Study of the feasibility of measuring vehicular Compressed Natural Gas (CNG) in Brazil by Gasoline Liter Equivalent (GLE) or Ethanol Liter Equivalent (ELE)

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Abstract. The natural gas used in Brazil is formed by a chain of hydrocarbons, mainly methane, in addition to gases in smaller proportions, such as ethane, propane, carbon dioxide, and nitrogen. It is a fossil fuel discovered in porous rocks derived from the organic matter of prehistoric animals and plants. The US calls natural gas shale gas. Its origin is from fossil residues identified in rocks with reduced porosity and permeability. The shale gas extraction method differs from the NG obtained in Brazil. CNG is measured in Brazil in volume (m^3) and the US in Gallons of Gasoline Equivalent (GEG). The study points out measurement inconsistencies of CNG per volume (m^3) and mathematics relates the amount paid in Reais for 1 m^3 of CNG, in mass (kg), Gasoline Liter Equivalent (GLE), and Ethanol Liter Equivalent (ELE). Studies present an unreliable CNG measure in GLE or ELE and volume (m^3) and recommend measuring CNG in mass (kg), in Brazil.

1. Introduction

1.1 Importance of natural gas in Brazil.

Natural gas is formed from a chain of hydrocarbons, mainly methane (CH_4) which represents 68% in volume percentage, in addition to other gases in smaller proportions such as ethane, propane, butane, and other elements such as carbon dioxide (CO_2), nitrogen (N_2) and oxygen (O_2) [1]. It is a fossil fuel found in porous rocks from the degradation of organic matter from prehistoric animals and plants [2].

Natural gas supplies 24.4 % of the world's primary energy consumption. This source has a variety of applications, being used in industrial processes, electricity generation, and the commercial, residential, and automotive sectors. In addition, it has recognized value as a raw material for various industrial sectors, including the chemical, petrochemical, and steel industries.

The natural gas chain structure is an integrated network, firstly for oil and gas production, which includes outflow/transfer and gas processing (upstream); in second place by transport (midstream); and finally for energy distribution to the final consumer (downstream).

From an environmental point of view, the use of natural gas has stood out in the global market, as it is a low-carbon energy source, especially considering the energy transition scenario. In this context, the exploration and production of natural gas in Brazil complement primary energy sources. But, as it is associated with oil, there are still challenges to disseminating it, considering the context of natural gas abundance from the Brazilian Pre-Salt [3].

The gas industry developed regionally based on the possibility of pipeline transport and a local market. However, this scenario has been changing radically since the beginning of this century. The insertion of natural gas liquefaction and regasification technology made long-distance trade possible, allowing for the development of new markets and a significant increase in the interregional volume traded. Interregional pipeline trade has grown by 31 % in the last two decades, while Liquefied Natural Gas (LNG) has increased by 3.7 times [3].

In Brazil, oil and natural gas production on land began in the early 1940s, gradually migrating to the sea from shallow waters to deep and ultra-deep waters. Along this path, gas production, generally associated with oil, is located mainly on the Fluminense continental shelf. Initially, this growth was due to the development of production in the Campos Basin (mainly from the 1980s onwards), forcing changes in the Brazilian regulatory framework and boosting the formulation of public policies to insert gas into the country's energy matrix [3].

Thus, it was possible to see an industry expansion panorama, which conditioned the growth of gas transport and distribution activities, the development of different demands for this energy source, and its increasing insertion in the national energy matrix [3].

More recently, the discovery of the immense potential for oil and natural gas in the pre-salt layer led to the development of this new province in Rio de Janeiro and to press for the expansion of the gas sector [3].

Figure 1 shows that in the first half of 2022, the country produced an average of 135 MM m^3/day of gas, a jump of 205 % compared to the 66 MM m^3/day recorded in 2011.

However, this significant production growth did not result in a similar increase in supply to the domestic market nor the elimination of imports. Although the higher gas production in 2022 was not enough for the national consumption, logistical issues prevented much of the local gas from reaching the final consumer, forcing re-injections and imports, which resulted in the approximate amount of 66 MM m^3/day and 28 MM m^3/day, respectively [3].

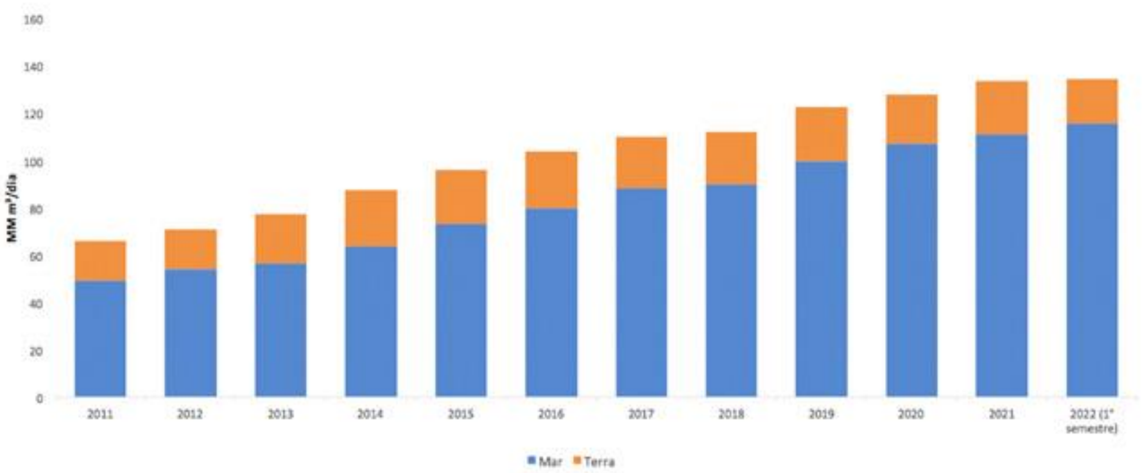

Figure 1: Natural Gas Productions 2011-2022.
Source: FUNDAÇÃO GETÚLIO VARGAS. Gás Natural: uma nova fase institucional, regulatória e econômica. 2023. *Cadernos FGV Energia*, 9, nº 19.
Agência Nacional de Petróleo (ANP) databases 2022.

Vehicular natural gas is a gaseous blend derived from natural gas or biogas, intended for vehicle use and whose main component is methane. CNG (Compressed Natural Gas) is for vehicle use, and Brazil consumed 6.2 million m^3/day of CNG in 2019. The country has a fleet of 41.2 million light vehicles [4], and only 1.6 million of them use CNG as fuel [5]. Therefore, there is a good margin for growth for natural gas to advance in this market.

Below is an infographic (Figure 2) on the economic competitiveness of CNG compared to gasoline and ethanol. It is possible to notice some parameters: the energy potential of CNG is superior to gasoline and alcohol, the cost per Megajoule is lower when compared to the other two fuels, higher performance in the city, lower price per kilometer, and a slight difference in engine efficiency. The Siena model from Fiat 1.4 Tetra Fuel engine performance was better using CNG than the other three types of fuels. CNG covered 14 km/L, 43.6 % less than gasoline, 40.5 % less than ethanol, and a lower cost per 100.00 km (R$ 24,928.57) [6].

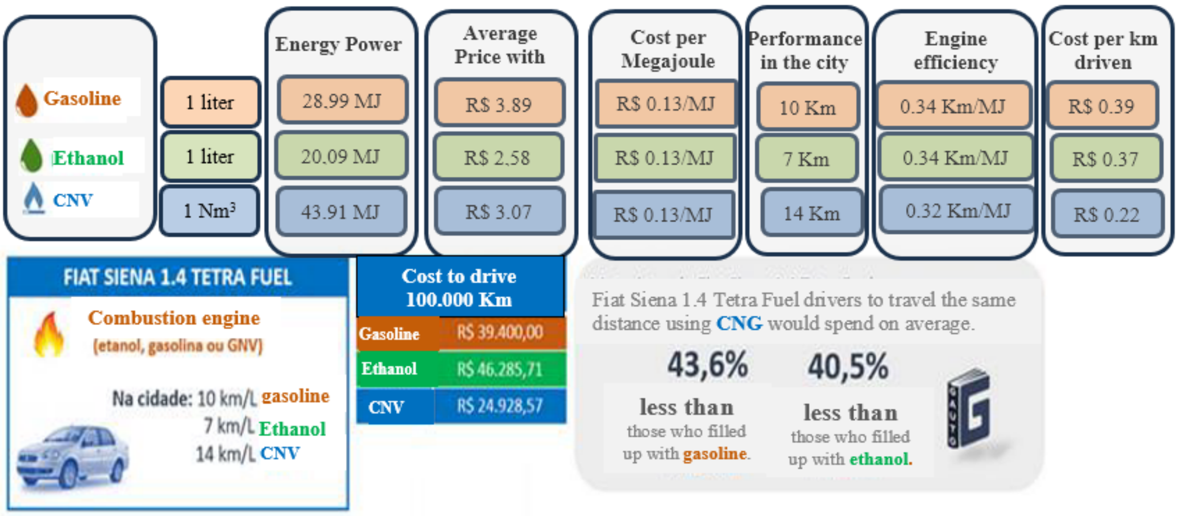

Figure 2: Economic competitiveness of CNV compared to gasoline and ethanol.
Adapted from: FUNDAÇÃO GETÚLIO VARGAS. Gás Natural: uma nova fase institucional, regulatória e econômica. 2023. *Cadernos FGV Energia*, **9**, nº 19.

1.2 CNG Legislation in Brazil

Ordinance nº 32 presented some gaps and could not be satisfactorily implemented, such as the absence of approved models, although their obligation in the Metrological Technical Regulation (MTR). Some demands of the Brazilian Legal Metrology and Quality Network - Inmetro (RBMLQ-I) did not meet, such as the differences in supply pressure in the CNG measurement systems presented at the fuel pumps, as well as complaints from consumers who noticed that the volume of gas registered by dispenser was more than the total tank capacity declared by the vehicle manufacturer.

After several frustrated attempts to correct regulatory legislation, Inmetro elaborated Ordinance nº 498/2021 in 2021, consolidating compliance with decree 10.139/2019, which "Provides for the revision and consolidation of normative acts below the decree." Besides the same issues that remained pointed out and the exclusion of dispensary model mandatory approval, this last ordinance is nothing more than the same previous one with a new date. Only two items were included: (1) the requirement of a plate on the body of the dispenser informing specific mass of the previous month - this information originating from the gas concessionaire - and (2) updating the Maximum Permitted Error (E) to 2%.

The lack of confidence in CNG measurement has causes and consequences that Regulatory Impact Analysis (RIA) studied to solve it. The problem causes are: (1) Ordinance nº 498 of 2021: (a) lack of approval model, (b) lack of initial verification standardization, (c) lack of subsequent verification standardization; (2) CNG measurement dependent on variables; and (3) sector resistance.

The consequences are: (1) Dispenser scrapped, (2) Potentially aggrieved consumers, (3) Possibility of unpaid taxes and (4) Difficulty tracking results and mass balance.

According to the AIR study, among the correction alternatives for the unreliability in the CNG measurement, the change in the measurement of volume (m^3) to mass (kg) would be a very adequate solution for the independence of the variables that fluctuate as temperature, volume and pressure. Measurement in volume (m^3) is extremely dependent on these variables, which causes errors in measuring CNG during fueling. For that, there is a big confrontation with the owners of gas stations since, apparently, the value in currency in mass (kg) for CNG would be higher than the value in currency in volume (m^3) for CNG. Although this had already been exhaustively discussed in face-to-face meetings in previous years with this sector, it was not possible to convince them of the opposite. There was a suggestion to measure CNG in Gasoline Liter Equivalent (GLE) or Ethanol Liter Equivalent (ELE).

In the US the CNG measurement is performed in GLE or ELE. This article proposes a feasibility study of adopting the same procedure in Brazil and compares both results of measurements in volume (m^3) and mass (kg).

2. Methodology

The proposed methodology was to use the same parameters for the calculations adopted in the United States of America (USA). Although the origin of the gas in both countries is different, the calculations were carried out identically, using CNG data in Brazil. To do this, consult: calorific value (kcal/kg), specific mass (kg/m^3) and dry natural gas (kcal/kg). This data was extracted directly from the website of the National Petroleum Agency (ANP) and Naturgy (gas concessionaire in Rio de Janeiro).

Initially, it was explained how natural gas measurements were carried out in the USA and the choice of Gasoline Liter Equivalent (GLE) or Ethanol Liter Equivalent (ELE). Next, how the process was carried out in Brazil.

The second step was to compare the values charged for CNG in Brazil in GLE, ELE, volume (m^3) and mass (kg).

This methodology proposes to adopt United States of America (USA) parameters for the calculations. Although the gas origin is different in both countries, the calculations were carried out identically, using CNG data in Brazil, by consulting: calorific value (kcal/kg), specific mass (kg/m^3) and dry natural gas (kcal/kg). Those data were found on the websites of National Petroleum Agency (ANP) and Naturgy (gas concessionaire in Rio de Janeiro).

Initially, it was explained how natural gas measurements were carried out in the USA and why they chose GLE or ELE calculations. Then, it is presented how the process was carried out in Brazil.

The second step was comparing which measurements could be paid for CNG in Brazil in GLE, ELE, volume (m^3) and mass (kg).

In 1993 in the United States of America (USA), the National Conference on Weights and Measures (NCWM) and the Compressed Natural Gas (CNG) Working Group met to determine how to sell CNG to the retail public as motor fuel. The working group focused on three issues: (1) How to provide the natural gas vehicle industry with a method that sells and is familiar and acceptable to consumers; (2) How to provide official weights and measures bodies with a verifiable and quantifiable means to accurately determine natural gas dispensers; (3) How to meet these requirements with a uniform standard.

The NCWM considered three proposals for the method of selling CNG: (1) Joules: unit of measurement of energy in SI units; (2) Mass; (3) The Gasoline Gallon Equivalent (GGE).

For the USA, the Natural Gas Vehicle Coalition America has recommended the adoption of Gasoline Gallon Equivalent (GGE) as the selling method for CNG based on the energy equivalent of a gallon of gasoline. GGE was mainly recommended for the convenience of the retail customer, comparing the cost and fuel economy of a CNG vehicle with a gasoline vehicle [7].

During the discussion, it was proposed to eliminate the reference to the energy content of CNG and replace it with a fixed conversion factor based on mass, with the fixed mass of CNG equal to one gallon of gasoline. Measuring mass at the retail outlet and checking weights and measures by employees is easier and less expensive than measuring energy content. The energy content of a unit of measurement of CNG and gasoline varies widely depending on the measured fuel sample. As the energy content of a unit of measurement of CNG (standard cubic foot) and gasoline (gallon) change widely, the reference gasoline gallon was determined to be indolene (standard vehicle test fuel), gasoline used to certify emissions and fuel economy with an energy content (lowest calorific value) of 114.118 BTU/gal. About 6,811 CNG samples were surveyed by the Gas Technology Institute across the US, and it was concluded that “average” natural gas has an energy content (lower calorific value) of 923.7 BTU/ft^3 and density of 0.0458172 lbs/ft^3. That's 20,160,551 BTU/gal of natural gas. The ratio between the energy content of 114,118 BTU/gal and the value of 20,160,551 BTU/gal of natural gas results in the value of 5,660 lbs of natural gas = 1 GGE. Similar calculations determine that 1 GLE is equivalent to 0.678 kg of natural gas [7].

In July 1994, the NCWM adopted the following resolutions: “Every natural gas held, offered, or displayed for sale or retailed as fuel, must be expressed in GGE or GLE. All retail CNG dispensers must present a permanently and visibly affixed label with a conversion factor in kilograms or pounds to the face of the dispenser written 1 Gasoline Liter Equivalent (GLE) 0.678 kg of CNG or 1 Gasoline Gallon Equivalent (GGE) equals 5660 pounds of CNG” according to the sales method used.[7].

The measurement result must be displayed or printed in mass units indicating volume or other quantities when applicable in System International (SI) units. In the case of national regulations of a specific country or state requiring units of measurement not included in the SI, it should be considered acceptable only for indications in a proper area [8].

In Brazil, the ordinance nº 32 of 1997, the Technical Metrological Regulation (RTM), makes the CNG measurement unit a choice: direct measurement in mass (kg) or direct/indirect measurement in volume (m^3). Consolidated Ordinance nº 498 of 2021 follows the same line as the previous Ordinance [9] [10]. Despite the dispensers being able to measure both magnitudes, Brazil chose volume measurement like Argentina, a pioneer in selling CNG in South America. However, the volume measurement brings some inconsistencies, such as the variation of parameters such as temperature, specific mass and pressure, which are floating variables, resulting in unreliability in the measurement of CNG to the final consumer. To avoid problems with the reliability of CNG measurement, *Organisation Internationale de Métrologie Légale* (OIML) recommends measuring and selling CNG in mass (kg) [8].

In the volume measurement operation in the transfer of custody in Brazil, when the Brazilian state-owned company, explorer and producer of natural gas sells to the concessionaire, the gas is traded and sold in energy. For that, it is necessary to install equipment such as a flow computer, gas chromatograph in line, and instruments that measure temperature, specific mass, and pressure in the city gate. From the data obtained, the volume of gas is measured and sold in Megajoules (MJ). After that, it is possible to start three more conversions in the CNG measurement. The concessionaire sells to gas stations in volume (m^3) or the producer sells gas to the concessionaire in energy (MJ), which the concessionaire converts into m^3. At this stage, the concessionaire must measure instruments that help correct the parameters that define the volume being sold, such as a flow computer, thermometer, pressure gauge, densimeter, and volume corrector. Therefore, the value in volume (m^3) is converted into mass (kg) by the dispenser, performing a third conversion. Then, this value in mass (kg) is converted back into volume (m^3) for sale to the final consumer performing the fourth conversion. Studies carried out previously (2019) noticed losses during this process that can reach 22 %, making the consumer extremely vulnerable and unreliable in measuring during supply [11] [14].

Table 1: Comparison table between Type C gasoline, hydrated alcohol, GLE, ELE, natural gas and values in Reais (R$).

	Gasoline C	Hydrated ethanol	Natural Gas
Lower Calorific Value (ANP)	9400 kcal/kg	6300 kcal/kg	-
Density (ANP)	754.3 kg/m^3	809 kg/m^3	-
Dry natural gas (ANP)	-	-	8800 kcal/kg
Density (Naturgy – obtained in the field)	-	-	0.7592 kg/m^3
1 GLE	0,806 kg of natural gas	-	-
1 ELE	-	0,579 kg of natural gas	-
Gas price (m^3) (ANP April 2023)	-	-	R$ 4.48
Gas price (kg)	-	-	R$ 5.82
Estimated price (LGE)	R$ 3.37	-	-
Estimated price (LEE)	-	R$ 4.69	-

3. Discussion

As shown in Table 1, the GLE value calculated for CNG from the USA (1 GLE = 0.678 kg) and the GLE value calculated for CNG from Brazil (1 LGE = 0.806 kg). This can be explained by several aspects: (1) The origin of the gas produced in both countries. The natural gas produced in the USA comes from a completely different source than the gas produced in Brazil. Natural gas is shale gas in the USA, a fossil residue found in rocks with reduced permeability and porosity, extracted from shale deposits, and which was responsible for leveraging natural gas production, giving the country the possibility of reformulating its energy matrix [12]. Shale gas is an unconventional gas, not associated with pockets of gas stored from the oil layer, and is a confined and tight gas, with methane associated with coal layers. Its exploitation differs from the traditional natural gas. Directional drilling with hydraulic fracturing of the shale present in the subsoil is necessary, releasing the generated gas. These holes can be vertical and horizontal to break through the rock layer and release shale gas. In addition to its complex exploitation, shale gas generates several environmental risks, such as groundwater pollution, great water use, and methane release into the atmosphere. Hydraulic fracturing (fracking) involves a mixture of water, chemical additives, and sand to prevent the fractures caused from closing [13]. (2) The USA resolves to eliminate the measure of CNG in energy (BTU) and replace it with a fixed conversion factor based on mass. This fixed mass of CNG would be equal to 1 gasoline of gallon. As the physical-chemical parameters of the gas fluctuated, they decided to establish an indolene sample, which, after exhaustive research, would represent the lowest calorific value of shale gas.

Establishing a comparison of volume magnitude (m^3) for GLE or ELE would not solve the question of obtaining reliability in the CNG measurement since confronting natural gas from the USA with natural gas from Brazil would incur the same errors. In other words, the oscillating physical-chemical parameters in volume measurement (m^3) that already exist today would expand even more since the physical-chemical parameters of USA gas also vary. Additionally, the US uses an indolene sample for this conversion calculation. Therefore, using the same factor to calculate CNG in GLE or ELE in Brazil is not possible. The values presented in Table 1 do not reflect the veracity of the conversion performed in the USA compared to Brazil.

It is possible to see that the price of CNG in mass (kg) is higher than that obtained in volume (m^3) since 1 kg of CNG is 30 % more in mass (kg) than in volume (m^3), which means that 1 kg = 1.3 m^3. It is a safe conversion and points to a precise converting system from volume to mass, eliminating potential oscillations in physical-chemical parameters since mass (kg) does not vary with temperature, pressure, or specific density.

4. Conclusion

According to the results presented, the feasibility of measuring CNG in GLE or ELE is as unfeasible as it is today to measure CNG in volume (m^3). Such a measurement would incur the same errors already practiced today, better saying, the variation of physical-chemical parameters such as pressure, temperature, and specific mass, which would not solve the problem of unreliability in measuring CNG. Undoubtedly changing the CNG measurement quantity from volume (m^3) to mass (kg) would definitively resolve these issues and would considerably increase reliability for the end consumer.

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