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Comparison and assessment of using Liquefied Petroleum Gas as a Transportation Fuel

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Abstract -Liquefied petroleum gas (LPG) is used for a variety of purposes around the world, including cooking, heating, energy production, and transportation. It is mostly produced by refining crude oil and processing natural gas. Light hydrocarbon molecules, mostly propane and butane, form LPG in different proportions depending on location and source. LPG is not a greenhouse gas (GHG) in its natural state, and the fumes are non-toxic. It can be kept and transported as a liquid in basic steel containers due to the low vapor pressure. It can be stored and transported in basic steel containers as a liquid.

Compared to traditional petroleum fuels such as gasoline and diesel, as well as alternative fuels such as ethanol and natural gas, LPG is an attractive transportation fuel. Its superior vaporization properties allow air fuels to mix better than liquid fuels while providing a higher energy density than other alternative fuels. Moreover, compared to regular gasoline, LPG has better octane rating and lower hydrogen-to-carbon ratio, which can improve performance and reduce emissions.

Keywords: Liquid Petroleum Gas, CO2 emissions, Running Costs

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1 INTRODUCTION

Diesel and gasoline are the world's main road fuels in a multi-billion dollar fuel industry, however, there is growth in the use of LPG or automotive gas. LPG is one of the gases that is a by-product of crude oil refining, which is among other things the source of gasoline and diesel [1]. LPG vehicles are rapidly being developed as economical and low-pollution vehicles [2,3]. The potential benefits of using LPG in diesel engines are economic and environmental [4]. Carbon dioxide emissions from road transport are increasing as energy consumption increases, while regulated emissions have been significantly reduced in markets such as the United States, Europe and Japan. However, only industrialized countries can afford modern low-emission transportation technologies, and therefore, increased mobility in developing countries will cause serious environmental problems [5].

The UK has a legally binding target of reducing greenhouse gas emissions by 12.5% over 1990 levels in 2008-12 as part of the international response following the Kyoto Climate Change Agreement in December 1997, along with a domestic target to reduce UK carbon dioxide emissions to 20% below 1990 levels by 2010. Although transportation is responsible for about 20% of carbon dioxide emissions (the main greenhouse gas), there is no current legislation limiting the amount of carbon dioxide produced by road vehicles. The European Commission's strategy on CO2 from cars aims to reduce CO2 emissions from new cars sold in the European Union to an average of 120 grams per kilometre. This is about a third off from the current average. The strategy, approved by the Cabinet in June 1996, seeks to achieve the goal in large part through a voluntary commitment by European car manufacturers, supplemented by fiscal measures and fuel economy signs to influence consumer demand. In July 1998, the Commission reached a formal agreement with ACEA, the representative of European car manufacturers. To do the following on passenger cars:

- Bring to market individual car models with CO2 emissions of 120 g/km or less by the year 2000;

_ to an indicative median target of 165-170 g/km (mean) in 2003 as a basis for monitoring progress;

_ to reduce CO2 emissions to 140 g/km by 2008 for all its new cars sold in the EU, i.e. a reduction of approximately 25% from current levels;

_ To review the possibility of making additional improvements that year with the goal of moving the average fleet of new cars to 120 g/km by 2012;

_ For ACEA to cooperate with UNHCR in monitoring commitment. Implementation will be jointly monitored by the Commission and ACEA, and the Commission will report to the European Parliament and the Council of Ministers annually. Similar voluntary agreements were agreed (in October 1999) between the commission and Japanese and Korean auto manufacturers that made a commitment to an average passenger vehicle fleet of 140 g/km by 2009 [5,6].

The number of cars produced worldwide in 2008 was expected to reach 71 million. With increasing recognition of climate change issues and the contribution of the transportation industry, improving vehicle fuel economy and emissions are the biggest challenges facing the industry [7,8]. To help reduce greenhouse gas emissions and achieve the goals of the Kyoto Protocol (the international treaty on global warming, the most notable feature of which is the agreement to reduce carbon dioxide emissions from new passenger cars to 140 grams of carbon dioxide per kilometer by 2008 mainly through vehicle technology), countries that ratify the Protocol are committed to reducing their emissions of carbon dioxide and other greenhouse gases associated with global warming

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[7,8]. In 2007, the European Union adapted a new strategy to reduce CO2 emissions from new cars and trucks sold in the European Union, to not exceed 120 grams of CO2 per kilometer by 2012 for new cars [9,10].

2. Fuel properties

LPG consists mostly of propane, but depending on the region in which it is produced or destined for sale, as well as the fuel specifications to which it is adhered, its composition and composition can vary. For example, the United States (USA) HD-5 standard for LPG consists of a minimum of 90 percent by volume of propane, a maximum of 2.5 percent by volume of butane and heavy hydrocarbons, and a maximum of 5 percent by volume of propylene [11]. Other regions of the world use higher formulations of butane, for example the butane content of certain countries in Europe ranges from 20 to 30 percent butane depending on the season [12], while Korea uses more than 85 percent of butane in LPG in the summer months [13]]. The ratios in which these components are present can have significant effects on the fuel properties of LPG such as energy content, vapor pressure, and octane number.

The composition of LPG also determines its carbon density which is often measured by the hydrogen to carbon (H:C) ratio of the fuel. Propane, the main component of natural gas, contains eight hydrogen atoms and three carbon atoms equivalent to a H:C ratio of about 2.67. The H:C ratio increases for lower order alkanes such as methane (4) and ethane (3) and decreases for higher order alkanes such as butane (2.5). On the other hand, conventional transportation fuels, i.e., gasoline and diesel, usually show an H:C ratio ranging from 1.7 to 1.9 [14]. In theory, this results in higher carbon dioxide (CO2) and soot production during combustion.

2.1. Energy content

The energy content of a fuel can be expressed on the basis of mass or on the basis of volume and can be measured through various methods. Table 1 provides the energy content via the low heating value method and the density of several common transportation fuels. Note that on a mass basis, LPG shows one of the highest energy contents (MJ/kg), slightly lower than LNG. However, on a volume basis, LPG has a lower energy content than conventional fuels such as gasoline and diesel. As shown in Table 1, this correlates with lower density of LPG versus these conventional fuels. This requires more fuel on a volume basis to achieve the same production as conventional fuel. LPG shows a small advantage in this regard compared to other alternative fuels, such as LNG and ethanol.

Table 1: Energy Content (Lower Heating Value) and Density of Select Fuels [15]

Fuel	Density (kg/liter)	Lower Heating value (MJ/liter)	Lower Heating value (MJ/kg)
LPG	0.58	23.7	46.6
Low-Sulfur Gasoline	0.748	31.7	42.4
Low-Sulfur Diesel	0.847	36.1	42.6
Liquefied Natural Gas	0.428	20.8	48.6
Ethanol	0.789	21.3	27.0

2.2. Octane number

Compared to gasoline available at the pump, LPG has a relatively high octane number. Although the octane rating of LPG can vary based on its composition, the HD-5 has an octane rating, a mean search octane number (RON) and an engine octane number (MON), around 105. In the United States, 93 octane (Average gasoline (RON and MON) is the highest octane rating available at gas stations while 87 octane is the most common [16]. Similarly, in the European Union (EU), the most commonly used gasoline is rated at 95 RON, which is approximately 91 octane (average RON and MON) [17]. In general, as the percentage of higher-order hydrocarbons than propane (eg butane) increases the octane number decreases and vice versa for lower-order hydrocarbons, eg methane and ethane. The higher octane number of LPG compared to gasoline can provide advantages in performance and efficiency. More advanced ignition timing and a higher compression ratio can be used with less pre-ignition or knocking when compared to the gasoline found at most petrol stations.

3. LPG fueling system technology:

There are an assortment of advances to meter LPG for interior ignition motors. These advances range in cost and intricacy, just as effectiveness and emanations execution. By and large, LPG energizing advances have firmly followed those of gas fueled motors. Concerning sparkle lighted motors, port fuel infusion (PFI) and direct infusion (DI) are the most important LPG energizing innovations at the present time[17].

3.1. Port Injection

PFI of LPG offers benefits over single reason behind infusion powering frameworks. LPG PFI frameworks are a nearby reproduction of electronically controlled multi-port fuel infusion frameworks for gas powered motors that have been broadly utilized throughout the previous twenty years. Truth be told, numerous vehicles furnished with LPG port infusion were initially intended for gas and later changed over to work on LPG. There are additionally various OEM LPG contributions, especially in the European and Asian business sectors. There are two sorts of changes; bi-fuel which permits the administrator to switch among gas and LPG and devoted which just consider procedure on LPG. Bi-fuel frameworks require the establishment of extra fuel injectors for LPG while devoted frameworks supplant the gas injectors with LPG injectors. This is essential because of the lower energy per volume of LPG and lubricity contrasts that require distinctive injector plans .Notwithstanding bi-fuel or devoted applications, these frameworks utilize a committed injector for every chamber and in this way offer more refined control of A:F proportion on a for each chamber premise contrasted with single point infusion frameworks. In a consecutive PFI framework, individual injectors can be controlled to convey pretty much fuel to explicit chambers dependent on wind current contrasts among the chambers. This gives more tight A:F proportion control to the motor in general, and accordingly more proficient TWC activity to all the while lessen carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NOX) in the exhaust. Besides, these injectors are for the most part situated in the admission complex somewhat near the admission valve offering faster reaction to transient motor activity and directed A:F proportion changes .

Consecutive multi-port fuel infusion of LPG can coordinate and even give lower levels of directed and unregulated discharges

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when contrasted with gas motors. Nonetheless, LPG transformations and even OEM LPG contributions are frequently in a difficult spot because of the way that the motors were initially intended for gas. The higher octane number of LPG contrasted with ordinary gas takes into consideration further developed start timing and higher pressure proportions. Without adjustment of the OEM gas start timing guides or pressure proportion, burning effectiveness can be lower eventually creating higher motor out HC and CO outflows, at the tradeoff of lower motor out NOX discharges. TWC for these vehicles are detailed for gas HCs which are higher request HC species contrasted with LPG which are innately lower HC species. In this manner, it is significant while looking at outflows from vehicles changed over to work on LPG comparative with gas vehicle to consider the innovation utilized, the current gas after treatment frameworks, and the degree of intricacy of start timing and powering control given by the transformation framework.

3.2. Direct Injection

The quantity of vehicles outfitted with flash touched off (SI) gas direct infusion (GDI) motors has filled essentially somewhat recently. Most of auto OEMs offer GDI motors basically because of their eco-friendliness benefits. GDI motors use a high strain fuel siphon and in-chamber fuel injector to straightforwardly infuse fuel into the burning chamber. This gives more exact control of the fuel infusion occasion contrasted with PFI frameworks. This upgraded infusion control takes into account infusion systems that limit motor thump and backing higher pressure proportions without high power fuel. By a similar thinking, GDI motors are more open to constrained acceptance techniques, for example, turbocharging and supercharging. A higher pressure proportion and constrained acceptance likens to higher force thickness and more noteworthy eco-friendliness especially when the motor is scaled back, for example lower uprooting .

While GDI motors can offer more prominent eco-friendliness contrasted with PFI motors, they do have specific downsides. Commonly, GDI motors utilize numerous infusion occasions to stifle motor thump and take into consideration higher pressure proportions. This methodology can bring about a more delineated air and fuel blend contrasted with PFI motors which give a more extended chance to the air and fuel to blend and consequently a more homogeneous combination. This delineated blend comprises of locally rich areas in the ignition chamber which builds the arrangement of particulate matter (PM) and CO. While a TWC can productively oxidize CO, expanded PM emanations stay an issue for GDI motors. The latest EU PM and molecule number (PN) guidelines have brought about specific producers presenting particulate channels for GDI motors. These without a doubt increment the expense and intricacy of vehicles notwithstanding likely decreases in eco-friendliness because of pressed the motor. It is expected that more makers will go with the same pattern, and different districts of the world will take on comparable guidelines making particulate channels for GDI motors ordinary. On the other hand, LPG enjoys an inborn benefit concerning PM arrangement contrasted with fuel in SI DI motors. The higher unpredictability of LPG advances blending inside the burning chamber giving a less separated air and fuel combination decreasing locally rich areas that are related with residue creation. The lower carbon force of LPG contrasted with gas lessens its inclination to deliver ash and cutoff points CO2 creation. Besides, DI of LPG in fluid state keeps up with and can surpass the effectiveness benefits of GDI motors.

3.3. Dual-Fuel Compression-Ignition

Pressure start (CI) motors, normally alluded to as diesel motors, generally offer preferable efficiency over SI motors. This can be ascribed to higher pressure proportions and the absence of a choke which decreases siphoning misfortunes. Besides, these motors commonly work at a general lean A:F proportion. Nonetheless, this lean A:F proportion requires the utilization of considerably more progressed fumes aftertreatment frameworks to decrease NOX emanations contrasted with SI motors and TWCs. A common present day diesel motor uses a particular synergist decrease (SCR) framework to lessen NOX which additionally requires diesel fumes liquid (DEF), a urea and water based arrangement, to be continued board the vehicle. Diesel fuel likewise has a lower H:C proportion contrasted with LPG and the DI framework utilized on by far most of current diesel motors brings about locally rich areas that produce essentially more significant levels of PM than SI motors. This expanded PM creation requires the utilization of diesel particulate channels (DPF) to fulfill administrative guidelines for PM. A diesel oxidation impetus (DOC) is for the most part likewise needed to diminish tailpipe emanations of HC and CO to administrative norms and give legitimate fumes conditions to the DPF and SCR framework. In certain occurrences, a smelling salts (NH3) slip impetus is needed after the SCR framework. These parts amount to an essentially more perplexing and expensive after treatment framework contrasted with a TWC, which can't diminish NOX in lean conditions .

The utilization of ordinarily SI powers, like fuel and LPG, in flawless structure in CI motors requires trend setting innovation and control, and has not been financially taken on. Be that as it may, high power powers, for example, LPG can be utilized in CI motors by subbing a piece of the diesel fuel with LPG. This innovation is called double fuel. Normally, the LPG or other high power fuel is infused through the admission port and a decreased amount of diesel fuel is infused straightforwardly into the chamber to touch off the LPG. Such a framework takes into consideration the utilization of LPG while holding the eco-friendliness related with traditional diesel motors. The lower carbon force of LPG can likewise assist with diminishing ash from these motors. Lamentably, these motors actually work at a general lean A:F proportion and require the utilization of perplexing present day diesel after treatment frameworks. Moreover, double fuel motors require the vehicle to convey two separate powers which can be dangerous on more modest vehicles where space is at a higher cost than expected and accordingly normally consigns this innovation to substantial vehicles[17,18].

4. Transportation Fuels

While analyzing various fills utilized for transportation it is significant not exclusively to consider the exhaust emanations created from ignition of a fuel, yet in addition the creation, preparing/refining, transportation/conveyance, and different wellsprings of discharges in the store network.

4.1. Production and Refining of Transportation Fuels

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Most of LPG is created from two sources; raw petroleum handling (roughly 40% around the world) and flammable gas creation and preparing (roughly 60% around the world) [19]. Every strategy for creation has various rules toxin and ozone depleting substance (GHG) discharges levels which can differ altogether. The portion of LPG created from each source fluctuates all through the world and even among various districts of a solitary nation or mainland. For instance, in the Marcellus Shale area of the U.S.A., LPG is delivered from flammable gas creation and preparing, while in the Inlet of Mexico locale critical amounts of LPG is created from unrefined petroleum refining tasks. The emanations from these exercises can likewise shift dependent on the underlying feedstock and the hardware used to concentrate and deal with gaseous petrol or raw petroleum. Discharges from these exercises are viewed as a piece of the "upstream outflows" concerning the general emanations from the utilization of LPG as a transportation fuel. Likewise remembered for the upstream outflows are those related with the pressure, transportation, and last conveyance of LPG. The blend of this load of upstream outflows is regularly alluded to as the well-to-tank (WTT) discharges. The variety underway techniques, transportation strategies and distance make evaluating WTT emanations troublesome. In any case, there are models that have been fostered that utilization industry information and suppositions to evaluate these emanations for both upstream and downstream exercises related with the transportation area; the Ozone depleting substances, Managed Outflows, and Energy use in Transportation (Welcome) model is one such instrument that has been used by concentrates on referred to in this report [20].

4.2. Crude oil: Gasoline and Diesel

Diesel and gas are the two most transcendently used transportation energizes on the planet. Petroleum product determined types of these energizes are created from unrefined petroleum extricated from the earth. Like different wellsprings of energy like gaseous petrol, LPG, and coal, the emanations from unrefined petroleum extraction and transportation to the treatment facility can fluctuate essentially relying upon the locale and gear utilized. For instance, a few areas on the planet import all of their oil from different locales and along these lines discharges related with marine big haulers, pipelines, rail line, or shipping should be considered for an exact well-to-wheels (WTW) evaluation. The refining system for diesel and gas is likewise a significant wellspring of WTW energy utilization and outflows creation.

4.3. Natural gas: LNG &CNG

The creation and use of petroleum gas has expanded drastically throughout the last decade, especially identified with eccentric recuperation methods like even boring and cracking. The emanations related with these exercises shift with the broadness and extent of their utilization. Like other energy sources, emanations from the conveyance and transportation of petroleum gas can differ essentially dependent on the area and the strategies utilized. Moreover, the essential part of flammable gas, methane (CH_4) is a powerful ozone harming substance itself. With an unnatural weather change potential (GWP) of 28 to 36 over a long term premise (CO_2 is given a GWP of 1), CH_4 outflows from the extraction, preparing, and transportation of flammable gas should likewise be considered for WTT and WTW GHG investigations of gaseous petrol emanations [21]. Concerning WTW, and all the more explicitly end use or tank-to-wheels (TTW) emanations in the transportation area, the strategy for capacity and related energy required should likewise be thought of. To accomplish adequate energy thickness for transportation utilize petroleum gas should be packed to high 11 pressures (CNG: roughly 200 to 250 bar) or cryogenically stuck to fluid structure (LNG: around - 160 °C) [22]. Both of these cycles are energy serious and add to the by and large WTT and WTW outflows .

4.4. Ethanol

As a transportation fuel, ethanol is for the most part blended in with gas for execution and security purposes. In the EU 72.4 percent of all gas sold in 2014 contained up to 5 percent ethanol (E5), while 10% contained up to 10 percent ethanol (E10) [17]. In the U.S.A. E10 is the most well-known mix and is sold for use in all vehicles. E15 (fuel with up to 15 percent ethanol) is additionally accessible in specific spaces of the U.S.A., yet it is just ensured for use in model year 2001 and more current vehicles [23]. Higher centralizations of ethanol for example E85 (gas containing up to 85 percent ethanol) must be utilized in vehicles with reason fabricated fuel frameworks and motor regulators. Ethanol can be created from various substances including sugar stick and corn through refining. WTT or WTW discharges from ethanol got from these inexhaustible plant sources should likewise think about the creation, refining, and transportation of the fuel. Nonetheless, ethanol from plant sources has a huge GHG advantage from photosynthesis that can counterbalance its GHG outflows from cultivating, creation, transportation, and end use.

5. Regulated Pollutants

For the proceeding analysis, information targeted on empirically measured regulated emissions, such as NOX, CO, total hydrocarbons (THC), non-methane hydrocarbons (NMHC), CH_4, PM, and PN, became accrued from 13 extraordinary sources which can be displayed in Table 2. Note that now not all of those emissions are regulated for the transportation zone in all international locations or areas. For example, CH_4 is regulated within the transportation quarter as a GHG in the U.S.A. But no longer inside the EU, whilst PN is regulated in the EU however now not within the U.S.A. The biggest resources of statistics have been, via far, a document by means of Atlantic Consulting identify "A Comparative Environmental Impact Assessment of Car-and-Van Fuels" [24] that utilized the car emissions database maintained by means of the KBA (Kraft fahrtbundesamt), Germany's Federal Agency for Motor Transport, and the united states A. Environmental Protection Agency (EPA) emissions certification database for cars and engines [25, 26]. These assets further to the others indexed in Table 2 protected records on diesel, fuel, E10, E85 and CNG fueled vehicles and engines compared to LPG. The records sources originated from multiple areas at some point of the arena and the model years taken into consideration ranged from 2000 to 2017, despite the fact that the general public of the records came from publish 2010 version yr vehicles bought inside the European and U.S.A. Markets. Consequently, the engine, gasoline injection gadget, and exhaust after treatment era was wide ranging many of the facts. Data become extracted from those sources for similarly evaluation and was only blanketed whilst

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exceedingly direct comparisons can be made for a selected fuel and LPG. For SI fuels consisting of fuel, E10, E85, and CNG, comparisons were made to LPG with the identical or pretty similar displacement engine and similar if no longer the equal automobiles based totally on gross vehicle weight rating and cut back weight. Comparing diesel to LPG is really more complex given that diesel engines utilize CI. For those comparisons, a vehicle that supplied a diesel engine, and LPG engine become used. Even with these constraints on comparisons there had been still several elements that can have an impact on or bias the character comparisons. These are discussed in addition for character fuels.

TABLE 2: SOURCES FOR REGULATED POLLUTANT DATA (SEE APPENDIC A)

Emissions records from the assets in Table 2 changed into presented in style of
devices including by extent and by using mass. The records become also normalized by way of extraordinary metrics; predominantly by way of distance and brake power. In order to evaluate and comparison the effects of multiple studies with diverse devices, a percentage differencing approach become used to gain a percentage boom or lower of emissions from a particular gasoline close to LPG. This allowed for the facts to be normalized for almost all of the studies, however, discrepancies can stand up by means of the percent differencing approach used, in particular the denominator used. For all but one of the studies, uncooked emissions data became extracted and the subsequent equation became used to calculate the percentage distinction.

$$\text{Percent Differe} = \frac{\text{Emissions}_{\text{lpg}} - \text{Emissions}_{\text{fuel x}}}{(\text{Emissions}_{\text{lpg}} + \text{Emissions}_{\text{fuel x}})/2} \ldots\ldots (1)$$

Where the distinction in emissions from LPG to the gas being in comparison to (Fuel X), is normalized with the aid of the average of the emissions from each fuels. From this method a bad percent difference suggests that LPG produced much less of that emissions constituent and vice versa. This method effects in a most or minimum of 200 and -200 percentage distinction, respectively. The handiest facts that changed into now not available in uncooked shape became from the take a look at name "Direct Injection LPG - Opportunity and Threat in Europe" [27] in Table 2. Only a percent increase or decrease of gas emissions in comparison to LPG changed into furnished (emissions from a single fuel within the denominator). Furthermore, it became uncertain what gasoline was used in the denominator. Another problem confronted with some information sources became the available decimal places for sure emissions materials. For instance, some resources used 0 for effects wherein the measured emissions level changed into past 2 decimal places. Additionally, a few resources used zero whilst an emissions constituent changed into no longer mentioned. In instances where a zero became present, a percentage distinction was now not calculated for the emissions constituent and the information become not blanketed within the analysis. From the usA. EPA certification database, there had been now and again a couple of consequences for LPG for a specific automobile or engine. In this example the producer or converter that had OEM guide (e.G. Roush® for Ford® cars, and Power Solutions Inc.® for General Motors® automobiles) become selected because the base to compare to. When this selection wasn't to be had the best acting LPG car or engine with admire to emissions become selected because the comparator. These elements, as well as the vast variety of automobile model years and technologies created a records set that had a extensive range of percent variations for the general public of the emissions parts. This huge variety can be located in Figure 1.

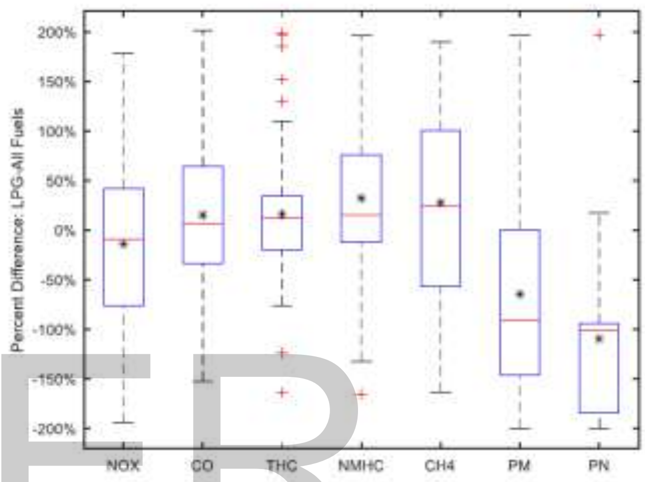

Figure 1: Regulated Emissions Data from All Fuels

The wide ranging version in the facts make it difficult to attract accurate overarching conclusions approximately the data. For example, the common percent difference of NOX emissions from LPG as opposed to all different fuels became about -14 percentage, i.E. LPG exhibited lower NOX emissions on average than the common of all different fuels taken into consideration. However, the massive span of the container and whiskers in Figure 1 demonstrates that there are times in which LPG produces drastically less and greater NOX emissions than other fuels. Thus the facts ought to be examined on a gas-through-fuel basis at the same time as thinking about the level of gasoline injection and after remedy generation, as well as the vicinity from which the era turned into applied and the emissions regulations that pertain to it.

6. GREENHOUSE GAS EMISSIONS

In many regions of the world regulations exist limiting the GHG emissions of engines and vehicles. These GHGs typically include CO_2, CH_4, and nitrous oxide (N_2O). For analysis, GHGs are typically examined on a WTT, TTW, and WTW basis. Additionally,

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results are commonly presented on a CO2 equivalent basis (CO2e) that includes CH4 and N2O with their respective GWPs.

6.1. Well-to-Tank

Four of the studies reviewed contained citable data regarding the upstream or WTT GHG emissions of LPG as compared to different fuels. Two of the studies, [38, 39], utilized the GREET version to estimate upstream GHG emissions elements for more than one fuels. The consequences from the first study used the GREET model model 1.8c and are displayed by table 3 [38]. The authors referred to that the default values for the enter parameters of the model have been used apart from uncompressed natural gas. Uncompressed herbal gas was modeled via placing the compression performance to one hundred percent basically getting rid of emissions from compression. However, as it pertains to transportation uncompressed or un-liquefied herbal gas isn't viable as a gasoline because of its very low energy density. It ought to also be stated that the feedstock ratio of LPG became a required enter to the model and the default values of 60 percentage from natural gas processing and forty percentage from crude refining have been used. With the exception of E85, the authors demonstrated that propane (i.E. LPG) produced the lowest WTT GHG emissions of all transportation fuels on a CO2e basis. As discussed in phase 4.4 the WTT CO2 emissions of E85 are offset by means of photosynthesis from the growth of plants used to produce ethanol. On the other hand, the N2O WTT emissions are substantially extra than any other gas.

Table 3: Upstream Emissions Factors (grams per million BTU) Note: LPG is labeled as Propane [38]

	CO2	CH4	N2O	TOTAL CO2 EQUIVALENT
PROPANE	9,195	115	0.16	12,124
NATURAL GAS*	5,480	239	0.09	11,471
COMPRESSED NATURAL GAS	11,468	247	0.17	17,684
ELECTRICITY	213,067	287	2.81	221,083
GASOLINE	16,812	109	1.14	19,871
DIESEL	15,488	105	0.25	18,175
E85	-10,464	109	30.64	1,385

A comparable study turned into conducted several years later making use of a more moderen version of the GREET model (2013) [39]. Again, default values have been used for the calculation of WTT GHG emissions apart from the compression efficiency of un-compressed herbal gas become set to one hundred percent. The feedstock ratio of LPG changed into additionally adjusted to 70 percent from herbal fuel processing and 30 percent from crude oil refining to reflect the maximum current marketplace proportion data to be had. Although absolutely the figures for WTT CO2e usually extended for all fuels examined, the identical fashion held actual, most of the fuels that can be used for transportation.

Table 4:Upstream Emissions Factors (Grams per million BTU) Note: LPG is labeled as Propane [39]

	CO2	CH4	N2O	TOTAL CO2 EQUIVALENT
ETHANOL	-14,409	113	41.0	-387
NATURAL GAS	6,995	317	1.34	16,228
PROPANE	12.,867	188	0.26	18,204
GASOLINE	16,010	118	3.95	20,368
COMPRESSED NATURAL GAS	10,985	324	1.4	20,429
DIESEL	18,727	118	0.31	22,104
FUEL OIL	18,727	118	0.31	22,104
ELECTRICITY	182,897	317	2.84	192,523

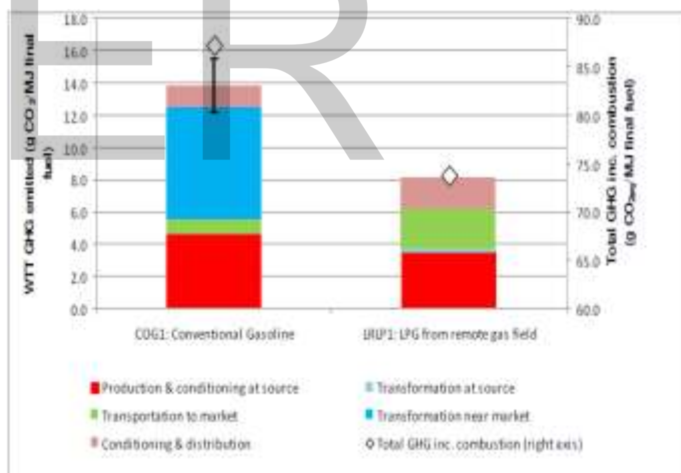

Figure 2: WTT GHG Balance of LPG Pathway [40]

Another examine commissioned by means of the European Commission, evaluated rules 443/2009 and 510/2011 on CO2 emissions from light-responsibility automobile [41]. The authors extracted information from the previously referred to file [40]. to provide a evaluation amongst fuel, diesel, CNG (indexed as natural fuel) produced in the EU, and LPG imported to the EU displayed through Table five. These results agree with others provided, LPG produces much less WTT CO2e emissions than the alternative fuels considered.

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TABLE 5: WTT EMISSION FACTORS [41]

Fuel	Well-to-tank emission factor (g co2e/MJ)
Petrol	13.8
Diesel	15.4
Natural gas	13.0
LPG	8.0

8. CONCLUSIONS :

The results presented in this document highlight the benefits of LPG compared to conventional and other alternative transportation fuels. The benefits of LPG in terms of emissions argue for its use, and its usefulness in current technologies like DI adds to that argument. When compared to gasoline-powered cars, LPG has shown to generate equal NOX, CO, and THC emissions while emitting less PM, PN, and CO2. In terms of greenhouse gas emissions, using LPG instead of gasoline yields considerably lower CO2e emissions on a WTW basis. Evidence also shows that applying LPG to contemporary DI technology might improve GDI's flaws, such as increasing accuracy.

When comparing LPG to diesel cars, it was discovered that LPG was capable of producing fewer NOX and PM emissions, even when diesel vehicles were equipped with more expensive and complicated after treatment systems. Despite the fact that diesel has a lower TTW GHG footprint, on a WTW basis, LPG emits similar to or fewer GHG emissions than diesel, depending on the literature source. The case for LPG is compelling when compared to other alternative fuels. In comparison to LPG-powered vehicles, NOX emissions from CNG-powered vehicles were lower on average, whereas THC and CO emissions were greater..

When compared to LPG-powered engines and cars, CH4 emissions, a strong GHG and one of CNG's major components, were substantially higher for CNG. On a WTW GHG emissions basis, the negative effect of CH4 emissions for CNG was also seen, where it was proven that the usage of LPG produces very similar or even lower GHG emissions on a CO2e basis than CNG, depending on the literature source. Furthermore, the characteristics of LPG vs CNG allow for far less expensive storage tanks. The average emissions from LPG-powered cars and engines were higher in NOX emissions, lower in HC emissions, and similar in CO emissions when compared to E85.

When comparing ethanol with LPG, it's vital to examine all elements of production, such as the fact that LPG doesn't share a food supply for feedstock like ethanol does, and that ethanol requires a lot of land to grow the crops needed to make it. Recent Bio LPG possibilities, such as those derived from renewable diesel fuel, may also have a WTW GHG footprint comparable to ethanol blends .

The case for LPG as a transportation fuel is compelling when you consider not only the LPG tailpipe emissions, but also the WTW GHG emissions. LPG offers a viable pathway to reduce regulated and GHG emissions compared to conventional fuels, while offering a less costly option and lower environmental impact compared to other popular alternative fuels.

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9. END SECTIONS

9.1. Appendic A

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Title	Fuels Compared to LPG	Date	Author	Region
Direct Injection LPG - Opportunity and Threat in Europe [27]	Gasoline	2017	Atlantic Consulting	Europe
A Comparative Environmental Impact Assessment of Car-and-Van Fuels [25]	Gasoline, Diesel, CNG, E85	2014	Atlantic Consulting	Germany
EETP: "European Emission Test Programme" Final Report [28]	Gasoline, Diesel, CNG	2004	INSTITUT FRANÇAIS DU PETROLE	Europe
Briefing note – the case for LPG taxis [29]	Diesel	2015	Calor	United Kingdom
Comparative Emission Analysis of Gasoline/LPG Automotive Bifuel Engine [30]	Gasoline	2009	R.R. Saraf, S.S.Thipse, P.K.Saxena	India
Performance and Emission Characterization of 1.2L MPI Engine with Multiple Fuels (E10, LPG and CNG) [31]	Gasoline, CNG	2010	R. Muthu Shanmugam, Nilesh M. Kankariya, Jacques Honvault, L. Srinivasan, H. C. Viswanatha, Patrice Nicolas, N. Saravanan, Dias Christian	India
Gasoline and LPG Vehicle Emission Factors in a Road Test [32]	Gasoline	2009	Jerzy Merkisz, Jacek Pielecha, Wojciech Gis	Poland
Emissions Testing of Gas-Powered Commercial Vehicles [33]	Diesel	2017	Brian Robinson	United Kingdom
JC08 Emission Data of LPG/Gasoline/Diesel [34]	Gasoline, Diesel	2015	National Institute for Environmental Studies, LPG Vehicle Promotion Association in Japan	Japan
Emission Characteristics of Gasoline and LPG in a Spray-Guided-Type Direct Injection Engine [35]	Gasoline	2013	Cheolwoong Park, Yunseo Park, Seungmook Oh, Yonggyu Lee, Tae Young Kim, Hongsuk Kim, Young Choi, Kern-Yong Kang	South Korea
The Evaluation Study on the Contribution Rate of Hazardous Pollutants from Passenger Cars Using Gasoline and LPG Fuel [13]	Gasoline	2013	Yunsung Lim, Hyung Jun Kim	South Korea
ELGAS HDDF LPG EMISSIONS DEMONSTRATION [36]	Diesel	2015	ABMARC	Australia
2015 Certified Vehicle Test Result Report Data (XLS) [25]	Gasoline, CNG, E85	2015	U.S.A Environmental Protection Agency	U.S.A
2016 Certified Vehicle Test Result Report Data (XLS) [25]	Petro, Diesel, CNG, E85	2016		U.S.A
2017 Certified Vehicle Test Result Report Data (XLS) [25]	Petro, Diesel, CNG, E85	2017		U.S.A
On-highway Heavy-duty Diesel and Gasoline FileMake Pro Certification Data for 2015 (XLS) [26]	Gasoline, Diesel, CNG	2015		U.S.A
On-highway Heavy-duty Diesel and Gasoline FileMake Pro Certification Data for 2016 (XLS) [26]	Gasoline, Diesel, CNG	2016		U.S.A
On-highway Heavy-duty Diesel and Gasoline Certification Data for 2017 (XLS) [26]	Gasoline, CNG	2017		U.S.A
Measuring Emission Performance of Autogas Cars in Real Driving Conditions [37]	Gasoline, Diesel	2017	European LPG Association	Europe