use the fuel efficiency reference in L /100 km provided by Transport Canada[28] for vehicles with gasoline and diesel. This fuel efficiency takes into account the age profile of the fleet by category of vehicle (in this case, 2006 vehicles). The fuel efficiency for vehicles with alternative fuel provided by Transport Canada is based on the report from the firm *Levelton Engineering Ltd* written for the *National Climate Change Process* in 1999[29].

In the following three scenarios, the fuel costs, according to current prices, classify propane among the most advantageous with 35 % savings compared with gasoline and considering fuel efficiency on vehicles. Compared with diesel, propane allows superior savings ranging from 2,5 to 10 times. E10 is associated with higher costs, even compared with gasoline. Only natural gas presents costs similar to those of propane. However, propane is the least expensive of all fuels for light-duty commercial vehicles considering the cost of compressed natural gas infrastructure in its price.

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[26] http://fuelfocus.nrcan.gc.ca/prices_bycity_f.cfm?PriceYear=2008&ProductID=1&LocationID=28#PriceGraph, online October 23rd, 2008.

[27] http://fuelfocus.nrcan.gc.ca/prices_bycity_f.cfm?PriceYear=2008&ProductID=5&LocationID=28#PriceGraph, online October 23rd, 2008.

[28] http://www.tc.gc.ca/programs/environment/UTEC/FuelEfficiency.fr.aspx, online October 23rd, 2008.

[29] Alternative and Future Fuels and Energy Sources for Road Vehicles » (Carburants et sources d'énergie alternatifs et futurs pour les véhicules routiers), Edwards , W., Dunlop, R., and Duo, W. Levelton Engineering Ltd. July 12th, 1999)

More precisely, conversion costs for propane and natural gas are fixed. Costs associated with the diesel engine are variable and depend on the vehicle's category. In our scenarios, the conversion and purchase costs for a diesel vehicle include Quebec taxes. We observed that the conversion costs for propane are approximately 33 % lower than those of natural gas for all categories.

Compared with diesel power, propane conversion costs are higher for passenger cars and passenger trucks. However, these costs become lower for diesel powered light-duty commercial vehicles (see table 2).

Overall, considering the conversion and purchase costs for vehicles running on an alternative fuel, propane has the advantage to have a better return on investment compared to other fuels.

Table 3: Fuel costs comparison

	Gasoline	Diesel	Propane	Natural gas	E10
Fuel price in Montreal per liter	$1,05	$1,21	**$0,56**	$0,83	$1,12
Consumption per vehicle category					
Light-duty passenger vehicle	9,8	7,3	12,1	8,1	10
Light-duty passenger truck (minivan, SUV, light truck)	12,6	10,6	15,6	10,4	12,9
Light-duty commercial vehicle	16,4	13,5	20,2	13,6	16,8
Costs per 100 Km	**Gasoline**	**Diesel**	**Propane**	**Natural gas**	**E10**
Light-duty passenger vehicle	$10,31	$8,83	$6,74	$6,72	$11,20
Light-duty passenger truck (minivan, SUV, light truck)	$13,26	$12,82	$8,69	$8,63	$14,45
Light-duty commercial vehicle	$17,25	$16,32	$11,25	$11,29	$18,82
Diesel engine and conversion costs	**Gasoline**	**Diesel**	**Propane**	**Natural gas**	**E10**
Light-duty passenger vehicle	$0,00	$2 257	$4 515	$6 772	$0,00
Light-duty passenger truck (minivan, SUV, light truck)	$0,00	$2 821	$4 515	$6 772	$0,00
Light-duty commercial vehicle	$0,00	$5 643	$4 515	$6 772	$0,00
Profitability (100 km)	Gasoline	Diesel	Propane	Natural gas	E10
Light-duty passenger vehicle					
Conversion costs (diesel engine)	$0,00	$2 257	$4 515	$6 772	$0,00
Costs per 100 km	$10,31	$8,83	$6,74	$6,72	$11,20
Alternative fuel costs reduction (100 km)		$-1,48	$-3,57	$-3,59	$+0,89
Alternative fuel costs reduction (%)		-14%	-35%	-35%	+8%
Break-even point		152 133	126 474	188 828	-
Light-duty passenger truck (minivan, SUV, light truck)					
Conversion costs (diesel engine)	$0,00	$2 821	$4 515	$6 772	$0,00
Costs per 100 km	$13,26	$12,82	$8,69	$8,63	$14,45
Alternative fuel costs reduction (100 km)		$-0,44	$-4,57	$-4,62	$+1,19
Alternative fuel costs reduction (%)		-3,5%	-35%	-35%	+9%
Break-even point		641 628	98 883	146 489	
Light-duty commercial vehicle					
Conversion costs (diesel engine)	$0,00	$5 643	$4 515	$6 772	$0,00
Costs per 100 km	$17,25	$16,32	$11,25	$11,29	$18,82
Alternative fuel costs reduction (100 km)		$ -0,93	$ -6,00	$-5,96	$+1,56
Alternative fuel costs reduction (%)		-5,5%	-35%	-35%	+9%
Break-even point		606 008	75 232	113 541	

In addition, we wanted to estimate the break-even point associated to the use of propane. In fact, it is relevant to estimate at which mileage propane becomes a profitable solution for a lightduty vehicle fleet. Figures 8, 9 and 10 are based on the scenarios developed before. They show that in the case of a light-duty vehicle, propane becomes profitable after only 125 000 km. In the case of a light-duty truck consuming 12,6 liters in 100 km this break-even point is established at 98 000 km, and at 75 000 km for light-duty commercial vehicles. The following figures (8 - 10) present the fuel costs by types of vehicles of the same category. Propane is the most economical alternative in every case.

Figure 8: Consumption curves for light-duty passenger vehicle

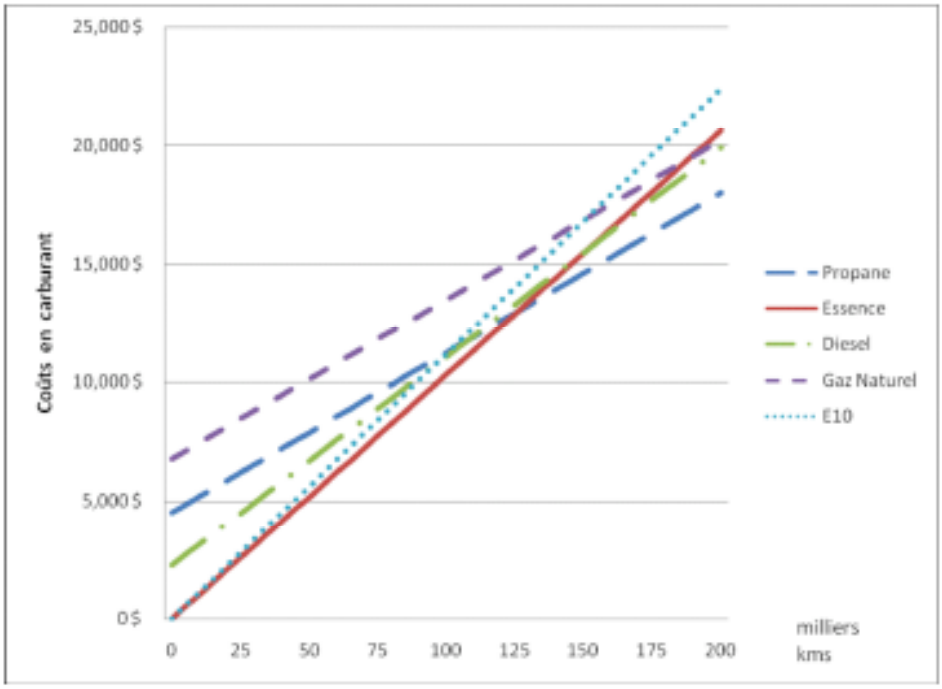


Figure 8 translation
Coûts en carburant = fuel costs
Propane = propane
Essence = gasoline
Diesel = diesel
Gaz naturel = natural gas
E10 = E10
Milliers kms = thousands kms

After only 125 000 km travelled, the user will pay off his conversion costs for a light-duty passenger vehicle.

Figure 9: Consumption curves for light-duty passenger truck (minivan, SUV, light truck)

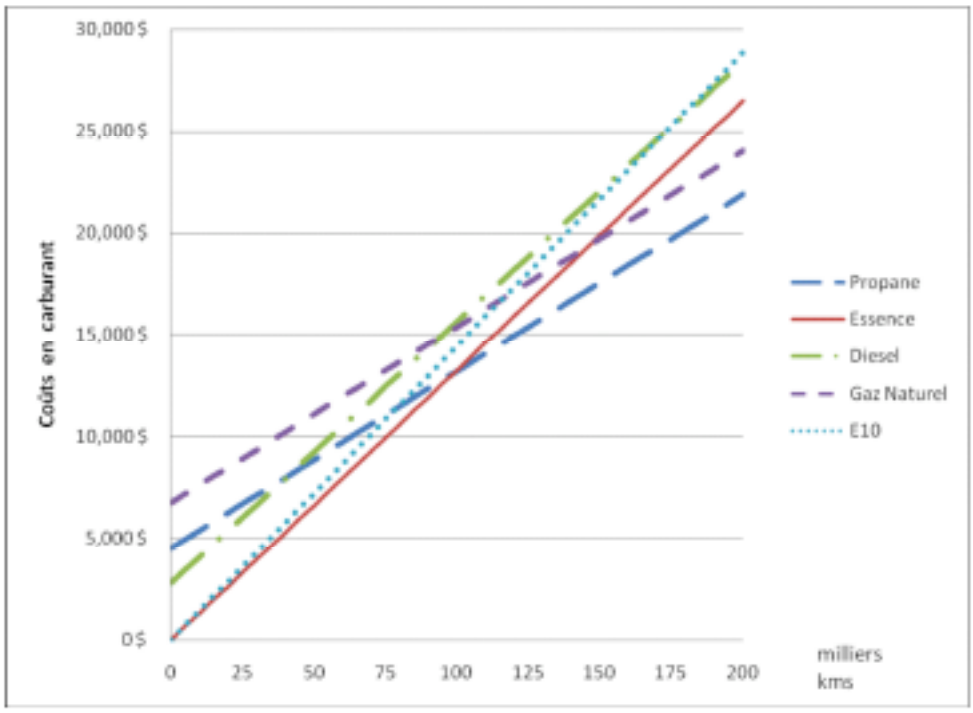


Figure 9 translation
Coûts en carburant = fuel costs
Propane = propane
Essence = gasoline
Diesel = diesel
Gaz naturel = natural gas
E10 = E10
Milliers kms = thousands kms

For a light-duty passenger truck, profitability is reached after only 90 000 km traveled.

Figure 10: Consumption curves for light-duty commercial vehicle

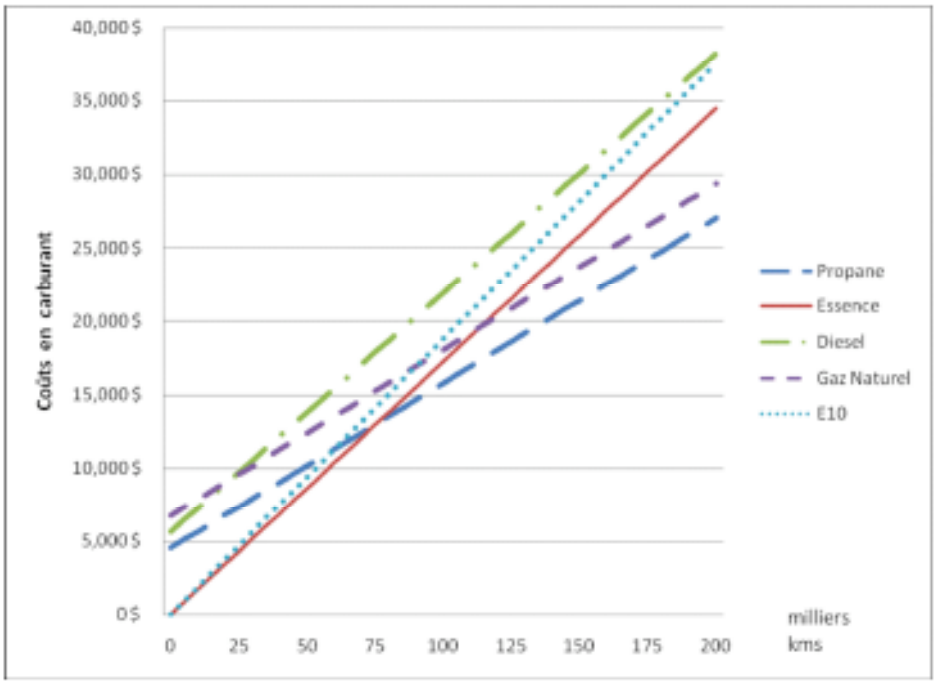


Figure 10 translation
Coûts en carburant = fuel costs
Propane = propane
Essence = gasoline
Diesel = diesel
Gaz naturel = natural gas
E10 = E10
Milliers kms = thousands kms

Propane is more profitable for a vehicle consuming more fuel per 100 km. Its breakeven point is reached after 75 000 km for light-duty commercial vehicles.

Therefore, we can conclude that from our conservative scenarios, the use of propane allows substantial savings in comparison to all selected alternative fuels. This conclusion is imperative when we take into account total costs, which include operation and conversion costs. Also, the higher the vehicle's fuel consumption, the more propane becomes advantageous.

4.3 Environmental impacts

Greenhouse gases are the object of discussions through the whole planet. It represents an important issue for several national and international governments and organizations. Moreover, the Kyoto protocol proposes a calendar for greenhouse gas emissions reduction which is considered being the main cause for global warming. This protocol benefits from significant public support in Quebec. The government of Quebec is also sensitive to these environmental issues, probably because of the public opinion pressures and the non-governmental groups. In the Quebecois context, questions regarding the environmental impacts of fuels are an important question for the adoption of an alternative fuel such as propane.

4.3.1 Greenhouse gas (GHG)

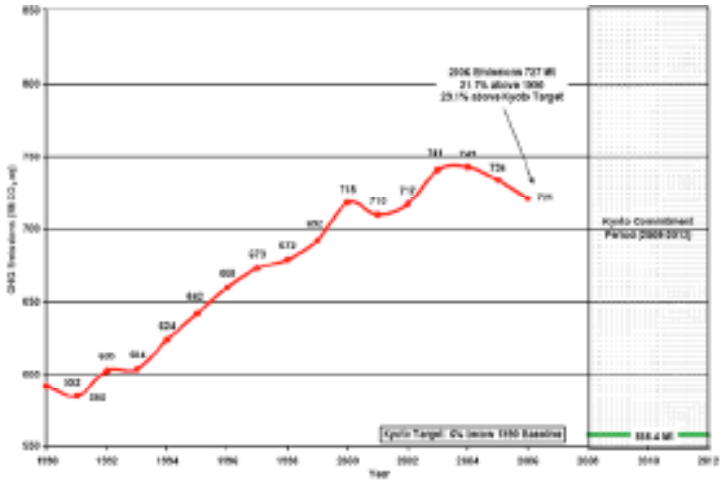
The Intergovernmental Panel on Climate Change (IPCC) listed more than forty GHG's. Canada, as signatory of the United Nations Framework Convention on Climate Change, must submit an annual inventory of the following six GHG:

- Carbon dioxide (CO2),
- Methane (CH4),
- Nitrous oxide (N2O),
- Sulfur hexafluoride (SF6),
- Perfluorocarbons (PFC),
- Hydroflourocarbons (HFC).

Figure 11, extracted from the report issued by Environment Canada on the Canadian inventory of the GHG for 2006[30], shows the evolution of the GHG emissions in Canada since 1990 and demonstrates their rapid growth in the last 15 years. This evolution underlines the importance in reducing these emissions.

[30] http://www.ec.gc.ca/pdb/ghg/inventory_report/2006/som-sum_fra.pdf

Figure 11: Evolution of GHG emissions in Canada from 1990 to 2006



Source: Environment Canada : Canada's 2006 Greenhouse Gas Inventory Trends resume

According to Natural Resources Canada, the transportation sector is responsible for 27% of GHG emissions in Canada, light-duty vehicles being responsible for nearly half of this total. An effort to reduce GHG emissions for this type of vehicles will thus have a positive impact on the environment.

4.3.2 Criteria Air Contaminants (CACs)

Air issues such as smog and acid rain result from the presence of, and interactions between, a group of pollutants known as Criteria Air Contaminants (CAC) and some related pollutants. CAC, in particular, refer to a group of pollutants that include:

- Suflur oxides,
- Nitrogen oxides,
- Particulate matter,
- Volatile organic compounds,
- Carbon monoxide

CAC are produced from a number of sources, including burning of fossil fuels (gasoline, diesel, natural gas …), and it is because of these shared sources that CAC are grouped together.

4.3.3 Health issues

Health Canada has identified eight significant health concerns related to climate change that cover a broad range of issues[31]. Asthma and other respiratory diseases as well as cardiovascular illnesses are amongst these issues.

Therefore, a reduction of GHG and CAC emissions would allow an improvement of the air quality which consequently would decrease the risks of diseases directly associated with the pollution owed largely to the transportation sector. The Lung Association[32] clearly recognizes the benefits of propane in comparison to gasoline and encourages this alternative fuel which is less fatal for the health.

Studies made by doctors and scientists of the university of California[33] demonstrate that emissions due to the use of diesel can entail important consequences on the health of people, in particular certain cancers.

Numerous school bus companies, of which *Blue Bird Corporation*, took initiative in the United States and converted their vehicles to propane to reduce the children's exposure to these pollutants, improve air quality and also realize considerable costs savings.

4.3.4 Natural gas, ethanol and biodiesel

Natural gas is considered the cleanest fossil fuel according to Environment Canada. Just like propane, it produces less toxic emissions than gasoline and diesel, and GHG emissions are reduced of about 22 % for natural gas compared with gasoline[34].

Ethanol also contributes to GHG emissions reduction. Therefore, the use of E10 entails a reduction of 4 to 6 % of GHG emissions compared with gasoline for corn ethanol[35].

Finally, biodiesel is biodegradable, non-toxic when used as fuel, but it is still used experimentally in Quebec because of the very cold winters, and only in 5 % concentrations. Besides, it is only distributed in 4 service stations in Montreal.

4.3.5 Propane emissions compared to gasoline and diesel

The use of propane as fuel instead of gasoline or diesel allows reducing GHG emissions as well as CAC emissions.

Therefore, according to Natural Resources Canada, *« propane burns more cleanly than gasoline or diesel fuel. On a per unit energy use basis, propane produces fewer greenhouse gas emissions that contribute to climate change. »* Concretely, the Ministry of Natural Resources of Canada quantifies this reduction to at least 20 % compared with gasoline[36]. According to the *Center For*

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[31] http://www.hc-sc.gc.ca/ewh-semt/climat/impact/index-fra.php#impacts
[32] http://www.poumon.ca/home-accueil_f.php
[33] "No Breathing in the Aisles: Diesel Exhaust Inside School Buses", Gina M. Solomon, M.D., M.P.H. Todd R. Campbell, M.E.S., M.P.P. Gail Ruderman Feur, Julie Masters, Artineh Samkian, Kavita Ann Paul, Contributor Jesus Santos Guzman, M.D., M.S., January, 2001
[34] Alternative and Future Fuels and energy sources for road vehicles. National climate change process. Prepared by Levelton engineering Ltd. July 1999. Page 142
[35] Alternative and Future Fuels and energy sources for road vehicles. National climate change process. Prepared by Levelton engineering Ltd. July 1999. Page 142
[36] http://oee.nrcan.gc.ca/transports/carburants/propane/propane-avantages.cfm?attr=16, online October 28th, 2008.

Clean Air Policy, these reductions could reach up to 26 %[37]. The low sulfur concentration allows contributing to the decrease of pollutants which generates smog.

In the United States, the *Argonne National Laboratory* of the energy department studied the complete life-cycle of propane in terms of GHG emissions, and concluded that they were 12 to 20% lower in comparison to the gasoline life-cycle[38].

Diesel fuel for vehicles certainly allows a GHG emissions reduction from 10 to 20 % compared with gasoline, but the particles emissions are of a considerable importance.

Numerous American studies confirm these results. Indeed, the *California Air Resources Board* (CARB) has identified a list of toxic matter which are emitted by the vehicles among which:

- 1,3 -butadiene,
- Formaldehyde,
- Benzene,
- Acetaldehyde,

Table 4 illustrates the presence of each of these substances in milligram for every kilometer traveled with gasoline, diesel and propane[39]:

[37] Center for Clean Air Policy, Greg Dierkers, Senior Policy Analyst, Briefing to Interested. California Stakeholders, 6 avril 2005.
[38] World LP Gas Association, LP Gas – Helping Solve the Climate Change Problem, An executive Summary of LP Gas Solutions for Climate Change
[39] World LP Gas Association–LP Gas and Climate Change: Targeting the Switch to Cleaner Fuels, page 28

Table 4: Substance emissions for ordinary fuel and propane

(mg/km)	1,3 -butadiene	Formaldehyde	Benzene	Acetaldehyde
Gasoline	0,35	1,24	4,77	0,38
Diesel	0,36	1,03	2,93	0,35
Propane	0,07	1,04	0,39	0,27

Source: Adapted from World Gas Association

Propane clearly appears to be less harmful for the health than gasoline and diesel.

4.3.6 Scenarios

The use of the propane as alternative fuel to gasoline allows a considerable GHG emissions reduction. Transport Canada details the GHG emissions due to public transit and has developed a tool which allows to estimates annual greenhouse gas (GHG) emissions[40]. As for the total costs fuels and propane usage, we analyzed scenarios for GHG emissions. We have selected the three categories of light-duty vehicles proposed by Transport Canada and their respective consumptions:

1. Light-duty passenger vehicle, 9,8 l/100km
2. Light-duty passenger truck (minivan, SUV, light truck), 12,6 l/100km
3. Light-duty commercial vehicles, 16,4 l/100 km

For each of these vehicles, the GHG emissions are calculated for several fuels: gasoline, diesel, propane, natural gas and 10% gasoline-ethanol. These emissions are considered in CO2 equivalent in gram by liter as well as in CO2 equivalent in gram by liter for a distance traveled of 100 km. The consumptions for various fuels are determined on the basis (1) of the 9,8 l / 100 km gas consumption, 12,6 l / 100 km and 16,4 l / 100 km respectively, and (2) of the energy ratio which expresses the consumption of the alternative fuel according to the gas consumption. Table 5 summarizes all results.

The analysis of these data brings us to the conclusion that propane turns out to be the fuel with the lowest greenhouse gas emissions. For a light-duty passenger vehicle, emissions related to propane amount to 18.392 kg, compared with 24.294 kg for gasoline, 20.389 kg for diesel, 19.205 kg for natural gas, and 22.310 kg for E10. The same proportions apply for the other categories of vehicles. In fact, compared with gasoline, propane is associated with emissions reductions in CO2 equivalent of 24,3 % for light-duty passenger vehicles, 24,1 % for light-duty passenger trucks and 24,5 % for light-duty commercial vehicles.

[40] http://www.tc.gc.ca/programs/environment/UTEC/menu-fra.htm, online October 28th 2008.

Table 5: CO_2 emissions for light-duty vehicle category per 100 km

Vehicle category		Gasoline	Diesel	Propane	Natural gas	E10
Light-duty passenger vehicle	Consumption (L/100km)	9.8	7.3	12.1	8.1	10
	Energy ratio	1	0.74	1.23	0.83	1.02
	CO_2 emissions equivalent in g/l	2 479	2 793	1 520	2 371	2 231
	CO_2 emissions equivalent for 100 km in g/l	24 294	20 389	18 392	19 205	22 310
	Propane emissions reductions allowed	25%	10%		5%	18%
Light-duty passenger truck (minivan, SUV, light truck)	Consumption (L/100km)	12.6	10.6	15.6	10.4	12.9
	Energy ratio	1	0.84	1.24	0.83	1.02
	CO_2 emissions equivalent in g/l	2 479	2 793	1 520	2 371	2 231
	CO_2 emissions equivalent for 100 km in g/l	31 235	29 606	23 712	24 658	28 780
	Propane emissions reductions allowed	24%	20%		5%	18%
Light-duty commercial truck	Consumption	16.4	13.5	20.2	13.6	16.8
	Energy ratio	1	0.82	1.23	0.83	1.02
	CO_2 emissions equivalent in g/l	2479	2 793	1 520	2 371	2 231
	CO_2 emissions equivalent for 100 km in g/l	40 656	37 706	30 704	32 246	37 481
	Propane emissions reductions allowed	25%	19%		5%	15%

4.4 Propane : safe and reliable

4.4.1 Standards and regulations

The standards and regulations relative to the installation of propane vehicle conversion equipment are very strict from a national or provincial point of view. The B149.5 Code of the Canadian Standards Association regulates the tank installation and the propane supply systems for over the road vehicles. Propane tanks used in vehicles are equipped with a stop-fill valve that stops the filling process when the tank reaches 80% of its liquid capacity and propane engine fuel systems are fitted with safety devices and shut-off valves that function automatically to prevent the escape of propane if the fuel line ruptures in an accident[41]. The propane industry in Quebec imposes numerous conditions in regards to the use of propane, such as the D-10 law which obliges the propane distributor to make sure of the correspondence and the safety of an installation before supplying it, even if a third person executed the installation. All these laws and regulations surrounding propane makes the use of propane vehicle very safe.

4.4.2 Flammability

The concentration of the gas in air must be between its lower flammable limit (LFL) and upper flammable limit (UFL) for it to burn. The flammable range of a gas includes all of its concentrations in air between the LFL and UFL. For a flammable gas within its flammable limits in air (or oxidizing gas) to ignite, an ignition source must be present. Any percentage of propane in a propane/air mixture between 2.15% and 9.6%[42] will be sufficient for propane to burn compared with gasoline which requires a gas concentration between 1,4 % and 7,6 %[43]. Gasoline thus ignites more quickly than propane because a 1,4 % concentration in the air is enough for it to burn. The vapors of gasoline stay at ground level whereas those some propane vaporizes and readily dissipate[44]. Propane is thus safer than gasoline considering that it ignites less easily and that propane vapors dissipate faster than gasoline.

4.4.3 Technology

For our evaluation of propane, it is also essential to understand if it is a reliable and secure technological alternative. The available information suggests that the conversion technology for a vehicle running on gasoline to running on propane is a simple, reliable and relatively inexpensive modification. The propane vehicle conversion is done by the installation of conversion equipment composed of three parts:

- An injection system injecting the gas in the engine by the inflow of air,
- An electronic module regulating the injection system according to the acceleration,
- An additional tank as illustrated in figure 12.

Propane is easily stored in a liquid state in a tank of 200 psi[45] which is an advantage compared with compressed natural gas which requires pressures from 3 000 to 4 000 psi. Natural gas is liquefied in a pressure of 3.6 psi but requires a temperature around - 163 degrees Celsius[46].

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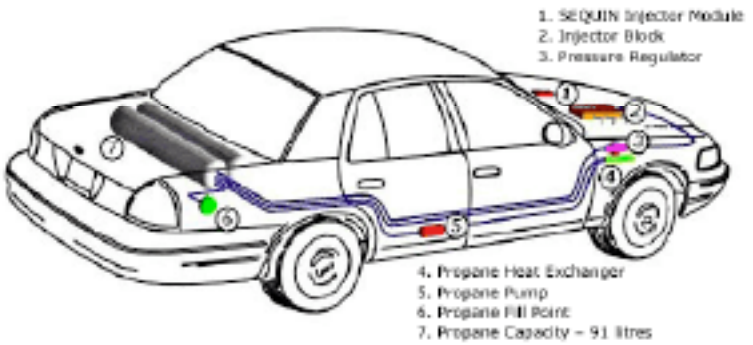
[41] http://www.propanegas.ca/auto/auto_vehiclesafetyfeatures.asp, online October 24th 2008.
[42] http://www.msp.gouv.qc.ca/incendie/incendie.asp?txtSection=publicat&txtCategorie=lignes_directrices&txtNomAutreFichier=propane.htm, online October 24th 2008.
[43] http://www.cchst.ca/reponsessst/chemicals/flammable/flam.html, online October 24th 2008.
[44] http://www.propanefacts.ca/safety/, online October 24th 2008.
[45] http://alternativefuels.about.com/od/generalmaintenance/a/gaspropanemaint.htm, online October 30th 2008.
[46] http://newenergyandfuel.com/http:/newenergyandfuel/com/2008/09/09/reality-check-where-to-put-all-thatmethane, online October 30th 2008.

Figure 12: Propane conversion equipment



Source : Technologie *SEQUIN* : http://www.eco-motion.ca/pages/new.html

Propane was first identified as a component in gasoline in 1910. Its use as alternative fuel to gasoline started in the 1920's. Propane became very popular in the 1950s when the *Chicago Transit Authority* ordered 1,000 propane-fueled buses[47]. Today, about 10 million vehicles worldwide use propane.

Before the arrival of the electronic gasoline injection systems in vehicles, the propane conversion system consisted of installing a simple vapor mixer in the intake system to introduce the gas into the engine. Between the 80s and 90s, carburetors were put aside for electronic injection systems allowing a better regulation of the air/fuel mixture introduced into the engine to obtain a better efficiency. During this period, the evolution of the *Environmental Protection Agency* (EPA)'s standards and the introduction of more competitive electronic injectors of second generation speeded up the abandonment of carburetors to the advantage of injectors in the automobile industry. The arrival of these systems on the market made incompatible the propane vehicle conversion which rested on a technology developed for systems with carburetion. The propane conversion equipment generated severe reliability problems and some even had to be removed from vehicles.

Since the end of 1990s, several American and European companies developed electronic injectors specifically designed for propane while respecting the standards of the *Original Equipment Manufacturer* (OEM). This new generation of conversion equipment continued to evolve significantly in the years 2000. Today, it presents reliability and results comparable to the gasoline engine in terms of performance, driving quality and safety. The new generation technology is normally EPA approved for emissions, CSA, EN67 and/or UL certified for safety, and meets the operational requirements (reliability, performance, emissions, regulatory compliance) of today's commercial fleet user. This includes reliabiltiy, performance, driveability, comfort, etc.

[47] http://en.wikipedia.org/wiki/Propane#Vehicle_fuel, online October 22nd 2008.

Propane conversion equipment suppliers and installers are numerous in Quebec and more than ten are listed in the region of Montreal. A detailed list is available via the *Association Québécoise du propane*. As for the technology used in Quebec, we find in particular the new generation conversion equipment *SEQUIN*™. It is a dual fuel technology which allows vehicles to use propane and\or gasoline, and which is in accordance with all environmental, safety and electronic current standards in North America.

Installation takes around 12 hours on an ordinary vehicle. The driver's adaptation takes one or two days. As for maintenance, no special equipment or additional efforts are needed, on the contrary, some the life-span of some parts will improve with the use of propane[48]. Furthermore, a propane tank fill-up takes only a few extra minutes contrary to compressed natural gas for which a fill-up requires five or six hours (liquefied natural gas is not available in Quebec).

An additional argument in favor of the reliability and of the safety of propane relies on numerous examples of vehicle fleets which use propane. Some of these examples are in Ontario (see table 6). These examples of propane adoption by several organizations, public as well as private, confirm the safety and reliability of this alternative. As example, the London Police Department, in Ontario, use patrol vehicles converted to propane. As for Quebec, the major part of the UPS fleet of vehicles has been working on propane for several years. In February, 2008, the company announced that 138 additional units were going to be converted, which bring the total number of vehicles running on propane to 2,000[49] in the UPS fleet.

No major incident due to the use of propane as alternative fuel was reported and the performance is comparable to those of vehicles running on gasoline.

Table 6: Examples of fleets of vehicles converted to propane

Blue Line Transportation Ltd., Hamilton, Ontario (population : 504 559 in 2006[50]) Blue Line Transportation Ltd. Is the largest s the largest taxi company in Hamilton, Ontario. In the early 1980s, Blue Line Transportation Ltd. began converting its taxis from gasoline to propane in an effort to reduce fuel and maintenance costs. Of the 200 cars and 27 vans, 69 vehicles run on propane, and 25 more can run on either natural gas or gasoline. Installing an on-site propane refueling system further reduced fuel costs and made refueling easier for the drivers. According to Tony Rizzuto, Blue Line owner, all of the equipment costs were recovered by savings on fuel. According to the company's calculation, conversion costs for propane are repaid in about nine months. The switch to alternative fuels has reduced operating and engine maintenance costs since some engine pieces, like spark plugs, last longer when running on propane. According to Mr. Haze, vice-president of Blue Line, the amount of money saved by using propane is very significant and the « advances in conversion kit technology have made these alternative fuels almost as reliable as gasoline »[51].
Robert Q Airbus, London, Ontario (population : 352,395 in 2006[52]) This company was originally established to provide a shuttle service between London and Lester B. Pearson International Airport in Toronto. The company's fleet consists of 32 maxi-wagons, all of which have been converted

[48] http://www.sfitechnologies.com/sequin/, online October 22nd 2008.
[49] http://www.visiondurable.com/article-188066-Livraison-au-propane-chez-UPS-Canada.html, online October 22nd 2008.
[50] Stats Canada 2006 Canadian Census: Hamilton, Ontario. Statistique Canada, online October 24th 2008.
[51] Office de l'efficacité énergétique, Ressources naturelles Canada http://ecoflotte.rncan.gc.ca/index.cfm?fuseaction=doc.voir&id=municipalites-blueline, online October 13th 2008.
[52] Stats Canada 2006 Canadian Census: London, Ontario. Statistique Canada

to run only on propane. According to Robert Q Airbus, three reasons have motivated this choice: (1) propane is less expensive than gasoline, (2) it offers the range needed to travel from London to Toronto and back without refueling and (3) the company chose propane over natural gas because it offers a longer range and requires less space for fuel storage tanks. According to company General Manager David Gray, including the conversion cost, propane allows a fuel-cost savings of about $30,000 per vehicle. Payback of the conversion cost is achieved in less than six months through fuel-cost savings[53].

The London Police Service, London, Ontario (population : 352,395 in 2006)
In 1982, the London Police Service tested propane as an alternative fuel in two of the service's fleet vehicles. The results were so encouraging that today close to 65 percent of the vehicles in the fleet have been converted to run on propane. This includes 71 full-sized sedans and 20 trucks and vans. In terms of performance, studies conducted by the London police department revealed that propane vehicles typically register about 110 wheel horsepower on propane, compared with 117 wheel horsepower on gasoline. Vehicle acceleration has also been tested and showed that a vehicle running on propane was only 0.5 seconds slower in going from 0 to 60 kilometers per hour at full throttle than an identical vehicle running on gasoline. In addition to performance comparable to gasoline vehicles, fuel-cost savings can reach up to $11,000 over the life of a typical vehicle, which is around two to three years.

According to the London Police Service, over the past 20 years, total savings from the conversion program are estimated to be between $3 million and $4 million. Finally, regarding safety, although the service's patrol vehicles have experienced collisions from all angles and some vehicles have been damaged beyond repair, « the propane tanks, fuel lines and other conversion equipment have with-stood the abuse »[54].

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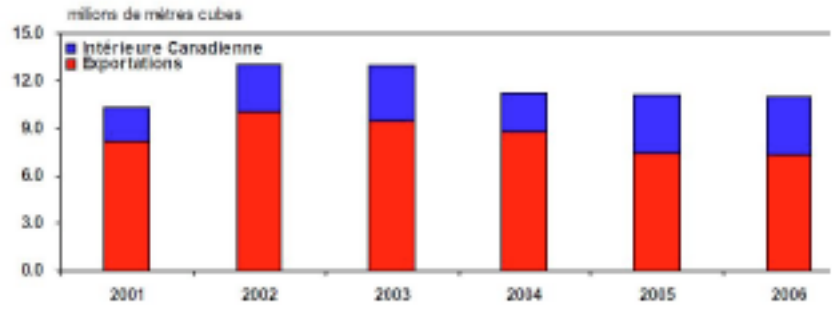
[53] Office de l'efficacité énergétique, Ressources naturelles Canada http://ecoflotte.rncan.gc.ca/index.cfm?fuseaction=doc.voir&id=camionnettes-fourg-airbus, online October 13th 2008.
[54] Office of Energy Efficiency, Natural Resources Canada http://ecoflotte.rncan.gc.ca/index.cfm?fuseaction=doc.voir&id=voitures-mini-fourg-london, online October 13th 2008.

4.5 Supply and availability

In 2006, Canada produced more than 11 million cubic meters of propane, which represents about 5 % of worldwide production, and puts it among the main producers of propane in the world. The entire production is located in Western Canada, predominantly in the province of Alberta (98 %) and the rest is shared between the provinces of British-Columbia (0,8%) and Saskatchewan (1,2 %). Propane is routed by the pipeline of Cochin from the west to the east to be then distributed to the retailers by railway or by road network. The retailers network represents 3 000 points of sale in Canada. It is the most important distribution network of alternative fuel in Canada.

Propane exportation is important in Canada who ships the majority of its production to the United-States, due to lack of domestic demand[55]. This national resource is under-utilized although broadly available across the country.

Figure 13: Domestic use and Canadian exportation of propane



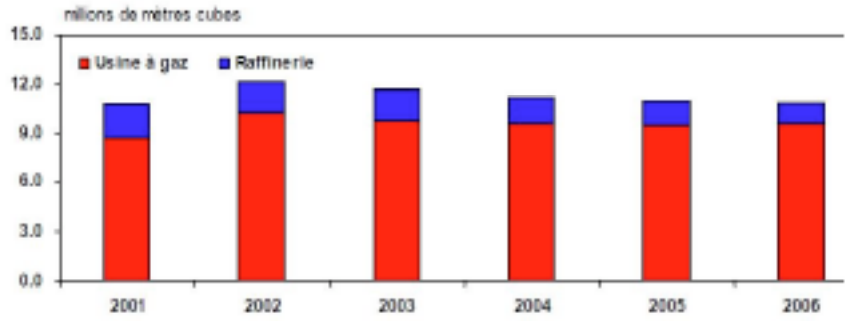
Source: Propane Market Study, Purvin and Gertz Inc.

Figure 13 translation:
Millions de mètres cubes: Million Cubic Meters
Intérieure Canadienne : Domestic
Exportations : Export

Canadian refinery propane production has been relatively stable over the last three years, but has remained below 15 percent of total supply.

[55] Propane Production and Supply in Canada, Chandra B. Prakesh, Ph.D. November 2001

Figure 14: Canadian propane supply by source



Source: Propane Market Study, Purvin and Gertz Inc.

Figure 14 translation:
Millions de mètres cubes: Million Cubic Meters
Usine à gaz: gas plan
Raffinerie : refinery

Refining consists in extracting propane of crude oil, the biggest stations are in Ontario (34 %), in Alberta (26 %) and in Quebec (19 %).

4.5.1 Crude oil refining

In Canada

The refining industry in Canada is essentially concentrated in Alberta and in Ontario. A total of 25 refineries exist across the country[56].

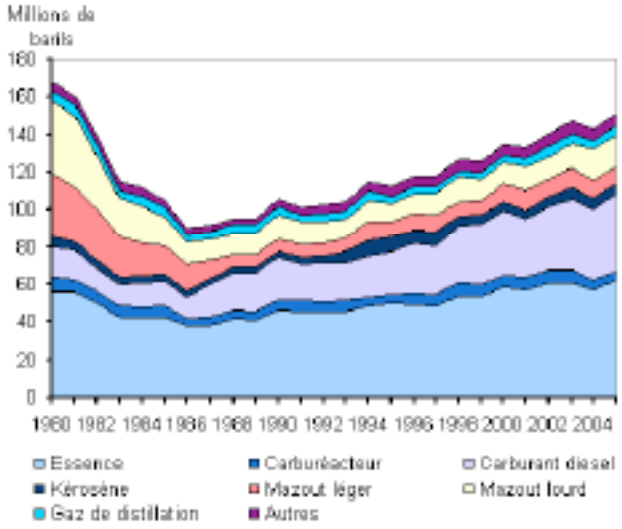
Table 7: Refineries in Canada

Alberta	8 refineries
Ontario	7 refineries
Quebec	3 refineries
Maritimes	3 refineries
Saskatchewan	2 refineries
British-Columbia	2 refineries

The main products resulting from the refining are gasoline (40 %) and heating oil (22 %). Six other petroleum products, including diesel and kerosene, take up the remaining 38 % (see figure 15). The demand for Canadian petroleum derived products increased of 3 % per year since 1993, and represent 18,5 billions $ a year.

[56] Natural Resources Canada website

Figure 15: Production of energy petroleum products from 1980 to 2005



Sources : Ministère des Ressources naturelles et de la Faune du Québec et Statistique Canada.

Figure 15 translation:
Millions de barils: millions of barrels
Essence : gasoline
Kérosène : kerosene
Gas de distillation : distillation gas
Carburéacteur : jet fuel
Mazout léger : furnace oil
Autres : Other
Carburant diesel : diesel fuel
Mazout lourd : bunker oil
Source: Quebec's Ministry of Natural Resources and Wildlife and Statistique Canada

In Quebec

Refining is made from crude oil, from bituminous minerals or resulting from their split distillation. The oil refining techniques are essentially activities of split distillation or direct distillation of crude oil. The extracted products are:

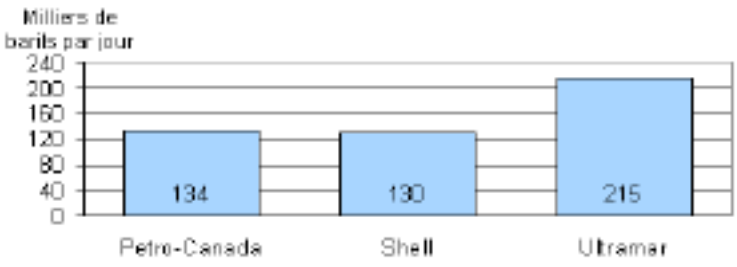
1. Fuel for engines such as gasoline, kerosene, etc.

2. Fuel such as light oil, half--heavy, heavy fuel and refinery gas such as ethane, propane, butane, etc.

3. Various degreasing oil and greases.

There are three refineries operating in Quebec: *Petro-Canada*, *Shell* and *Ultramar*[57].

Figure 16: Production capacity of refineries



Source : Ministère des Ressources naturelles et de la Faune du Québec.

Figure 16 translation
Milliers de barils par jour : millions of barrels per day
Source: Quebec's Ministry of Natural Resources and Wildlife

The total production capacity of refineries in Quebec was 478 750 barrels per day, which represents approximately a quarter of the total refining capacity in Canada.

Having known a decrease between 1980 and 1986 due to the closure of four refineries in Quebec, the capacity of refining has been growing since 1987. The structure of Quebec's production changed during the last 25 years. Gasoline is the main product resulting from refining, going from 34 % to 41 %. Diesel production has also experienced a very strong increase, going from 10 to 28 %. Furnace oil production has gone from 20 % to 6 %.

Quebec consumes an average of 500 and 550 millions of liters of propane yearly, which represents 1 % of the complete energy balance sheet. About 75 % of this consumption comes from Western Canada, and is routed in most cases by railcar or truck transport from Sarnia in Ontario. As for the remaining 25 %, these come from refineries in Quebec[58]. This capacity of refinement in Quebec and the propane availability across Canada makes the accessibility and supply of this combustible significantly easier.

4.5.2 Infrastructures required for propane

Beyond the availability of propane, we also considered its distribution to commercial and institutional customers. This mainly concerns examining facilities requested for its use.
The propane distributing companies generally provide a tank to the customer, who maybe either rent (approximately 500 $ per year), or buy (approximately 10 000 $). Once the tank is installed, the distribution is regularly insured by tankers. The supplying of the tanks is a fast and completely secure process.

[57] Ministry of Natural Resources and Wildlife website.
[58] www.propanequebec.com/propane.htm, online October 7th 2008.

In Quebec, the distribution is assured by more than 80 retailers located throughout the province. Besides the delivery of propane, they also supply sale, installation and propane equipment maintenance support. A detailed list is available via the Association québécoise de propane (http://www.propanequebec.com/distributeur/liste.htm[59]).

Availability of other alternative fuels

Natural gas has a vast network implanted in Quebec by *Gaz Métropolitain*. However, the cost associated with the installation of the supply infrastructures of this alternative fuel constitutes a barrier to its availability. Indeed, besides the purchase of a storage tank whose price is equivalent to that of the propane, it is also necessary to consider the purchase of a natural gas compressor whose price varies from 25 000 $, for a private use, to 400 000 $ per appliance for a commercial device intended for busy fueling stations (equivalent to gasoline stations).

Ethanol is produced in more than 120 million liters a year in Quebec largely because of the *Éthanol Greenfield* plant in Varennes. E5 is sold in certain gas stations in Quebec, contrary to E10 of which selling points are rather rare, or E85 which is still not distributed in Quebec. The biggest distributor of ethanol in Quebec is *Petro Sonic* distributing this fuel in 50 % of its gas stations, which is equivalent to less than a hundred stations[60].

The availability of ethanol in Canada, and thus in Quebec, remains problematic as we consider that the needs of this market will amount to 2.0 billion liters annually, while the production capacity does not exceed 1,7 billions. This is all the more problematic if we consider that the government of Quebec voted, by means of the C-33 law, for the obligation to have a minimum of 5 % of ethanol in the composition of the fuel sold in the province and this, with the objective of reaching its objectives in GHG reduction.

Besides, because of its capacity to store water, ethanol cannot be transported in pipelines. The only ways of transportation remain the train and the trucks, where containers must be specially fitted for the ethanol/gasoline mixture because of its composition. These measures apply to the transport as well as to the storage of this alternative fuel[61]. However, although the distribution network of this biofuel knows an important development, it is necessary to underline the fact that the reduction of GHG emissions of a fuel like E5 hardly exceeds 4 to 5 %, contrary to propane which can achieve up to 26 %. Furthermore, several environmental organizations militate so that the C-33 law be revised as far as this one emphasizes the pressures linked to the context of the food crisis.

Biodiesel is an exclusive production of *Rothsay Biodiesel* in Quebec, which reaches 35 million litres annually, and remains an alternative fuel hardly distributed in the province. For instance, B5 is distributed in only four stations in Montreal. However, *Petro Sonic,* in partnership with Norcan, should begin to set up a more reliable distributive network in the next years.

Therefore, contrary to biodiesel and ethanol that remain hardly distributed, propane is, for the moment, an available, accessible and inexpensive alternative.

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[59] www.propanequebec.com, online October 7th 2008.
[60] http://www.lacoop.coop/medias/communiques/2008/BiodieselLancement.pdf, online October 8th 2008.
[61] An Assessment of Propane As a Transportation Fuel For Light-Duty Fleets in Canada Gerald R. Higgins, January 2008.

5. Propane: The answer to political and environmental issues

Propane as fuel is the answer to the public and private institutions' desire to contribute to the improvement of air quality and to the reduction of greenhouse gas emissions (GHG).

5.1.1 Federal government

The government of Canada has put in place a plan to help reduce GHG emissions and atmospheric pollution in his « Turning the Corner Action Plan »[62]. The objective consists in reducing Canada's GHG emissions of 20 % from 2006 levels by 2020. This requires a commitment of the federal government, provincial governments, companies and private individuals. It is necessary to be able to reduce emissions and fight against climate change without affecting the economic growth of the country.

Road transport is the first cause of GHG emissions across the world and Canada is no exception.

In fact, according to an inventory report on GHG in Canada[63], GHG emissions for 2005 would be 747 Mt of CO2 equivalents of which 200 Mt come from the transport sector. GHG emissions due to transport account for 26 % of Canada's GHG emissions. Table 8 demonstrates the quantity of light-duty and heavy-duty vehicles circulating in Canada between 1990 and 2005:

[62] http://www.ec.gc.ca/doc/virage-corner/2008-03/pdf/COM-541_Cadre.pdf, online October 7th 2008.
[63] http://www.ec.gc.ca/pdb/ghg/inventory_report/2005_report/ta8_2_fra.cfm, online October 7th 2008.

Table 8: Trends in vehicle populations for Canada, 1990-2005[64]

Year	Number of vehicles (000s)							Total
	LDGVs	LDGTs	HDGVs	MCs	LDDVs	LDDTs	HDDVs	
1990	10 646	3 308	518	261	109	112	402	15 356
1991	10 677	3 496	463	255	110	117	394	15 512
1992	10 674	3 712	432	248	109	126	397	15 698
1993	10 761	4 019	425	247	111	145	442	16 149
1994	10 694	4 305	428	234	108	165	487	16 421
1995	10 590	4 395	387	226	104	183	513	16 398
1996	10 273	4 517	383	213	99	174	498	16 157
1997	10 420	4 939	388	225	101	188	537	16 797
1998	10 250	5 347	395	263	107	204	629	17 195
1999	10 696	5 787	349	257	114	205	616	18 024
2000	10 863	6 065	376	288	123	224	649	18 587
2001	10 969	6 266	407	327	131	231	713	19 045
2002	10 929	6 421	394	359	138	234	724	19 200
2003	10 940	6 688	410	390	142	243	742	19 554
2004	10 931	6 959	429	417	153	254	801	19 944
2005	10 961	7 386	435	437	159	277	856	20 510

Notes:
HDDVs : Heavy-Duty Diesel Vehicles
HDGVs : Heavy-Duty Gasoline Vehicles
LDDTs : Light-Duty Diesel Trucks
LDDVs : Light-Duty Diesel Vehicles
LDGTs : Light-Duty Gasoline Trucks
LDGVs : Light-Duty Gasoline Vehicles
MCs: Motorcycles
Mcs : Motorcycles

Source: National inventory report 1990-2005: Greenhouse gas sources and sinks in Canada

increasing growth in road transport emissions between 1990 and 2005 in Canada demonstrates the importance to act and find solutions to reduce vehicle's GHG emissions to reach the objectives fixed in the « Turning the Corner Action Plan ».

5.1.2 Quebec's government and municipalities

In 2005, the total GHG emissions in Quebec amounted to 92 megatons of CO2 equivalent, which represented 12,3 % of Canadian emissions[65]. In Quebec also, the transport sector is the one which produces most emissions with 35,6 megatons of CO2 equivalent, which is more than 35 % of emissions. It is thus essential to work on this sector to be able to reduce emissions while protecting the competitiveness of Quebec's companies.

A plan including twenty four actions was adopted by the government of Quebec in June, 2007[66].

This plan aims at reducing GHG emissions and at adapting itself to climate change before 2012. One of the actions of this plan consists in encouraging municipalities to adopt a regulation to fight against the polluting effects resulting from vehicle idling before 2010. Solutions are imperative to be able to solve these problems.

The government of Quebec recognizes the important role of municipalities in the GHG reduction and the decrease of the operating costs of public fleets. Municipalities, with their population and their industrial activities, are great fuel users. Propane is destined for cities of small to medium sizes, remote from big municipalities and self-sufficient in fuel supplying but also for large municipalities which have high fuel consumptions.

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[64] http://www.ec.gc.ca/pdb/ghg/inventory_report/2005_report/s2_fra.cfm#t2_5, online October 7th 2008.
[65] http://www.mddep.gouv.qc.ca/changements/ges/2005/inventaire2005.pdf, online October 7th 2008.
[66] http://communiques.gouv.qc.ca/gouvqc/communiques/GPQF/Juin2006/15/c9630.html, online October 7th 2008.

5.1.3 Private companies

Numerous private companies in Quebec have considerable fleets of vehicles. They have to face gasoline price increase and thus surmount the difficulties associated with the management of their budget in situations like winter 2008, when the price of gasoline exceeded 1,5 $ the liter. Therefore, companies look for solutions to reduce costs associated to vehicles consumption and therefore reduce GHG emissions.

Some companies use specified vehicles adapted to their service and mobile maintenance needs. These vehicles, running on gasoline, are equipped with powerful electronic systems with high consumption in electrical energy. In addition to transporting material, these vehicles serve as generator to allow the equipment to function on maintenance zones where there is no electric connection. The engine keeps running when stopped to feed the electric equipments and allow the technicians to operate. In this particular case, even if the mileage is not significant, the use of propane is a very profitable and effective alternative solution to decrease the operating costs of these vehicles whose consumption sometimes reaches 25 liters per 100 km. Pollution is also very important because the vehicle remains stationary for long hours.

Whether it is for private fleets which travel many kilometers like taxis or for fleets of vehicles with low mileage but which consume a lot of fuel such as vehicles equipped with electric systems, an alternative solution to gasoline is imperative. There is no alternative other than propane to decrease in a simple and effective way greenhouse gas emission and reduce the operating costs of these specific vehicles that run continuously to produce electricity. Propane represents an optimal solution for this category of vehicle.

5.2 The advantages of using propane

Now's the time to synthesize our analyses and observations to highlight the main advantages associated with the use of propane as alternative fuel for fleets of light-duty vehicles.

We have taken note that propane is destined to all public and private companies who wish to realize costs savings as well as reduce their GHG emissions.

Over the last 5 years, prices for propane transportation fuel have been over 40 % less than gasoline prices. The average retail price for propane sold in Montreal in 2008 has been of 0,95 $/l compared to 1,27 $/l for gasoline[67]. Propane price is less volatile than gasoline or diesel prices, which makes it more attractive and this, even though 1,2 liter of propane is required to travel the same distance as with 1 liter of gasoline.

From an environmental point of view, the combustion of propane is cleaner than that of gasoline. Propane produces 20 to 26 % fewer GHG than gasoline. The GHG emissions in the complete life cycle of propane are from 12 to 20 % lower than those of the gasoline life cycle. Furthermore, propane emits significantly fewer pollutant emissions in the air than diesel, which makes it less toxic.

In sum, regarding operating costs and GHG emissions reductions, propane has an undeniable advantage in comparison to other fuels (see table 9).

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67 http://fuelfocus.nrcan.gc.ca/prices_bycity_f.cfm?PriceYear=2008&ProductID=6&LocationID=28#PriceGraph, online October 21st 2008.

Table 9: Synthesis of operating costs and GHG emissions reductions compared to gasoline

Vehicle category	Reduction (%)	Diesel	Propane	Natural gas	E10
Light-duty passenger vehicles	Fuel costs	-14%	-35%	-35%	8%
	Equivalent CO_2 emissions	-16%	-24%	-21%	-8%
Light-duty passenger trucks (minivans, SUV, light trucks)	Fuel costs	-3,5%	-35%	-35%	9%
	Equivalent CO_2 emissions	-5%	-24%	-21%	-8%
Light-duty commercial vehicles	Fuel costs (%)	-5,5%	-35%	-35%	9%
	Equivalent CO_2 emissions	-7%	-24%	-21%	-8%

Prices in date of October 21st 2008 (see table 2: Fuel prices)

To further this synthesis we have included other parameters used for our comparison. This includes conversion and installation costs, availability, reliability and safety. Table 10 shows the results of this synthesis.

We also suggest giving a rank (from 1 to 5) to each of the alternative fuels according to their performance for each of seven parameters: operating costs, GHG emissions, conversion costs, reliability, safety, supply and availability. A rank of 1 represents the best performance of the fuel in relation to this parameter, a rank of 5, the worst performance.

Table 10: Comparative advantages of propane – A multicriteria approach

	Gasoline	Diesel	Propane	Natural gas	E10
Operating costs	5	4	1	1	3
GHG	5	4	1	2	3
Conversion costs	1	2	3	4	1
Reliability	1	1	1	3	2
Safety	1	1	1	4	3
Supplying	1	1	2	3	2
Availability	1	1	3	5	4
Total	**15**	**14**	**12**	**22**	**17**
Final rank	*3rd*	*2nd*	*1st*	*5th*	*4th*

Essentially, propane constitutes the most economic alternative fuel when taking into account total costs regarding both operating and conversion costs. It is also the least harmful alternative fuel and thus the cleanest. Propane offers, in addition to these performances, availability, reliability and safety superior to other alternative fuels. In fact, its reliability and its safety are at least equivalent to traditional fuels, in other words advantageous performances at an advantageous cost. Finally, propane is a technology available now, of which we can take advantage right now, contrary to other alternative technologies which are simply not.

The sum of this classification allows us to conclude that propane is an optimal solution for fleets of light-duty vehicles of commercial and institutional use. Diesel comes in second with a performance in terms of safety, reliability and availability which compensates for its high costs and emissions. Last is natural gas which, in spite of good results for its costs and emissions, is greatly disadvantaged compared with other criteria, notably conversion costs, safety and availability. The first to last rank is occupied by E10. In spite of its disadvantages, gasoline is in the middle of the group.

6. Conclusion

This report had for objective to estimate propane's potential of use for light-duty vehicles fleets. We compared propane with traditional fuels, i.e. gasoline and diesel as well as alternative fuels such as ethanol, biodiesel, natural gas, hydrogen and finally compared to hybrid and electric technologies.

Our analyses indicated that the alternative fuels considered are not all available as of today, because of their development phase or their availability on the market. Electric cars, just like hydrogen technology, can not be considered for car fleets because of their autonomy or their limited supply network. Although hybrid vehicles are in demand in Quebec, the fact remains that their use does not satisfy the various needs of commercial light-duty vehicle fleets.

Furthermore, our study revealed that propane was the least expensive fuel among all considered alternatives. Besides generating fuel cost savings compared with gasoline, the costs associated with vehicle conversion and the installation of the infrastructure necessary for supplying the fleet are also more advantageous than its closest competitor, compressed natural gas. The conversion cost amortization varies according to the various categories of light-duty vehicles, light-duty passenger vehicles, light-duty passenger trucks and light-duty commercial vehicles. Propane has the best profitability among diesel, natural gas and ethanol E10. For example, the propane conversion for light-duty commercial vehicles consuming an average of 16 liters per 100 km is paid off after only 75 000 km while the amortization for natural gas takes a little more than 100 000 km. For fleets of light-duty vehicles, propane is the least polluting alternative fuel before natural gas, ethanol (E10) or biodiesel. Whether it is for light-duty passenger vehicles, light-duty passenger trucks or light-duty commercial vehicles, the CO2 emissions reduction per 100 km with propane compared to regular gasoline is the most important with approximately 24% of reduction.

The propane conversion technology has considerably evolved since the arrival of electronic injection systems for gasoline engines. This technology is proven today, reliable, safe and allows obtaining performances equivalent to those of a common vehicle as shown with several case studies. These new conversion equipments respect all the standards of emissions, the security and the reliability of the automobile industry.

Although natural gas is strongly present on the Quebecois territory, the costs of infrastructures associated with its use as an alternative fuel constitutes a restraint to its availability. As for biodiesel and ethanol (E10 and E85), the points of distribution of these fuels remain very rare in Quebec. Propane, thanks to the presence of more than 80 distribution companies across Quebec, is the alternative - with E5, which remains however very polluting and more expensive – the most available and presently accessible on the market.

In sum, it is our opinion that propane represents an optimal solution for fleet operators who look for cost reductions at as well as greenhouse gas emissions, and this, by means of a proven, reliable and readily available technology. In front of such a conclusion, we can only encourage the fleet operators to consider this option for their fleet of vehicles.

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