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Using compressed and liquefied natural gas as a fuel in long-distance road freight transport – opportunities, challenges, and threats from the Polish perspective

The development of road transport, including freight, is inextricably linked with the attempt to find a fuel optimal in terms of costs, distribution, and operation, as well as environmental impact. For decades, the most commonly used fuels have been products of crude oil processing – gasoline and diesel oil. As such, they have powered road transport from the very beginning of their practical use. However, nearly all that time attempts have been made to find other propellants, including electricity and various types of gases. The main aim of this article is to analyze whether in today's Polish reality it is profitable to introduce gas (mainly LNG) as a fuel for long-distance road freight transport. The analysis is based on real data obtained from companies that use LNG trucks in normal road traffic. The data indicate that under certain conditions, especially when the weight of the load does not exceed 70–80% of the nominal load capacity and the roads are largely flat, the use of gas becomes economically viable. Nevertheless, there are still some unknowns related to, i.a., higher operating costs of gas vehicles, which are of great practical importance – for besides environmental considerations, each carrier must also take into account the purely economic aspect of its operations.

Keywords: gas, fuel, long-distance road freight transport

JEL classification: R40, R42

Introduction

For over 100 years, in fact from the very beginning of their practical use, motorized road transport has been based on petroleum refining products – gasoline and diesel oil. However, almost immediately people started looking for an alternative, i.a. in electricity and various types of gases. As a fuel for vehicles, the former are available as natural gas and biogas, and can be either liquefied or compressed (LNG and CNG). For many years, however, the use of gas a fuel in road freight transport was limited by a number of factors, including low power and low torque of gas engines and the relatively short range of gas-powered vehicles. As a result, gas trucks were usually operated in short-haul transport – in distribution or municipal services.

It is only in the last few years that a significant breakthrough has taken place in this area. On the one hand, it was somewhat "forced" by the EU's pro-environmental policy to reduce emissions of harmful substances, including those generated by road transport, which at this stage relates mainly to CO_2. On the other hand, the EU – primarily for strategic and political reasons – wants to be as independent from oil imports as possible. Additionally, transport vehicles that meet the parameters required by customers in key areas, such as performance, range, and weight, must be available on the market. In addition, they must be absolutely profitable in terms of operation compared to their traditional counterparts – they must pass economical muster even without fees and subsidies. In our system, these potential fees and subsidies should only constitute an additional stimulating factor and not the main criterion for choosing the alternative fuel.

This article aims to determine whether with the current condition of the Polish long-distance road freight transport sector it makes sense for the companies operating in it to purchase gas-powered vehicles. Its primary goal is thus to ascertain the profitability of introducing gas as a fuel for long-distance road freight transport in today's Polish reality. This goal is achieved by means of analysis and inference. The analysis is based on the results of official tests carried out in our country by suppliers of gas trucks and takes into account such important factors as the costs of building and operating various types of gas filling stations. It is presented in the main section of the article and complemented by the author's conclusions and assessments.

1. General conditions for introducing gas as a fuel in long-distance road freight transport

When considering the development of a new type of vehicle powered by alternative fuel, the target must be a drive system with low or even no CO_2 emissions [Scania, 2016, p. 22]. Accordingly, battery-electric drive and fuel cell technologies are advanced [Grumbach et al., 2021]. All the more so as vehicle manufacturers and politicians agree on one thing: they want to reduce dependence on oil and, by 2030, cut greenhouse gas emissions by an average of 30% compared to 2005. This is a highly ambitious undertaking; as agreed, long-term reduction goals can only be achieved by developing and using carbon-free or low-carbon fuels, low- or no-CO_2 combustion fuels, and alternative drives. As a result, a multi-faceted approach should be adopted, tailored to the specific areas of application. In such a reality, in which today electric drives are the focus of attention, suppliers will likely increasingly concentrate on such drives in the future, as they are almost ideally suited for distribution and, in part, long-distance transport. Heavy urban distribution transport is a typical initial field of application. In its case, in addition to load capacity and cargo volume, the main requirements concern sustainability and quiet operation. Considering frequent stopping – the number of start-and-stop operations, braking and acceleration – this is also where the advantages of battery-electric drive technology can be fully exploited, as the electric motor can recover energy during the braking phase.

However, it should be emphasized that in the medium term, long-haul transport will still depend on the combustion engine. At the same time, for users, reducing fuel consumption is one of the most effective ways to lower the total cost of ownership and disposal of the fleet and thus to reduce the overall operating costs. The same applies to both large fleets and smaller carriers. Consequently, even the slightest potential savings can significantly impact the overall cost of transport equipment when it comes to fuel economy. Equally important, fuel consumption and CO_2 emissions are linear variables – they are wholly correlated with each other. Therefore, lower fuel consumption automatically means lower emissions. As a result, the more stringent emission limits of the future can only be met by reducing fuel consumption. However, the variety of combinations and areas of application makes it difficult to accurately calculate this consumption for trucks.

In addition, with regard to ecologically clean transport, it should be stressed that the internal combustion engine is not in itself dirty, while alternative power units do not always turn out to be so clean. Transport generates 24% of global energy-related CO_2 emissions, making it a major contributor to anthropogenic climate impacts, and freight trucks account for 25% of those emissions. At the same time, however, between 1965 and 2014, i.e., by the time the Euro 6 exhaust gas cleanliness standard came into force, their fuel consumption per tonne transported was reduced by as much as 60%. A further reduction of CO_2 emissions by 20% required an integrated approach covering the complete vehicle, i.e. the tractor, trailers, and tires, as well as operations, infrastructure, and the process of fleet renewal. With a typical trailer combination, fitting the appropriate tires, improving the aerodynamics of the entire train, and using predictive cruise control should translate into a reduction of fuel consumption and CO_2 emissions by an average of 12–14%. Using extended trains – two heavier and longer vehicles instead of three normal ones – would further increase this value to 17%. Furthermore, an important role is played by driver behavior, i.e., energy-efficient driving that combines the time aspect (shortest possible time) with the cost aspect (lowest possible costs). In addition to driver training, introduction of advanced driver assistance systems also promotes fuel-efficiency. However, the dissemination of autonomous driving encounters a substantial legal obstacle in the form of the Vienna Convention on Road Traffic and EU regulations (specifically ECE R79).

Based on these fundamental considerations, companies develop reasonable offers. Scania's offer is based on the following components: high energy efficiency, alternative fuels and electrification, as well as intelligent (smart) and safe transport [Scania, 2019, p. 12]. For many decades now Scania has been relying heavily on the use of alternative fuels and alternative drive units in road transport, seeking the best solutions. Reality, however, does not make it easy. Unfortunately, thus far there is no optimal substitute for crude oil as a fuel base. The company therefore has to rely on a highly individualized approach that can be described as market by market, user by user, fuel by fuel. Worse still, some proposals it considered turned out to be development dead-ends. Such was the case of, e.g., ethanol and bioethanol.

At the same time, constant technological progress means that some of the previously analyzed alternatives, once marked by a number of key disadvantages, are now slowly starting to present a more sensible solution. This applies primarily to natural gas (CNG or LNG) used as a fuel in road transport. For decades, the main accusations raised against it concerned the following spheres:

- poor performance of gas engines compared to their diesel counterparts (insufficient maximum power output and torque),
- relatively small tank capacity, essentially limiting non-stop range and usefulness (suited at best for domestic distribution and transports),
- relatively space-consuming tanks,
- higher purchase price (although partially or fully compensated over many years of operation, depending on the mileage and the amount of taxes and local fees for specific types of transport, including possible preferential treatment of more environmentally friendly vehicles).

Considering the above, for gas to be used as a fuel in trucks intended for long-distance traffic, the following boundary conditions have to be met:

- engine with sufficient power and torque (over 400 HP and at least 1,700–2,000 Nm),
- mounted tank technology allowing for a non-stop range of at least 1,200–1,500 km (calculated for a road train combination with a total weight of 36–38 t, i.e., up to 80% of weight capacity),
- driving quality indistinguishable from that of classic vehicles (comfort, handling, etc.).

The following key issues remain:

- higher purchasing and operating costs of gas trucks (TCO, TCM, and TOE),
- limited availability of gas refueling stations,
- possible discounts or subsidies for the purchase and use of gas-powered vehicles.

2. Gas as a fuel – a sensible alternative

Now, however, for political, economic, and purely practical reasons, there is a growing interest in gas. First of all, its reserves are more evenly distributed worldwide than those of oil, and unlike them from today's perspective they appear highly future-proof. Taking into account the currently known sources or locations and extraction technologies on the one hand, and the current and future demand on the other, in 50 years oil reserves might be depleted, but there is enough natural gas for up to 250 years. In addition, natural gas consists mainly of methane – it does not emit odors, it does not contaminate soil or water, and its combustion produces fewer particles as well as less nitrogen oxides and carbon dioxide. Although also a fossil fuel, it is therefore much more environmentally friendly than regular diesel. Moreover, unlike crude oil and its alternative substitutes, it can be replaced with renewable biogas, which is a product of the decomposition of organic particles and thus easily obtainable worldwide wherever any organic waste is fermented (although naturally in limited amounts). Generally speaking, agricultural, meat, and paper producers as well as sewage management agencies may act as biogas suppliers.

Biogas and natural gas find the same applications. They can be both used to power vehicles, and they both allow them to run much quieter (72 dB) than their diesel counterparts. But their advantages go beyond all those already mentioned. The most important of them include:

- high consumption substitutability between NG, BG, and a NG/BG mixture,
- wide possibility of use in transport as well as heat, energy, and fuel production,
- availability in both compressed and liquefied forms (NG/BG, CNG/LNG, and CBG/LBG are commonly used acronyms and trademarks),
- safety of gas as a fuel in general[1] and renewability of biogas in particular.

Moreover, the use of biogas is expected to not simply reduce CO_2 emissions, but reduce them by over 100% (surpassing diesel fuel by up to 90%). This excess of 100% is due to the fact that organic waste from agriculture that is subjected to anaerobic digestion in order to produce biogas, would otherwise be used as fertilizer

[1] Noteworthy, a NG/BG explosion can only occur when there is 5–17% of gas in the gas–air mixture; the mixture is too lean if it contains less than 5% of gas and too rich if it contains more than 17% of gas. Moreover, LNG is non-toxic when inhaled (although it poses a risk of suffocation in closed spaces), odorless, and non-flammable as a liquid. To ignite, the liquid must first evaporate and come into contact with fire within the narrow flammability limits of 5–15%. Touching LNG can, however, cause frostbite. Nonetheless, contrary to popular concerns, gas accident rates remain low, and natural gas vehicles are allowed to travel on ferries and through tunnels as well as to transport ADR substances. As for the enclosed spaces of NGV facilities, provided they meet the relevant criteria, first and foremost with regard to proper ventilation, LNG vehicles may use them, but should stay away from areas with fire sources, inflammables, and explosives (no such restrictions are imposed on CNG vehicles).

on farmland, where during decomposition it would emit methane, a greenhouse gas much more harmful than CO_2.

The infrastructure and the means for transporting gas are constantly evolving. The global network for the distribution of compressed gas is well-developed and relatively reliable, and liquefied gas is carried by a fleet of carrier ships owned by countries such as Qatar, Saudi Arabia, and the US, the latter heavily benefiting from the so-called shale revolution.

There are several reasons for increasing the use of LNG/LBG. In the process of liquefaction, it reaches the temperature of –162ºC. As a result, it has higher energy density and occupies seven times less space than an equivalent amount of CNG/CBG, which makes its storage and transport more efficient and extends the non-stop range of vehicles that use it as fuel. A smaller amount of LNG than of CNG is thus enough to reach operating conditions similar to those ensured by conventional fuels and vehicles.

The following considerations further support the use of gas as a fuel [Korus, Dawidczyk, 2019]:

- gas is readily available from transmission pipelines and does not necessarily require liquefaction,
- it would contribute to the diversification of energy sources and their substitutability,
- it has a high methane content (ca. 97.4–99.7%),
- it shows no significant impurities and allows for a high degree of compression,
- its price is not imposed by regulations but established freely in the market, making it possible to buy it cheaply,
- the price of 1 m^3 of gas is consistently 40% lower than the price of 1 l of diesel (hydration cost = PLN 1.20/1 m^3, compression cost = PLN 0.50/1 m^3).

It also generates no additional costs as a result of "excess pressure".

In addition, when it comes specifically to road transport, gas-powered vehicles could easily replace diesel-powered units and use the network of existing refueling stations, without the need for any changes in the logistics process.

The interest of European – mainly Western-European – consumers in gas-powered passenger cars and freight vehicles, including long-distance ones, is growing at a pace that encourages investments from truck suppliers. At the same time, methane fuel, including biogas, which is regarded as the fuel of the future, is also rapidly gaining popularity and is already prevalent in several markets, most notably in Italy, Germany, Norway, Sweden, and France. This is due to its greater availability, constantly developed infrastructure, and accessible cost of ownership of methane-powered vehicles.

It is now possible to propose a basic vision of a sustainable strategy for gas-based transport [Korus, Dawidczyk, 2019], This strategy rests on the following pillars:

- as the fuel of the future, gas serves as a bridge between today's needs and future technology,
- using gas allows to reduce CO_2 emissions by 15–90%, NO_x by 40–60%, and PM by 95%,
- gas engine technology limits noise pollution,
- gas fuel system is easily installed in vehicles with a permissible total weight above 18 t,
- basing transport on gas does not necessitate a change in goods distribution.

Until now, most gas engines were not powerful enough or gas-powered vehicles had insufficient range to be useful in heavy-duty transport, but this vital barrier is slowly disappearing. Since 2016, Scania, Volvo, and IVECO have made available gas trucks with engines achieving over 400 HP and 1,700–2,000 Nm or even more. Everything indicates that gas engines will lead to breakthroughs in long-haul transport and the construction industry. Since consumers are no longer faced with inadequate engine power or discomfort, the development of refueling infrastructure in several European countries is accompanied by a growing willingness to use gas in transport, informed also by issues of sustainable development. With that in mind, driving support systems have been introduced to improve engine efficiency. These include, first and foremost, advanced gear shifting systems, adaptive cruise control, and free rolling functions, which allow to lower fuel consumption by up to 10%.

3. Polish conditions for introducing gas as a fuel

Our country has recently started to see more initiatives aimed at popularizing gas production and electromobility, which are being undertaken in response to EU and internal regulations [Brach, 2020, pp. 39–43]. Those are:

- EU low-emission law,
- Act of 11 January 2018 on electromobility and alternative fuels, which deals with, i.a., the use of natural gas as a fuel in transport,
- Regulation of the Minister of Infrastructure and Construction of 11 December 2017, which states that in the case of a vehicle powered by alternative fuel, the permissible total weight may be increased by an "ecological weight" of up to 1,000 kg.

Other provisions of the Polish law favoring alternative low-emission fuels, concern, e.g., lower taxes on gas, better availability of refueling stations, various privileges for low-emission vehicles, aid funds for purchase subsidies, and reduced road tolls. Additional benefits of driving low-emission vehicles include the use of a bus lane, free parking spaces, entry to zero-emission zones, reduced road tax, and exemption from excise duty.

EU low-emission law comprises several executive acts, chief of which sets an obligation to reduce CO_2 emissions in all sectors of the economy, including transport, in order to stop the rise of global temperature as a result of anthropogenic greenhouse effect. Excluding the issues surrounding the derogation situation, particular ministries have a responsibility to ensure that these executive regulations are reflected in the domestic legal order of the member states. To help with that, of particular importance are the bills on:

- excise duty on LNG and CNG fuel,
- subsidies for the purchase of low- and zero-emission vehicles,
- subsidies for the construction of refueling and charging stations,
- targeted loans from the low-carbon fund.

An example of the implementation of EU low-emission law is the already mentioned electromobility act, which sets targets for the public vehicle fleet (10% green by 2021, 20% by 2023, and 30% by 2025). Taking any steps to meet these specific and other more general objectives in the area of transport requires to first choose which gas variant to introduce. This decision must take into account related important economic and operational factors. Particularly, it must allow to maximally optimize the efficiency of vehicles. This can be achieved by:

- tailoring every solution to the individual client based on a thorough interview about the intended use of the vehicle,
- providing detailed technical advice with regard to each solution, including its strengths and weaknesses,
- carefully explaining the rules of use.

Undertaking these measures should ensure higher TCO, lower TOE, and maximized use of vehicles in the logistics process, thus boosting their overall cost-effectiveness. Ecological considerations, such as the level of CO_2 emissions, also play a significant role; however, no project to implement more environmentally friendly means of transport will be successful if their exploitation does not prove economically viable – altruism alone will not inspire sufficient investments.

4. Operating costs of gas-powered vehicles in long-distance road transport

In 2019, Scania Polska conducted a series of tests to determine the advisability of introducing gas-powered trucks in long-distance road transport [Korus, Dawidczyk, 2019; Brach, 2020]. The unit they used was a 2-axle LNG tractor equipped with an extended cab with a raised roof and powered by a gas engine with a maximum power of 410 HP and torque of 2,000 Nm. The idea was to prove the profitability of purchasing and using CNG- and LNG-powered trucks despite their much higher purchase price as well as higher costs of maintenance (as a result of, i.a., reduction of service intervals to 45,000 km, compared to 60,000 km for diesel), financing, and insurance (see Table 1). For LNG units, another disadvantage is the assumed 10-year period of physical depreciation (compared to 12–14 years for CNG and diesel). Cost-efficiency is also affected by factors such as tank supervision requirements (every year for LNG, every three years for CNG, and a pressure test every ten years), the boil-off rate of LNG, refueling, and licenses (noteworthy, all necessary licenses and certifications are issued at Scania's service stations).

Table 1. Costs associated with the purchase and use of a gas truck compared to a diesel counterpart

Costs	CNG / LNG
vehicle price	EUR +18,000 / EUR +30,000
service costs	+25% / +40%
financing costs	+20% / +35%
insurance costs	+10% / +15%
fuel price	PLN –2.66 (–40%) / PLN –2.80 (–40%)
eco-costs	–? / –?
Maut toll	EUR 0.187/km

Source: [Korus, Dawidczyk, 2019].

The main components of a CNG installation kit are a two-stage pressure reducer, a gas filter, gas tanks, manual valves, and solenoid valves. Depending on the wheelbase, different tanks are available (8 × 80 l, 8 × 95 l, and 8 × 118 l). Vehicle range with a 118 l tank is assessed based on CNG mass at a pressure of 200 bar (0.126 kg/l), total tank capacity (8 × 118 l = 944 l), and average gas consumption (22 kg/100 km). This allows to calculate gas weight (944 l × 0.126 kg/l = ~120 kg), and finally theoretical range (120 kg / 22 kg × 100 km = ~540 km). In practice, range will depend on actual gas consumption (e.g. ~667 km for 18 kg/100 km or 480 km for 25 kg/100 km).

The basic components of a LNG installation kit are a tank, a pressure reducer, a pressure gauge, electric valves, a venting system, and a gas filter with a separator. Depending on the wheelbase, different vehicle-mounted tanks are available for the tractor (406 l and 352 l) and for the chassis (406 l, 550 l, 406 l + 352 l, and 550 l + 550 l). Vehicle range for the tractor is assessed based on LNG mass at the pressure of 10 bar (0.45 kg/l), real tank capacity (454 l + 386 l = 840 l), and average gas consumption (22 kg/100 km). This allows to calculate gas weight (840 l × 0.45 kg/l

= 378 kg), and finally theoretical range (378 kg / 22 kg × 100 km = ~1,720 km). For the chassis, given its tank capacity (550 l + 550 l = 1,100 l) and gas weight (1,100 l × 0.45 kg/l = 495 kg), theoretical range can be similarly calculated (495 kg / 22 kg × 100 km = ~2,250 km). In practice, however, tractor range and chassis range are considerably lower (1,200 km and 1,500 km), but can be improved with more efficient gas consumption (e.g. 1,890 km for 20 kg/100 km in the case of the tractor).

During the tests, the reference vehicle traveled 18,171 km at an average speed of 65 km/h. The total weight of the road train combination was 28 t, and average fuel consumption 22 kg/100 km (Table 2).

Table 2. LNG tractor test results

Start date	Distance covered (km)	Average fuel consumption (kg/100 km)	Average weight (t)	Average speed (km/h)
15 July 2019	3,303	21.7	24	60
1 August 2019	5,303	24.0	31	61
28 September 2018	5,670	21.6	30	68
7 October 2019	3,895	20.8	27	69
Total	18,171	22.0	28	65

Source: [Korus, Dawidczyk, 2019].

Based on the above results and assuming annual mileage of 120,000 km and gas consumption of 22 kg/100 km, Scania expects that the CNG variant will pay for itself within 4 years, and the LNG variant within just 2.7 years. After that, the overall operating costs will be no different for a gas fleet than for a diesel fleet.

An important factor in the analysis are the costs of acquiring or building a gas station. A slow-refueling 750 m^3 CNG station for four trucks and two delivery vans is an expense of PLN 150,000–180,000 (all in 2019–2020 prices). A quick-refueling CNG station for ten trucks refuels two trucks per hour, but costs PLN 500,000. A 45 m^3 LNG station with a cylinder without a cooling system and with a cryogenic pump outside the main tank requires an expenditure of PLN 0.98–1.26 million, and a cylinder with a cooling system and a pump in the cylinder takes it up to PLN 2.6 million. A 80 m^3 C-LNG station with a cylinder with a cooling system, two distributors, and a CNG gas vapor recovery system costs up to PLN 3.8 million. Servicing a fleet of 50 vehicles therefore requires an investment of PLN 2.5–4 million.

Conclusions

At this stage of development of the automotive industry, when the electrification of heavy commercial vehicles still poses many problems, gas is a good, relatively widely available, and environmentally friendly alternative solution. Gas extraction, distribution, and application are based on well-established technologies. Gas-powered engines already have parameters sufficient to power heavy-duty trucks used in long-distance transport, and what is equally important, are ecologically, operationally, and economically viable.

Even correcting for potentially biased interpretation of the data presented above and multiplying the result by 150%, the period needed to recuperate the investment is no longer than 6 years – which is the *de facto* minimum lifespan of a truck in westward long-distance traffic. And today, especially with Western European countries introducing numerous incentives for using gas-powered vehicles (e.g. German Maut toll), this period could be extended to 8–10 years. Given their improving availability, also in Poland, this will bring on a rise in the popularity of gas trucks in long-distance freight transport.

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