Summary

Study on Alternative Fuels for Maritime Transportation in Quebec

February 2022

(Full report December 2021)

A study of

MeRLIN

TECHNOPOLE MARITIME DU QUÉBEC

Produced by

INNOVATION MARITIME

INSTITUT MARITIME DU QUÉBEC

Context

While the shipping industry seeks to reduce its greenhouse gas emissions and decarbonize its activities, traditional fuels based on petroleum products are increasingly criticized and questioned (environmental impact, new regulations, dependencies on oil market variations). Alternative solutions are emerging and developing in order to meet the need to reduce the carbon footprint of maritime transport and to deal with the tightening of international maritime standards on greenhouse gas emissions. The question then is: what would be the most relevant alternative fuels to adopt in Quebec?

It is in this context that the MeRLIN network led by Technopole maritime du Québec commissioned this study from Innovation maritime. The latter aims to make an inventory of the different types of fuels currently emerging by emphasizing current or future projects in Quebec, both in terms of production, distribution, and research on new fuels for maritime transport. This report thus provides essential elements for making informed choices about the marine fuels of the future in Quebec.

About MeRLIN

Spearheaded and managed by Technopole maritime du Québec (TMQ), MeRLIN is an industrial network dedicated to innovation in the shipping and port sectors. The network aims to provide greater access to R&D expertise as it seeks to facilitate the implementation of innovative projects that address the challenges of the maritime industry.

MeRLIN supports the industry in defining its research needs, stimulating collaborative work on shared objectives, encouraging reflection and the quest for concrete solutions, promoting the implementation of long-term planning tools and fostering ties between stakeholders within the maritime community.

MeRLIN is the result of the contribution of its industrial members and its financial partners, Canada Economic Development (CED) and the Créneau Ressources Sciences et Technologies Marines.

MeRLIN members

Port Québec · Port Montréal · Canada Steamship Lines · Corporation de Gestion de la Voie Maritime du Saint-Laurent · Fednav · Groupe Desgagnés inc. · Port Trois-Rivières · Urgence Marine · Ocean

Financial Partners

Développement économique Canada pour les régions du Québec / Canada Economic Development for Quebec Regions

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01 | Alternative fuels - overview

This study presents an overall picture of alternative marine fuels. With MGO used as the reference fuel, seven alternatives are presented: LNG, LPG, methanol, ammonia, hydrogen and biofuels, which can be divided into two groups: biodiesel (FAME) and renewable diesel (HVO). A general description of each fuel, an overview of prices, an assessment of existing infrastructure (supply, storage system), regulatory aspects, environmental impacts and state of the art were presented in a global context.

The Table 1 summarizes the data for the fuels discussed. Here, the calorific value is presented in terms of both mass and volume. The price per kWh has been added to the price per ton overview. The price of HVO can be considered higher than that of FAME ($US/t). If there exist different types of fuel (green, blue, grey) the prices are always given for the grey alternative. Details for other fuel colours are presented in the main report. Details of well to tank GHG reduction is discussed further in the summary.

Table 1 Summary of properties of alternative fuels presented

Carburant	PCI MJ/kg	PCI MJ/L	Densité [kg/m³] @15ºC 1bar (**0ºC 1 bar)	Emission SO_x [%]	Tier III conformité sans traitement des gaz d'échappement	Emission CO_2 kg_{CO2}/kg carburant (TTP)	Prix $US/t (septembre 2021) (*juillet 2020)	Prix cent/kWh (septembre 2021)
MGO	42,8	36,6	0,86	0,1 – 1,5	non	3,2	675	5,7
GNL	47,1	20,8	0,43	-	selon moteur oui /no	2,75	462	3,4
GPL	45,5	24,4	0,54	-	selon moteur oui /no	3,01	673	5,3
Méthanol	19,9	15,8	0,79	-	non	1,37	439	10,6
FAME	37,1	33,3	0,88	-	non	2,85	1600	15,3
HVO	43,7	34,4	0,78	-	non	3,01	n/d	n/d
Hydrogène**	120	0,01	0.09	-	oui	-	1800*	5,4*
Ammoniac	22,5	15,6	0,62	-	non	-	241	4,6

Batteries, which are not fuels in the strict sense of the term, were also considered, as they are worth mentioning because of the hydroelectricity in Quebec.

02 | Alternative fuels in Quebec

In the second section, the situation of alternative fuels in Quebec and Canada was analyzed. To this end, research has identified the current players in the alternative-fuel industry. Attention was also given to future alternative fuel projects and government funding programs that could support developments. The experiences and opinions of shipowners (CSL, Desgagnés, Fednav) and ports (APM, APTR, APQ) were reported.

2.1 Liquefy natural gas

Natural gas (NG) is produced on a large scale in Canada. Natural gas can be extracted in the conventional way when extracting oil or shale rock by fracturing. Once liquefied, it is called LNG. LNG is available in sufficient quantities in Canada to support some degree of transition to this fuel in the maritime sector. In theory, extraction, transportation (mainly by pipeline) and liquefaction infrastructures are also well developed. The Government of Canada is planning 13 natural gas import/export centres on the West Coast and five on the East Coast. Concessions of 20 to 25 years are planned, including two in Quebec. These two concessions were intended for the GNL Quebec company and the Stolt LNGaz project. As neither of these projects has been implemented, no expansion of the natural gas system in Quebec is expected in the near future. Quebec itself also has natural gas reserves (shale resources) that have been identified but are not currently being extracted.

LNG is available in sufficient quantities in Canada to support some degree of transition to this fuel in the maritime sector.

2.2 Renewable natural gas

Biogas is an alternative to natural gas. Biogas is produced when organic waste is fermented under anaerobic conditions. The resulting gas is called renewable natural gas (RNG). From a technical point of view, it can be used as a NG.

There are a few biorefinery projects that could produce RNG, including two in Varennes (Enerkem and Greenfield Global), since RNG is a fraction by-product of biofuel production via fermentation. Both companies aim to produce biofuels from organic waste. The third project is the La Tuque BELT project, which will produce biofuels from forestry waste. With the projects currently under discussion, renewable natural gas may be available in sufficient quantities to be of interest to the maritime sector. RNG has an even more effective greenhouse gas reduction potential than conventional natural gas. However, no liquefaction facility is planned, which makes it difficult to use as a marine fuel. When liquefied, RNG can replace 100% of LNG, which would be an advantage for all DF-LNG powered vessels.

2.3 Liquefied petroleum gas

The term "liquefied petroleum gas" (LPG) refers to a gas composed of propane, butane or a mixture of both. In most cases, LPG refers to a gas that is primarily propane.

With LPG, CO2 emissions can be reduced by about 15%. This is low compared to other alternative fuels. Availability in Canada is good, but LPG must be transported by rail or road to ports in Quebec. This, combined with the lack of infrastructure, makes LPG unattractive for use in Quebec.

2.4 Hydrogen (grey – blue – green)

In Canada and Quebec, most hydrogen is currently obtained from natural gas and must therefore be classified as grey. One plant in Edmonton produces blue hydrogen for the petroleum industry. This hydrogen also comes from NG, but it is designated as blue because the CO2 released during the process is captured, liquefied and stored underground.

Quebec, a major producer of hydroelectricity, is becoming a key player in the production of green hydrogen via electrolysis of water into hydrogen and oxygen. There is currently a pilot plant for the production of green hydrogen from water at Air Liquide in Bécancour. At the moment, it is unique in the world and provides about eight tons of hydrogen per day. The hydrogen formed is liquefied on site and stored until it is distributed by tanker.

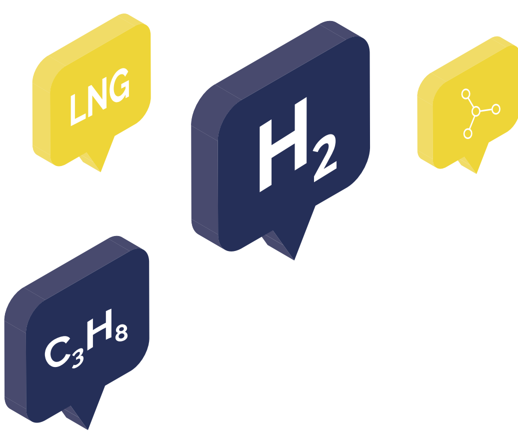
Hydrogen as an energy carrier has great potential in Quebec. It can be obtained by electrolysis, which in turn can be powered by hydroelectricity. A few pilot projects (including a hydrogen filling station) exist, as well as a project for industrial production of green hydrogen by Air Liquide. The TRPA is currently studying various projects to diversify its energy sources to support port operations. Hydrogen is among the options being considered.

Opinions are still divided on whether hydrogen can be an alternative energy source in the maritime sector. It is likely that developments over the next few years will help clarify the potential role of hydrogen in achieving a carbon-neutral target for the maritime sector.

2.5 Methanol (grey – green)

If the source of methanol production is natural gas (synthesis by steam reforming), it is called grey methanol. If the methanol is made from biomass and green hydrogen, it is called green methanol. There is also such a thing as blue methanol. In Canada, production of (grey) methanol largely takes place in Western Canada. There is no methanol production in Quebec, but it is exported from the province by sea. This process relies on infrastructure that is already well established.

Methanol is not a short-term solution as an alternative marine fuel in Quebec. On the one hand, shipowners have not moved toward using methanol, and on the other, green methanol is not yet being produced in Quebec. Furthermore, it has a low calorific potential and is classified toxic as per GHS and classified as D1B in the Canadian WHMIS.



2.6 Ammonia (grey – green)

LCanada produces a large amount of fertilizer. To produce nitrogen fertilizers, ammonia is needed as the starting point for production. Ammonia is produced by converting nitrogen and hydrogen using the Haber-Bosch process. Most of the nitrogen comes from the air. Hydrogen is mainly produced from the reforming of (grey) natural gas, resulting in the production of grey ammonia. Nevertheless, efforts are underway to build green ammonia production plants. Generally speaking, wherever hydrogen is produced, ammonia can also be easily produced.

In the short-to medium-term, ammonia is not seen to be a potential fuel for the maritime sector in Quebec.

One project that applies explicitly to ammonia production is the German company Hy2gen's plan to build a green ammonia plant in Quebec. Work is scheduled to begin in 2022. The location of the plant has not yet been announced.

In the short-to medium-term, ammonia is not seen to be a potential fuel for the maritime sector in Quebec. For one thing, green ammonia is not yet being produced in Quebec or in Canada. In addition, it has a low calorific potential, is classified toxic and harmful for aquatic life in GHS and very toxic as D1A in WHMIS, and has a competing use as a raw material for fertilizer production. As a result of this competition, the price of ammonia is also linked to the agricultural sector and is therefore not always in line with the transport industry.

2.7 Biofuels

Biofuel is a generic term for all fuels made from primary biomass (first generation) or organic waste (second generation), or extracted from biomass produced by micro-organisms (third generation). First-generation fuels are already available in significant quantities. Second-generation biofuels are being commercialized, but in smaller quantities. The main types of biofuels are FAME (biodiesel) and hydro treated vegetable oil (HVO). FAME is a fatty acid methyl ester. HVO, which does not contain esters, is more similar to petroleum diesel.

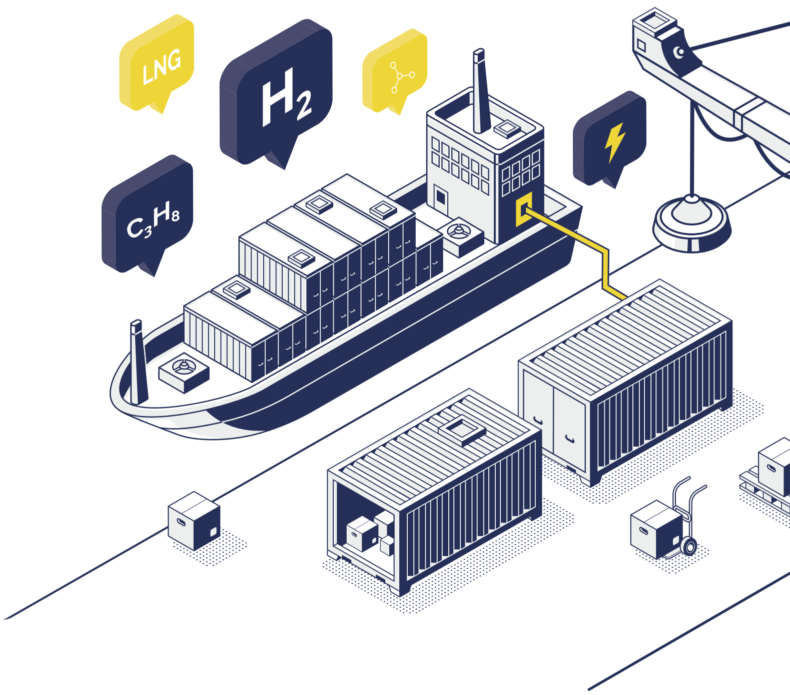
Positive experiences with biodiesel, the large production capacity in Canada and the United States and its potential to reduce greenhouse gases by considering their life-cycles make FAME and HVO a promising alternative for Quebec, particularly in the case of FAME. However, in order for biodiesel to become a fully developed alternative, overall demand will have to increase, and more shipowners will have to use it as a fuel. This would make the establishment of a permanent supply at ports more likely. At the same time, Canadian production of second-generation fuels should be increased with projects such as BELT (in La Tuque). HVO, on the other hand, has many advantages over FAME, as it is indistinguishable from petrochemical diesel (in its chemical structure and calorific value), has a longer storage life and can be used at low temperatures. However, HVO is not yet being produced in Canada and it is more expensive than FAME.

Overall demand will have to increase, and more shipowners will have to use it as a fuel.

2.8 Batteries
Green electricity

"Green electricity" is used here to refer to the use of batteries or fuel cells. In the 2019 federal budget, $130M was set aside over five years to expand infrastructure for zero-emission land vehicles. Marine propulsion technology can also benefit from the progression of land-based electromobility.

The example of Basto Electric, a Norwegian ferry, shows that an all-electric ship can make ecological and economic sense. However, the use of battery-powered vessels depends on a suitable power supply in the port. The quay must have sufficient electrification.



03 | Alternative fuels' potential to reduce GHG, and options for Quebec

In the final part of the study, greenhouse gas emissions are evaluated and life-cycle analyses from the literature are discussed. A multi-criteria analysis is made in order to evaluate the most appropriate alternative fuel for Quebec.

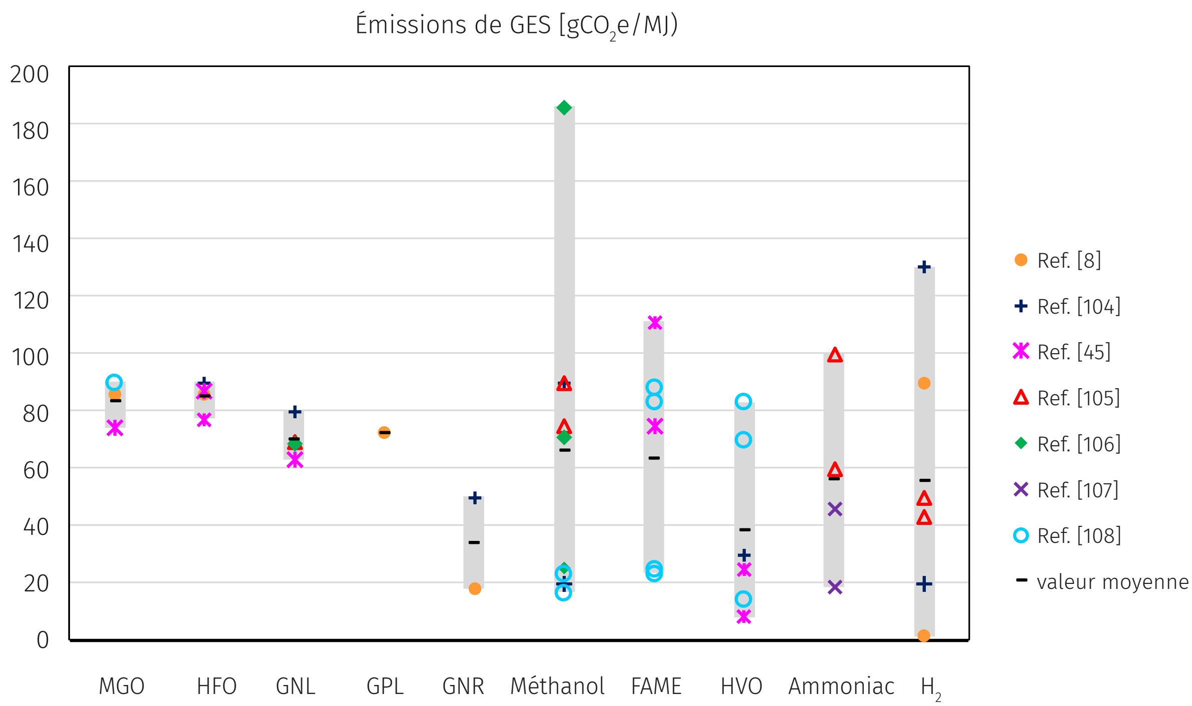
3.1 Life-cycle analysis of alternative fuels

In order to understand the effects of alternative fuels on greenhouse gas emissions, a life-cycle analysis of each is needed. It is necessary to analyze the amount of energy and CO2 produced during raw material production, transport for further processing (at the refinery) and transport to consumers. Emissions produced up to this point are referred to as "well-to-tank" (WTT) emissions. The second block of emissions to be considered is called "tank-to-propeller" (TTP). After this, emissions values depend on the engine, the class of the vessel and the driving profile. To add to this complexity, several models for GHG evaluation are used. This can lead to differences in the emissions values. For example, emissions from the waste cooking oil-based FAME used in one model results in 21.27 gCO2e/MJ, which is seven times higher than for another model, which produces a value of only 2.99 gCO2e/MJ. These differences are due to particularities in the models used (European model or North American model). This further complicates the greenhouse gas issue, especially for the international maritime sector. Does the calculation relate to the vessel's national flag, the country of operation, the fuel used or the country where the fuel was manufactured? This complexity may explain why the IMO only takes into account the calculation of CO2 emissions of the TTP at the moment, and not the "well to propeller" (WTP). This exclusive consideration of TTP means that currently, none of the biofuels can be considered as a real alternative to marine fuels as long as the IMO, or other relevant authorities, point of view does not change.

This further complicates the greenhouse gas issue, especially for the international maritime sector.

An overview of the GHG emission values for each fuel is provided in Graph 1. The values come from different references and consider the whole life cycle (WTP). Hydrogen and ammonia are exceptions: only well-to-tank (WTT) values are given, as it is assumed that no greenhouse gases are produced during their combustion. This may seem unintuitive, but the combustion of hydrogen does not emit GHG and ammoniac can only be used with ERC/SGR installed since the Tier III limit can't be achieved otherwise. The combustion of ammoniac produces nitrogen derived molecules. With this exhaust gas treatment installed, the sources of GHG molecules produced are controlled. Furthermore, only TTP values are listed in the maritime LCA literature used for the study. Literature concerning the WTP LCA for ammoniac could not be found by the author at the moment of writing.

Graph 1 - Overview of the Warming Potential of Individual Fuels



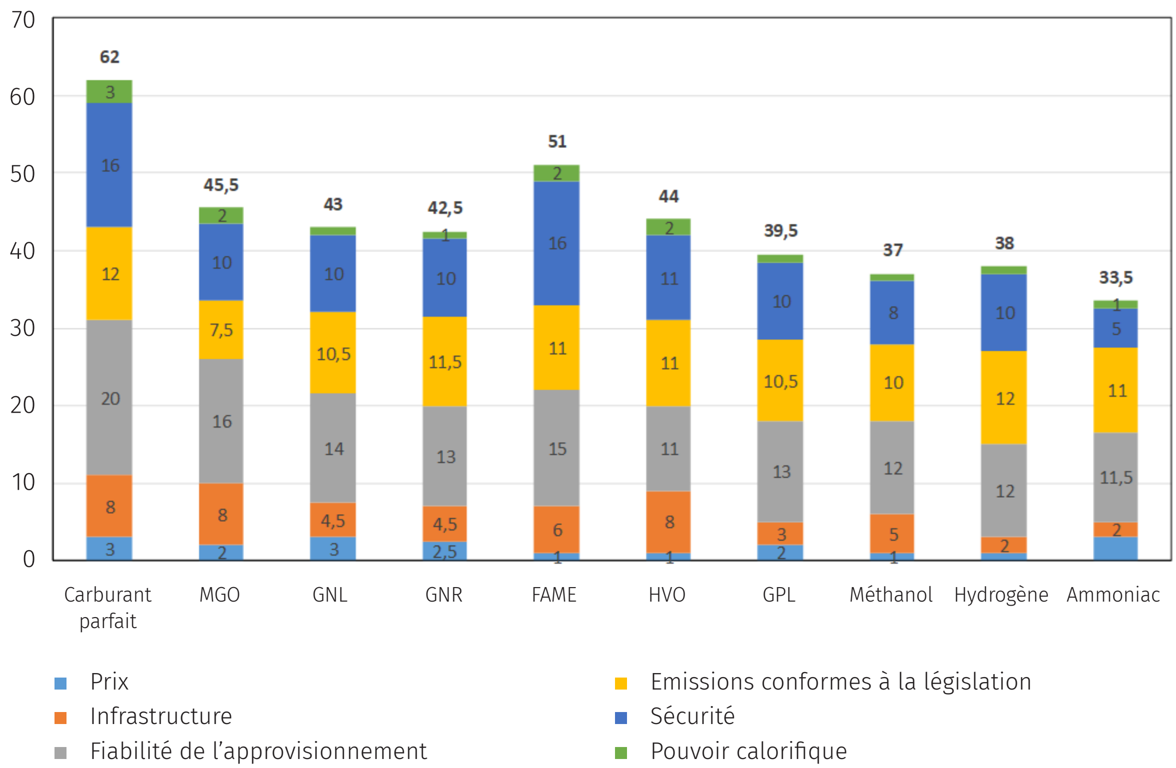
All information refers to the complete life cycle, except for H2 and ammonia data. These take into account well-to-tank only. The data is extracted from the following references and is listed in the full report: [104][45][105][8][106][107][108].

Emissions values for petrochemical fuels vary less than those for alternative fuels. The differences in GHG emissions for renewable fuels (RNG, methanol, FAME, HVO) are largely due to the use of different raw materials, whether first or second generation. Second-generation biofuels generally perform better than the first generation. In the case of ammonia and hydrogen, it is the method of hydrogen production—whether from water or from natural gas—that influences the emissions values.

3.2 Alternative fuels for the maritime sector in Quebec

To assess which fuel is the most promising for the Quebec maritime sector, a multi-criteria approach has been adopted to compare the different fuels. A score is assigned for each criterion. The following criteria have been taken into account: price, available infrastructure, emissions values, safety factors and calorific value. The fuel with the highest score is the most promising alternative for Quebec. In the calculation used, the criteria were not weighted in any way, in order to preserve the objectivity of the study (e.g. price is just as important as safety factors). The "perfect fuel / carburant parfait" shows the maximum score attainable in each category.

Graph 2 - Survey of Alternative Fuels for Quebec



The four winning fuels: LNG, RNG, FAME and HVO

Four alternative fuels received more than 40 points and are therefore close enough to the MGO benchmark to be considered winners.

- LNG, with 43 points, is only 2.5 points below MGO. It is a mature product that has been used as a fuel since 2000. Canada has significant natural gas reserves, which has a positive impact on valuation. LNG is cheaper than MGO in terms of price per kWh.
- The renewable variant of LNG, renewable natural gas (RNG), does almost as well as its petrochemical counterpart, with 42.5 points. To become a real alternative to MGO, its production capacity needs to be expanded so that significant quantities of RNG are available.
- HVO and FAME biodiesel are also among the four most promising candidates. HVO and FAME can replace diesel and therefore MGO in many vessels, almost without modification. The main disadvantage of these fuels is their high price, but is largely compensated with zero CAPEX investment for retrofits. In terms of emissions compliance, FAME and HVO score 11 points out of 12. Of course, this score assumes that the IMO life cycle calculation method is re-evaluated.

LPG evaluation

LPG scores 39.5 points and differs only slightly from LNG. LPG receives fewer points than LNG in the safety of supply and infrastructure category, because almost no production is currently taking place in Quebec. The proportion of LPG-fuelled ships is also very low worldwide; the use of LPG for propulsion is more profitable for LPG carriers.

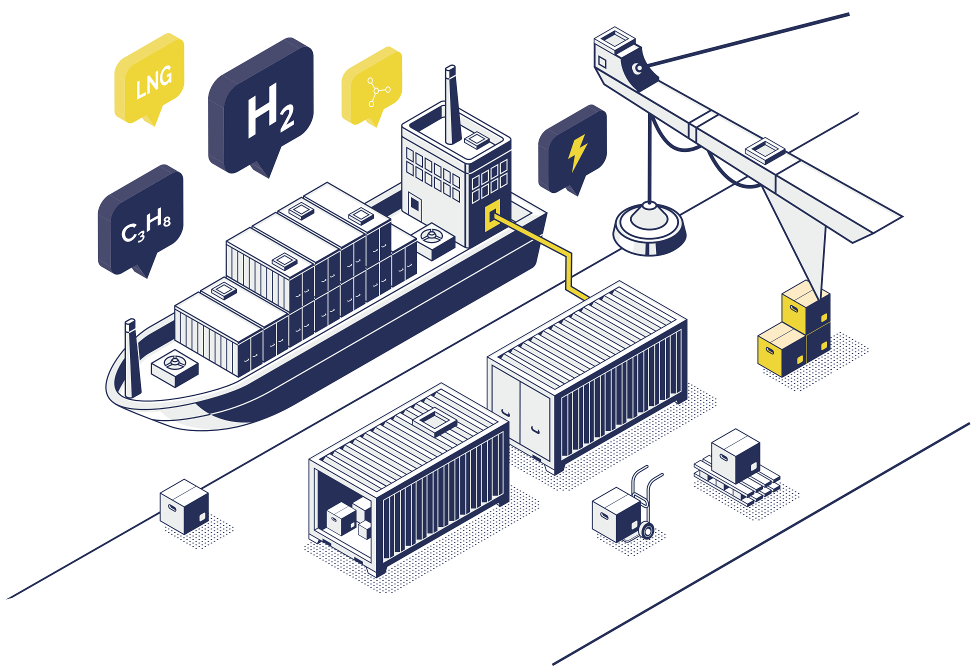
Methanol evaluation

Of all the carbon-based alternative fuels, methanol scores the lowest, with 37 points. There are already ships powered by internal combustion engines using methanol, but their number is limited and reliability results are based on 5 years of experience. Up to date, results are encouraging. Another alternative would be the use of methanol in fuel cells, but this is still far from being technically developed. Methanol availability is very good in Canada, but it is grey methanol. Biorefineries exist for green methanol, but not in Quebec at the moment. Due to its toxicity, special safety measures must be observed for its use and staff must be specially trained. Also, at 15.5 MJ/L, it has less than half the calorific value of MGO and is more expensive in terms of price per kWh. All things considered, methanol is not currently a convincing alternative for Quebec as of today, no green production is active. A reassessment of the situation has to be considered in 3 to 5 years.

Alternative fuels with no GHG emissions: ammonia and hydrogen

The fuel group that currently ranks lowest is ammonia and hydrogen. Both are carbon-free fuels: they burn naturally without emitting CO2 or other GHGs (if ammonia is equipped with an exhaust gas treatment). Both ammonia and hydrogen can be used in fuel cells. At present, it seems that the use of both substances is primarily being developed for combustion engines. Hydrogen ranks behind several other fuels because its volumetric energy density is significantly lower (0.01 MJ/L @ 0°C 1 bar) than that of MGO (36.6 MJ/L @ 15°C 1 bar). Hydrogen is downgraded in terms of technical maturity, both in terms of engine technology and the supply situation. In terms of safety, points have been deducted because hydrogen presents a high risk of explosion so the staff has to be specially trained. The Air Liquide hydrogen plant in Bécancour is a flagship hydrogen project for Quebec. Unfortunately, the quantities generated are not yet sufficient.

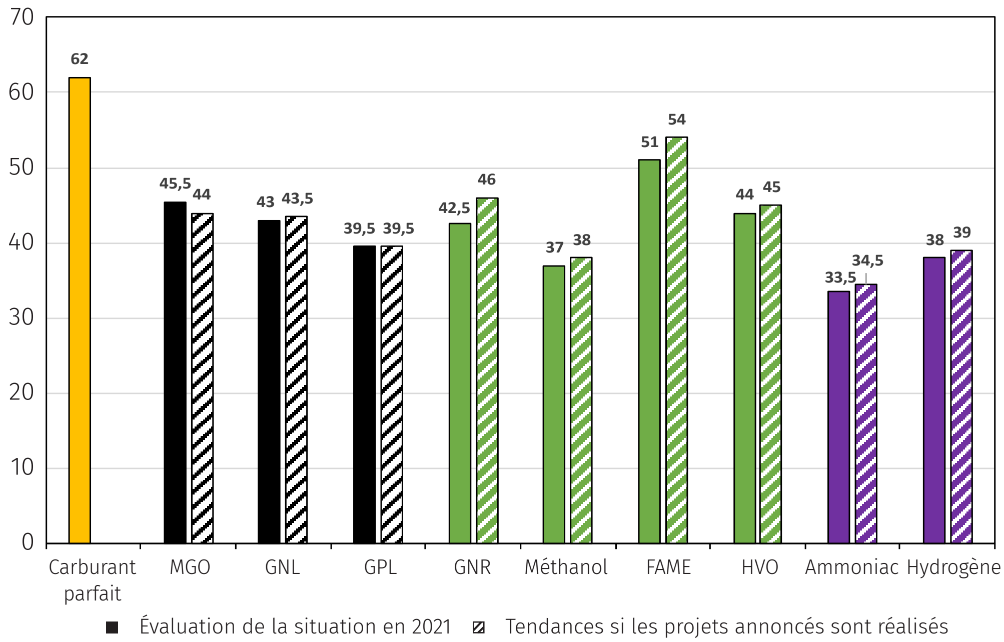
The final fuel to be evaluated is ammonia, which comes last in the ranking with 31.5 points. This low score is explained by its low calorific value of 15.6 MJ/L, a lack of maturity in terms of techniques and the absence of green ammonia production. Where safety is concerned, points were necessarily deducted as ammonia can be fatal for humans; as a result, staff must be specially trained. Ammonia does well in terms of price, as it is cheaper than MGO. Finally, the impact of an ammonia spill raises concerns linked to its high level of toxicity.



Trends for the sector

Before presenting an assessment and a possible solution for Quebec, this section examines availability trends for the various fuels. The unstriped bars in the histogram correspond to those in Graph 2. The striped bars are an evaluation of what would happen if all the alternative fuel projects announced were implemented.

Graph 3 - Alternative Fuel Trends for Quebec



This is a comparison between the situation in September 2021 and the possible situation if all of the alternative fuel projects presented in Section 3 were realized..

Projects have been announced for seven of the eight alternatives presented. Looking at the overall trends, the relative score for each of the fuels does not change much compared to the situation in September 2021. The positive trend toward the use of alternative fuels will depend largely on the implementation of the Hy2gen projects. Hy2gen is involved in the development of four fuels (RNG, methanol, ammonia and green hydrogen). FAME would be advanced by the BELT project in La Tuque.

3.3 Possible avenue for the Quebec maritime sector

To date, it is impossible to predict whether the future will be dominated by a single alternative fuel or whether the maritime sector will opt for a multi-fuel approach. This means that in the short- and medium-term, it makes sense to focus on flexibility, which is possible with dual-fuel engines that can use LNG and biodiesel (and/or HVO). These are two fuels that are already available and for which the technologies are mature. A dual-fuel strategy also allows for quick switching between fuels if one is not available or if the price of one fuel is temporarily too high. There is already practical experience with the use of LNG and biofuel in Quebec. On the other hand, biodiesel production in a biorefinery also produces RNG, which could help reduce the CO2 output of LNG ships. If DF engines cannot be used, biodiesel and renewable diesel is the way to go to replace MGO, at the moment in Quebec. To be noted that biodiesel and renewable diesel also have to be used in DF fuel engines to replace MGO if available.

If DF engines cannot be used, biodiesel and renewable diesel is the way to go to replace MGO, at the moment in Quebec.

- LPG is not a viable option for Quebec.
- Methanol, which occupies the second-to-last place, cannot be considered as an alternative at the moment. The combination of low calorific potential, high price, safety concerns and the lack of green methanol in Quebec all count against the development of this infrastructure for maritime use. A reassessment will have to be made when green methanol becomes available in Quebec.
- The situation is similar for ammonia. Its low calorific value, the lack of infrastructure, its toxicity and the fact that neither green nor grey ammonia is produced in Quebec preclude its consideration as a short-term alternative to fossil fuels.
- Objectively speaking, hydrogen is not currently a strong candidate for an alternative marine fuel. The high price, the lack of infrastructure, the small quantities of green hydrogen production and, above all, its highly explosive potential stand in the way of its development with existing technologies. Considering that Quebec could be a leader in the development of hydrogen, its real potential for the maritime sector should be re-examined in a few years.

In the long-term, it makes sense for Quebec to invest in hydrogen technology. Production of methanol, ammonia, FAME or HVO requires the use of hydrogen. Development efforts for hydrogen will therefore indirectly serve the production of other alternative fuels.

04 | Conclusion

For fuel alternatives for Quebec, the situation is as follows: biodiesel ranks the highest, followed by HVO and LNG. In fourth place is RNG. Biodiesel and LNG are already in use, but the infrastructure used to supply them should be further expanded. In the short- and medium-term, it makes sense to use dual-fuel engines, as they offer the greatest flexibility. LNG can be replaced by RNG, and MGO can be replaced by biodiesel or HVO. Among the fuels requiring further development in terms of motorization for use in the maritime field, hydrogen is the most promising.

Given the availability of hydroelectricity in Quebec, the flagship project in Bécancour and long-term research (at UQTR), it seems logical to invest in this technology. Will hydrogen become the fuel that powers the ships of the future? It is not yet possible to provide a clear answer to this question. However, it is reasonable for Quebec to invest in hydrogen, because whatever the fuel of the future turns out to be, hydrogen will be necessary for its synthesis.

