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# Literature Review on LCA of LPG as a Transportation and Cooking Fuel

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## Abstract

Over the past few decades climate has been changed drastically and it has become a crying need to control greenhouse gas emissions for the gas and oil industries. So, it is important to know the impacts on the environment of the gases that we use in our day to day lives while cooking or while using transportation. Life Cycle Assessment (LCA) is an effective method to determine and differentiate the environmental impact of different types of fuels in cooking aspect as well as transportation aspect. In the third world countries and developing countries like Ghana, India, Sri Lanka etc. LPG (Liquefied Petroliam Gas) is one of the most dominant fuel in urban area as well as rural areas. Since LPG has an excellent environmental payoff and less GHG (Green House Gas) emission it has created a lot of emerging possibilities as it has reduced pressures on forests and achieved modest climate benefits. This review paper shows how it is easy to store and transport LPG gas. With this study it brings a lot of possibility for diverse usage for LPG in cooking and transportation as it is believed to be a very attractive fuel option for its outstanding chemical properties that makes it an ideal fuel choice.

## Keywords
LCA, LPG, Transportation, Cooking, GHG

## 1. Introduction
LPG is an exciting prospect in the field of energy. Its properties open new horizons on how we may use it. Thus, it is essential that we realize the effect on the environment before we use LPG on a massive scale.

### 1.1 Introduction to LPG and LCA
Liquefied Petroleum Gas (LPG) may be a co-product of gas production and petroleum refining. It's an odorless, non-toxic hydrocarbon gas, consisting of propane, butane, and traces of other light C2 to C5 hydrocarbons. LPG may be a gas at ambient pressure and temperatures. It's stored during a liquefied state to facilitate transport and storage. 2 hundred seventy units of propane vapor condense to at least one unit of liquid. At 70oF, the pressure in an LPG tank is about 100 psi, counting on composition. For safety reasons LPG is odorized to point the presence of the gas in air (DOE, 2015b).

Life cycle assessment could be a methodology access the environmental impacts of a product, processor service using "cradle to grave" concept. LCA quantifies the environmental impacts of products, process or service throughout their life cycle, which incorporates various stages of raw material extraction, processing, manufacturing, transportation and distribution of product by consumers and therefore the disposal and recovery of product after its useful life.

### 1.2 LPG as a Transportation Fuel and its LCA Methodology
LPG produced from crude oil 40% and from natural 60%. With a global warming potential (GWP) of 28 to 36 over a 100 year basis ($CO_2$ is given a GWP of 1), $CH_4$ emissions from the extraction, processing, and transportation of natural gas must also be considered for WTT and WTW GHG analyses of natural gas emissions. (TTW) emissions in the transportation sector, the method of storage and associated energy required must also be considered. From the U.S.A. EPA certification database, there were sometimes multiple results for LPG for a specific vehicle or engine. In this situation the manufacturer or converter that had OEM support (e.g. Roush for Ford vehicles, and Power Solutions Inc. for General Motors

vehicles) was chosen as the base to compare to. When this option wasn't available the best performing LPG vehicle or engine with respect to emissions was chosen as the comparator. LPG on-road vehicles are either dedicated or bi-, or dual-fuel models that contain spark ignition engines or, as a supplement in compression ignition engines. 10,000 LPG vehicles operating in California. Government and municipal fleets, school bus fleets, state agencies and propane providers are the main users of LPG vehicles. More than 80,000 bus, taxi and delivery services, and other fleets are fueled by LPG. For 2016 Ford is offering several models of trucks with the LPG option (ICF, 2013) (U.S). There are currently over four million vehicles using LPG in Italy, Holland, the former Soviet Union, Japan, Australia, South Korea, the USA and Canada. In Europe, the LPG vehicle population numbers around two million vehicles. In the UK, there are over one 100,000 LPG vehicles in use. The majority of these are cars and light-duty vans, most which are bi-fuel conversions.

For car conversions, LPG tanks are either cylindrical and located within the boot space or doughnut-shaped to fit into the recess normally occupied by the spare wheel. As LPG is a gas at room temperature, a pressurized tank is required. The composition of the gas varies across Europe. Whereas UK gas typically contains more than 90% propane, in Italy this can be as low as 20%.

### 1.3 LPG as a Cooking Fuel and its LCA Methodology

Cooking exercises can be followed back to the early long periods of social developmental phases of human progress and keeps on being the most key need of human culture. The reasonability of cooking fuel choices to the families can be supposed to be a key determinant of financial turn of events and comprehensive development. In India, 65% of the population in urban area depends on LPG. In Sri Lanka 95% of the urban households are dominated by LPG .According to the Energy Commission of Ghana, the noncommercial sector of the country's economy accounts for about 50% of the total national energy consumption. People in rural areas of Ghana mostly use firewood for cooking and charcoal is used in urban areas.As these causes deforestation and air pollution, The Ministry of Energy of Ghana has been promoting a shift to liquefied petroleum gas (LPG), which, in its opinion, is a more efficient and cleaner-burning fuel as far as household usage is concerned. Standard life cycle assessment (LCA) methodology is used to determine and compare the environmental impacts of liquefied petroleum gas (LPG) that looks at the environmental aspects of LPG.

### 1.4 Objectives

The objectives of the study mentioned in this paper are:

i. 1.To determine the effects of LPG on the environment during production stage
ii. 2.To determine the effects of LPG on the environment when used as a cooking fuel
iii. 3.To determine the effects of LPG on the environment when used as a transportation fuel

## 2. Literature Review

Over the last decade immense research has been conducted on the effects of traditional fuels on the environment. With climate change being a major concern, environmental impact due to fuel has to be studied. For fuels that have heavy impact must be replaced. We must be more responsible towards our planet. Such an alternate for commonly used fuel is LPG. But before we promote its usage, we must keep in check what its effects are on the environment. LPG is largely used as a cooking and transportation fuel. Therefore, we must first evaluate LPG's emission in these cases. The most reliable method of calculating GHG and other emissions are through software's such as GREET. This has been demonstrated on JACOB's consultancy's report for Alberta Energy Research Institute (2009). For different stages different methods are used to present the environmental impacts of LPG. Such as during production stage we use the CML and Eco Indicator 99 Method as demonstrated by Marmar (2017). She also concludes from her calculation that LPG has the least effect on the environment when compared to other equal amount produced fuels. Cashman (2016) conducted a study on cookstove fuels life cycle assessment where she concluded that to reduce several impacts such as efficiency loss, eutrophication excreta a solution could be to replace coal, wood excreta with LPG. Afrane and Ntiamoah(2011) conducted a similar study in Ghana where they also were in agreement with Cashman's findings. Kaushik and Muthukumar (2018) further studied to show that LPG if combined with technologies such as Two Layer Porous Radiant Burners can further improve efficiency and reduce emissions.Ryskamp (2017), Unnasch and Goyal (2017), Dr. Lane (2006) all did LCA using different methods on different vehicle fuels. All reached the same conclusion on LPG being the most environmentally friendly fuel in a WTW analysis.

# 3. Methods

## 3.1 Goal and Scope

The aim of this analysis was to calculate, through the creation of the FUNNEL-GHG-CCO model, the cumulative WTW life cycle GHG emissions for transportation fuel LPG which is converted from conventional crudes oil. Global warming potential (GWP) was used as the impact category for conducting the LCA. The practical unit considered in this analysis was 1 MJ of fuel. The estimation of energy is based on the lower heating value. The scope of this research covers all phases of the life cycle of LPG , from crude oil recovery to the combustion of transportation fuels in vehicle engines. Emissions from infrastructure and machinery manufacturing were not included in the review.

## 3.2 Life Cycle Assessment (LCA) Boundary

Life cycle of LPG, GHG emissions consist of well-to-tank (WTT) emission and from tank-to-wheel (TTW). The WTT stage includes Extraction, Feedstock Transport, Fuel Production, Transport, Blending Storage, Distribution, Vehicle use. The combustion of transportation fuels in vehicle engines is considered the TTW stage.

# 4. Results and Discussion

## 4.1 Numerical Results

It is essential to evaluate a fuels impact on environment from the very start.LPG is usually a product received from the distillation of crude oil. A refinery treating 4.5 MMTPA (Million Metric Ton Per Annum) crude oil produces 0.136 MMTPA LPG

## 4.2 Input

From mass allocation we get that to produce 1 kg of LPG output per second we need the following resources: -

- 1.031 kg/second crude oil
- 2.27 MJ Energy
- 0.2 kg/second Iron
- 57 kg/second Water
- 0.43 kg/second Bauxite
- 0.37 kg/second Coal
  (Source: Trupti 2017)

## 4.3 Output

Manufacturing processes are bound to create unwanted waste products. These products are released in the air, water, solid and as non-material emissions. Emission to air, water, solid and non-material emission from the production on 1 Kg LPG are shown in Table 4.1, 4.2, 4.3 and 4.4 respectively. These outputs do affect the environment and should be accounted for.

Table 4.1 Emission to Air from production of 1 kg LPG. (All emissions are in grams) (Trupti,2017)

| Substance | LPG |
|---|---|
| $CO_2$ | 300 |
| CO | 0.090 |
| Hydrocarbons | 3.620 |
| HCl | 0.001 |
| $NO_2$ | 0.520 |
| Dust | 0.325 |
| $SO_2$ | 0.640 |
| $H_2$ | 0.004 |
| $H_2S$ | 0.003 |

Table 4.2 Emission to Water from production of 1 kg LPG. (All emissions are in grams) (Trupti,2017)

| Substance | LPG |
|---|---|
| $NH_2$ | 0.010 |
| BOD | 0.010 |
| COD | 0.040 |
| CT | 0.020 |
| Metallid ions | 0.001 |
| $H_2$ | 0.001 |
| Hydrocarbons | 0.020 |

Table 4.3 Solid emissions from production of 1 kg LPG. All emissions are in grams. (Trupti,2017)

| Substance | LPG |
|---|---|
| Inorganic Waste | 1.20E-4 |
| Slag | 5.00E-4 |

Table 4.4 Non-Material Emissions from the production of LPG. All emissions are in grams [Trupti,2017]

| Substance | LPG |
|---|---|
| Conventional to Industrial Area | 8.29E-6 |
| Occupational as Industrial Area | 5.57E-3 |

Table 4.5 Characterization value of impact indicators for production of 1 kg of LPG CML Method. All amounts in kg (Trupti,2017)

| Impact | Substances | Amount (kg) | Factor | Result |
|---|---|---|---|---|
| Indicator (Unit) | | LPG | (kg) | LPG |
| Green House (kg GWP) | CO2 | 0.30 | 1 | 0.30 |
| Ozone Depletion (kg ODP) | - | - | - | - |
| Eco toxicity (m'mgECA) | HC | 20(mg) | 0.05(mg) | 1.00 |
| | CO | 0.00009 | 0.012 | 1.08E-6 |
| | HC | 0.00362 | 0.022 | 7.96E-5 |
| Human | H2S | 0.000003 | 0.78 | 2.34E-6 |
| toxicity (HCA/HCW) | HCI | 0.000001 | 0.033 | 3.30E-8 |
| | NO2 | 0.000520 | 0.78 | 4.06E-4 |
| | SO2 | 0.000640 | 1.20 | 7.68E-4 |
| | HC | 0.00002 | 0.0019 | 3.80E-8 |
| | Metallic ions | 0.000001 | 0.0036 | 3.60E-9 |
| | NH3 | 0.00001 | 0.0017 | 1.70E-8 |
| Eutrophication | NO2 | 0.000520 | 0.13 | 6.76E-5 |
| (Kg NP) | COD | 0.00004 | 0.022 | 8.80E-7 |
| | NH3 | 0.00001 | 0.33 | 3.30E-6 |
| Acidification | HCI | 0.000001 | 0.88 | 8.80E-7 |
| (Kg AP) | NO2 | 0.000520 | 0.70 | 3.64E-4 |
| | SO2 | 0.000640 | 1.00 | 6.40E-4 |
| Summer smog (kg POCP) | HC | 0.00362 | 0.398 | 1.44E-3 |
| Energy | Crude oil | 1.031 | 42.70 | 44 |
| Resources (MJ | Coal | 0.00037 | 29.30 | 0.011 |
| LHV) | energy | 2.27(MJ) | 1.00(MJ) | 2.27 |
| Solid Waste (kg waste) | Inorganic waste | 0.00012 | 1.00 | 0.00012 |
| | Slag | 0.0005 | 1.00 | 0.0005 |

Table 4.6 Characterization value of impact indicators for production of 1 kg of LPG Eco Indicator 99 Method. All amounts in kg (Trupti,2017)

| Impact indicator | Substances | Amount (kg) | Factor (kg) | Characterized Value | Total |
|---|---|---|---|---|---|
| (unit) | | LPG | | LPG | LPG |
| Carcinogen $ (DAILY) | Metallic ions | 0.000001 | 4.272E-5 | 4.272E- 11 | 4.27 E-11 |
| Respiratory organics (DAILY) | Hydrocarbo ns | 0.00362 | 1.28E-6 | 4.630E- 9 | 4.63 0E-9 |
| Respiratory inorganic | Dust (SPM) | 0.00325 | 1.1E-4 | 3.575E- 8 | 1.17 E-7 |
| (DAILY) | NO2 | 0.000520 | 8.87E-5 | 4.612E- 3 | |
| | SO2 | 0.000640 | 5.46E-5 | 3.494E- 8 | |
| Climate change (DAILY) | CO2 | 0.30 | 2.10E-7 | 6.30E-8 | 6.30 E-8 |
| Ozone layer (DAILY) | - | - | - | - | - |
| Radiation (DAILY) | - | - | - | - | - |
| Ecotoxicity (PDF*m²yr ) | Metallic ions | 0.000001 | 3.57 | 3.57E-6 | 3.57 E-6 |
| Acidificati on/ | NO2 | 0.000520 | 5.173 | 2.97E-3 | 3.63 E-3 |
| Eutrophicat 10n (PDF*m²yr ) | SO2 | 0.000640 | 1.041 | 6.66E-4 | |
| Land use (PDF*m²yr ) | Conventiona 1 to industrial area | 8.92E-6 | 25.16 (m²) | 2.085E- 4 | 4.88 E-3 |
| | Occupationa 1 to industrial area | 5.57E-3 | 0.84 (mi²a) | 4.670E- 3 | |
| Minerals (MJ | Bauxite | 0.00043 | 0.50 | 2.15E-4 | 2.21 E-4 |
| surplus) | Iron | 0.00022 | 0.029 | 6.38E5 | |
| Fossil fuels | Crude oil | 1.031 | 6.15 | 6.34 | 6.34 |
| (MJ surplus) | Coal | 0.00037 | 0.252 | 9.32E-5 | |

| Damage | Impact category | Substances | Factor | Damage Indicator Value | Total |
|---|---|---|---|---|---|
| Indicator | | | | LPG | LPG |
| | Climate change | CO2 | 1 | 6.30E-8 | |
| | Respiratory organics | Hydrocarbons | 1 | 4.63E-9 | |
| | Respiratory inorganic | Dust (SPM) | 1 | 3.58E-8 | |
| Human | | NO2 | 1 | 4.61E-8 | 1.87 E-7 |
| health | | SO2 | 1 | 3.49-E8 | |
| | Carcinogens | Metallic ions | 1 | 4.27E-11 | |
| | Ozone layer | - | - | - | |
| | Radiation | - | - | - | |
| | Acidification/ Eutrophication | NO2 | 1 | 2.97E-3 | |
| | | SO2 | 1 | 6.66E-4 | 8.52E |
| Eco- system | Ecotoxicity | Metallic ions | 0.1 | 3.57E-7 | -3 |
| quality | Land use | Conventional to industrial area | 1 | 2.08E-4 | |
| | | Occupational to Industrial Area | 1 | 4.68E-3 | 7.45E-3 |
| Resources | Minerals | Bauxite | 1 | 2.15E-4 | |
| | | Iron | 1 | 6.38E-6 | 6.34 |
| | Fossil Fuels | Crude Oil | 1 | 6.34 | |
| | | Coal | 1 | 9.32E-5 | |

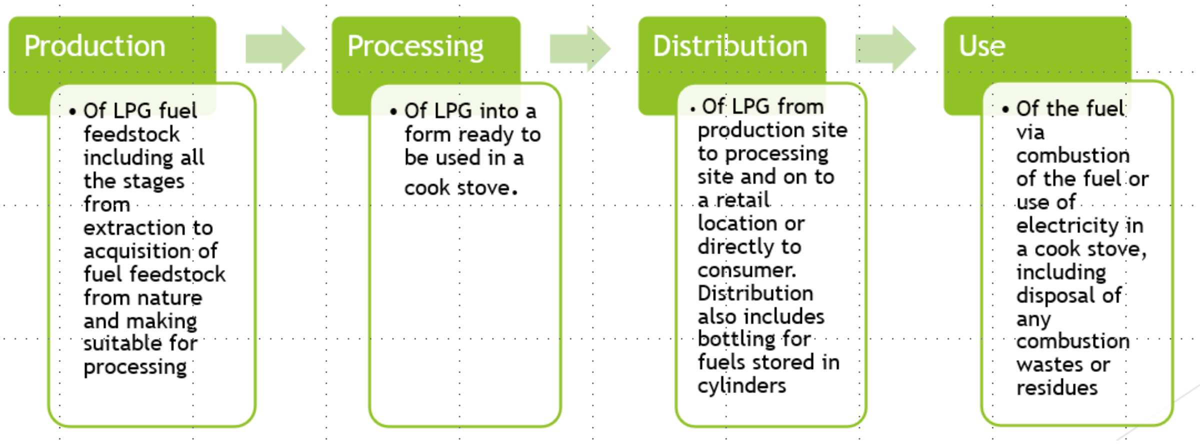


Figure 4.1 Stages of LCA of LPG (Cooking)

Table 4.7 Quantified Environmental Profile of LPG on the basis of the CML 2001 environmental impact assessment (Afrane,2011)

| Environmental impact category | LPG | Unit |
|---|---|---|
| Acidification potential (AP) | 2.25E-05 | Kg SO2 equivalent |
| Eutrophication potential (EP) | 1.4 | Kg PO43- equivalent |
| Freshwater aquatic Eco toxicity potential (FAETP) | 0.05 | Kg DCB equivalent |
| Global warming potential (GWP) | 0.12 | Kg CO2 equivalent |
| Human Toxicity potential (HTP) | 37 | Kg DCB equivalent |
| Photochemical ozone creation potential (POCP) | 2.83E-04 | Kg C2H4 equivalent |
| Terrestrial Eco toxicity potential (TETP) | 2.13 | Kg DCB equivalent |

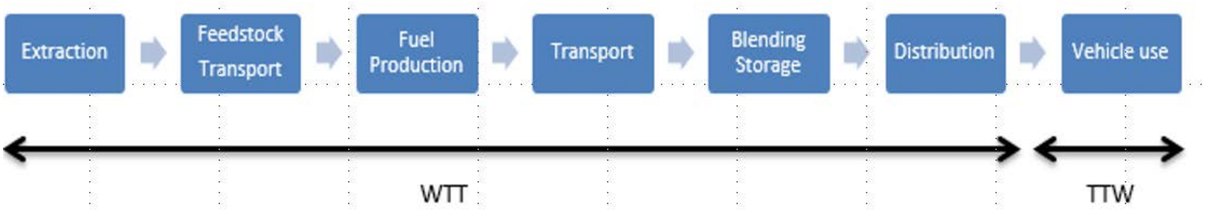


Figure 4.2 Stages of LCA of LPG (Transportation)

Using GREET model 2013 we get Well to Wheel emission factor 8 (gCO2e/MJ). Unit is grams of carbon dioxide equivalent per megajoule of energy which is also known as carbon intensity. It is the measure of greenhouse gas (GHG) emissions associated with producing and consuming a transportation fuel. [Jacobs Consultancy, 2009]

## 4.4 Proposed Improvements

Cases vary from country to country. Thus, the different parameters can lead to a different result. Although we can expect similar results for research purpose a study on the Bangladeshi scenario can be conducted to see if LPG is truly the optimum fuel choice for a developing country. Furthermore, economic analysis and comparison to other fuel will further prove if LPG is economically justified along with being environmentally safer. More improvement can be done if we can combine new technologies that will enhance LPG usage by increasing effectiveness, efficiency and reducing emission.

## 5. Conclusion

We see the different emission data from the 3 different cases. With that we can make a reasonable comment on the impact LPG has on the environment. The papers reviewed here suggest that LPG is better environmentally compared to other commonly used fuels from the very production stage to its usage stages. Its superiority in emitting less GHGs and outstanding properties makes it very attractive. However, it is shown that, even thought LPG emits less it is not completely environment friendly. It still does contribute negatively to the earth. For developing and poor countries that cannot yet fully shift to completely renewable energy sources LPG is the optimum choice. With initial study suggesting economic feasibility and low emission this could heavily reduce the effect on the environment. But this is until renewable energy sources can be opted. Compared to petrol, diesel, charcoal etc. LPG is superior but if clean sources such as electric motor cars, fuel cells, electric ovens excreta that are powered from electricity sources such as geothermal plants, hydro-electric plants are available, in that case LPG is inferior.

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