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Application of ethanol-hydrogen based biofuel in the energy industry and its sustainable and economical utilization to world environment and international markets

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ABSTRACT

Bioethanol is the world's largest-produced alternative to petroleum-derived transportation fuels due to its compatibility within existing spark-ignition engines and its relatively modern and sustainable production technology. A major breakthrough is yet to be seen in the energy industry where; renewable fuels would take over the energy industry, becoming the self-sufficient fuel of the future. It's Due to Bioethanol's low calorific value, the modern-day fuel hasn't reached its optimal potential yet. Hence producing sustainable blends would be the ideal solution to this hypothesis. The utilization of coffee grounds as a primary source of raw material would be extremely cost-effective since deriving bioethanol from such a source would only require manufacturing and operating cost. The study also notices the trend of the global economy shifting to using biofuels as a primary source of fuel such as the aviation industry aiming for a carbon-neutral economy by 2030 [4]. The blend of ethanol and Hydrogen would be the optimal fuel for the future. Hydrogen produces a net calorific Value of 120 MJ/kg compared to Bioethanol's Calorific value of 18.2 MJ/kg [3]. Petrol generates approximately 40MJ/kg upon burning that makes the blend of Hydrogen and Bioethanol an optimal, potential source of energy [3].

***Keywords**: Bioethanol, Coffee, Hydrogen, Fuel Cell*

1. INTRODUCTION

The world drinks approximately 2.5 billion cups of coffee every day, generating an estimated 18 million tons of spent coffee grounds each year [1]. The generated coffee grounds are disposed of to mass landfills without being separated or treated, causing landfills to overflow and contribute to numerous health and safety hazards as well as climate change. Disposing coffee grounds in landfills produces acidic leachate, which makes the soil extremely acidic and damages the ecosystem around it [2]. Subsequently, these coffee grounds produce an extensive amount of Green-House Gases (GHGs) such as methane which contribute to climate change and the ozone layer depletion.

The purpose of this study is to introduce an alternative to the common use of crops such as Jatropha and Corn as a source of Bioethanol and replacing it with coffee grounds. This study has critically analyzed the energy efficiency and productivity of latest renewable energy sources and questioned the economic demerits of existing biofuel production sources and suggests changes to be made.

Upon looking over previous hypothesis and raising question to whether Bioethanol is efficient enough to sustain itself. This research fills in the gap between the energy requirement in the transportation industry and also helps progress in a more economically profitable and environmentally sustainable energy.

2. METHODS

(I) Bioethanol Production: Chemicals and Lab Procedures

The raw materials used in this study as a source of Bioethanol were Jaggery (Cane sugar), Coffee grounds and Rice. The glassware included Distillation pipes, conical flasks, test tubes, beakers, measuring jars, micropipettes etc. The glassware was soaked in chromic acid solution (2:5 ratio of Potassium Dichromate solution: Conc. Sulphuric Acid) for three hours to remove residues and was subsequently rinsed with distilled water. A total of 50g of ethyl di-amine tetra acetic acid (EDTA) was dissolved in 1100 ml of Distilled water. A Fehling's solution was made by mixing solutions A and B. Copper Sulphate solution (A) - Exactly 34.639g of copper sulphate (CuSo4, 5H2O) dissolved in water and 0.5 ml of concentrated sulphuric acid of specific gravity 1.84. This solution was diluted to 500 ml in a volumetric flask and filtered [5]. Alkaline tartarate solution (B) - Rochelle Salt or Potassium sodium tartarate

(KNaC4H4O64H2O) 173 g and 50g of sodium hydroxide (NaOH) were dissolved in water and diluted to 500 ml. It was let to stand for 2 days and filtered [5].

Sample Substrates for analysis

Organic raw materials such as Jaggery, Coffee grounds & Rice were taken for the purpose of this study. The substrates were critically examined for its total reducing sugars for the Bioethanol producing capacity and non-fermentable sugars.

Preparation of Sample for testing

About 12.5 g of individual substrates were weighed accurately and transferred to a 250 ml volumetric flask. To this 40 ml of EDTA solution was added and made up to the volume of 250 ml and mixed well. From this solution 100 ml was taken in a 500ml volumetric flask and made up to volume with water and mixed. From the above sample, 50ml was taken in a 100ml volumetric flask, to this 2.5ml of concentrated HCL was added. The flask was kept in the water bath with constant agitation till the temperature raised to 70oC and allowed to keep for 5 minutes. Then the flask was kept in cold water at 20oC till the contents reached to 35oC. Then about 2 – 3 drops of phenolphthalein were added to the flask and neutralized the solution with 6N sodium hydroxide till the solution turned slightly pink. The flask was kept at 20oC for 30 minutes and made up to the volume with water and mixed the solution well (Jayaraman, P., et al. "Evaluation of ethanol production using various carbon substrates by Sacharomyces cerevisiae and Schizosacharomyces pombae." J. Pure App. Microb 11 (2017): 1469-1478).

Figure 1: Rice Sample (Figures by Author)

Figure 2: Cane sugar sample (Figures by author)

Figure 3: Coffee ground sample

(Figures by Author)

Special Preparation of Rice Sample for testing

Twenty gram of rice was mixed in 100 ml of distilled water and 2 ml of amylase enzyme was added. The solution was stirred well and added about 900 ml of gently boiling water in a large beaker and cooked well. The cooked solutions were mixed well and the gelatinized starch solutions were kept in room temperature for hydrolysis reaction. Then the hydrolyzed solutions were used as invert solutions of rice substrate for analysis of reducing sugars (Dalel Singh et. al., 2007).

Calculation

$$\text{Total reducing sugars in 100ml of sample} = \frac{\text{Fehling's factor (F) X 100 X 2500 mg}}{\text{Titration factor x Weight of substrate taken}}$$

$$\text{Total fermentable sugars} = \text{Total Reducing Substances (TRS)} - \text{Non-Fermentable Sugar (NFS)}$$

Fermentation Process

Samples of Jaggery, coffee grounds and Rice were taken for fermentation of alcohol by yeast. A total of seven different 300 ml conical flasks were taken and filled with 150ml of distilled water. Dissolve 25 gm of substrate in each conical flask and mix it well. The cooked rice weighed about 25 g and 150 ml of water was added. About 10 ml of 48-hour old activated yeast culture suspension was added to the solution and stirred well. The individual flasks containing all contents of fermentation were incubated at 36 ^{o}Cfor 48-72 hours. After the incubation period, the fermented broth was analyzed for the yield of ethanol by multiple tests.

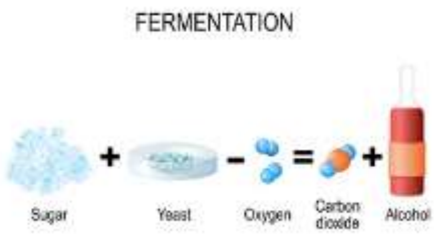


Figure 4: Fermentation process

(Figure from https://bit.ly/3zQ5ovl)

Distillation of solution and recovery of Alcohol
Exactly 150 ml of fermented sample broth was measured in a volumetric flask. The content was transferred to 500 ml flat bottomed flask. The standard flask was rinsed with 25 ml of distilled water twice and combined the washings with sample. The flask was connected to the still head and condenser. About 125 ml of the sample was distilled out and the distilled sample was made up to 150 ml with distilled water (Jayaraman, P., et al. "Evaluation of ethanol production using various carbon substrates by Sacharomyces cerevisiae and App. Microb 11 (2017): 1469-1478).

Figure 5: Distillation and recovery of alcohol (Figure from Author)

Efficiency of Bioethanol Retrieved

(II) Hydrogen Production:
Director Ethanol Fuel Cell (DEFC)
Ethanol can be directly employed as fuel in the FC in a DEFC system. Ethanol is an organic fuel produced from coal or agricultural products. In DEFCs, both the cathode and the anode are platinum or platinum-adopted catalysts. The electrolyte solution used is tri-fluromethane sulfonic acid. A DEFC is an example of a low temperature non-fuel flexible fuel cell. These fuel cells were initially implemented in small portable electronic devices, such as laptops and cell phones [43]. Compared to the PEMFC, the DEFC has lower density and efficiency.

Reaction Mechanism
H2 production from ethanol is normally carried out via multiple steps of conversion and separation processes [6], [7]. The main reactions occurring in the EAR reactor are:

$$C2H5OH \rightarrow H2+CO+CH4 \Delta H0298K=51.3kJ/mol \quad (1)$$

$$CH4+H2O \leftrightarrow 3H2+CO \Delta H0298K=206.2kJ/mol \quad (2)$$

$$CH4+0.5O2 \leftrightarrow 2H2+CO \Delta H0298K=-38kJ/mol \quad (3)$$

$$CO+H2O \leftrightarrow H2+CO2 \Delta H0298K=-41.2kJ/mol \quad (4)$$

In the complete process, the H2 yield can be enhanced by employing additional water-gas-shift (WGS) reactors, producing H2 and CO2 while reducing the CO content below 1–0.5 vol% In some processes, the presence of CO in the H2-rich stream acts as a poison for the materials of the downstream units (e.g. fuel cells, NH3 synthesis, etc.). In these cases, a further purification step is required to obtain high purity H2, and usually a methanation reactor is considered to further decrease the CO content to below 10 ppm converting CO into CH4 [8]. Alternatively, pressure swing absorption (PSA), cryogenic distillation, or membrane technology can be used to produce high purity H2 (>99.99%) [9].

Models, Prototypes and Mechanism

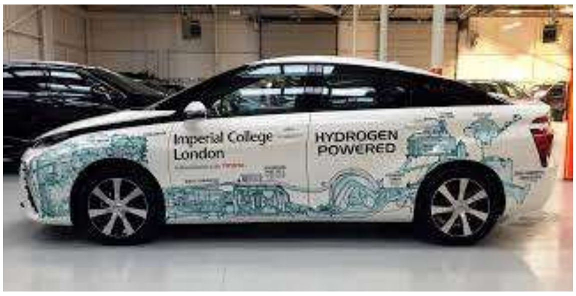


Figure 6: Hydrogen Powered Car Prototype

(Figure by Imperial College London; Energy Futures Lab)

The Prototype is powered by electricity generated on-board by a fuel cell stack through the process of combining hydrogen with oxygen. On a full tank it can cover around 300 miles, with smooth, near-silent running and producing no emissions other than pure water. The car has been acquired with support from the Office for Low Emission Vehicles (OLEV), Hydrogen Mobility Europe (H2 ME) and the Fuel Cells and Hydrogen Joint Undertaking (FCHJU) [14].

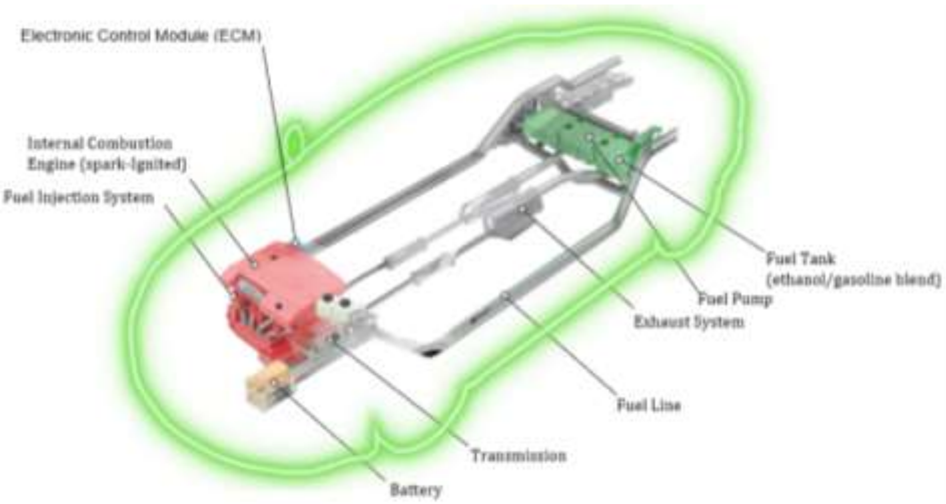


Figure 7: Flexible Fuel Vehicle

(Figure by Author)

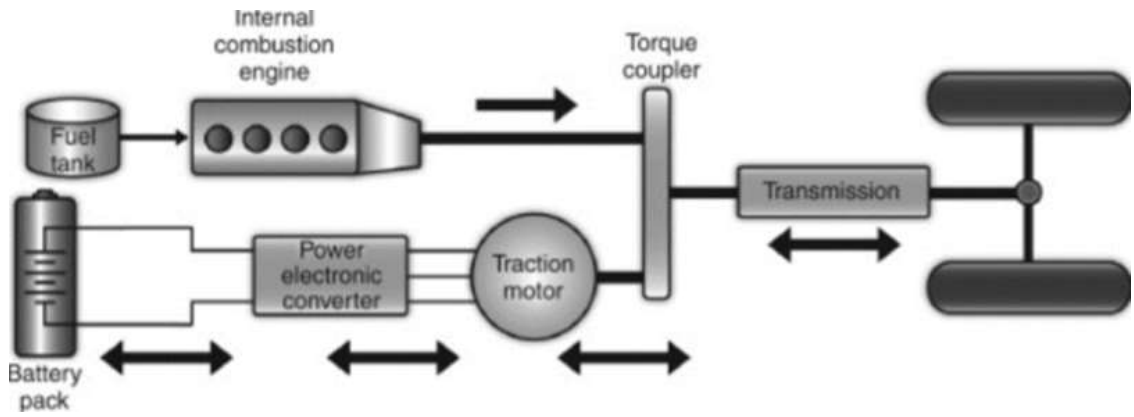


Figure 8: Configuration of fuel transmission

(Figure by https://www.mdpi.com/2076-3417/9/11/2296)

RESULTS

The total reducing sugar content of Coffee bean grounds was very high 92.4% followed by Jaggery of 80.4% and finally Rice (63.5%). The amount of non-fermentable sugars subtracted from total reducing sugars designated as fermentable sugars which are in the range of Coffee grounds (74.4%), Jaggery (68.8%) and Rice (54.7%).

The ethanol yield can be calculated from the table below:

$$\text{Expected Value of Ethanol produced} = \frac{(\text{Weight of Substrate Taken X Fermentable sugar}) * 0.644}{100}$$

$$\text{Observed Value} = \frac{\text{Ethanol\% X Total Volume}}{100}$$

$$\text{Efficiency} = \frac{\text{Observed Value}}{\text{Expected Value}}$$

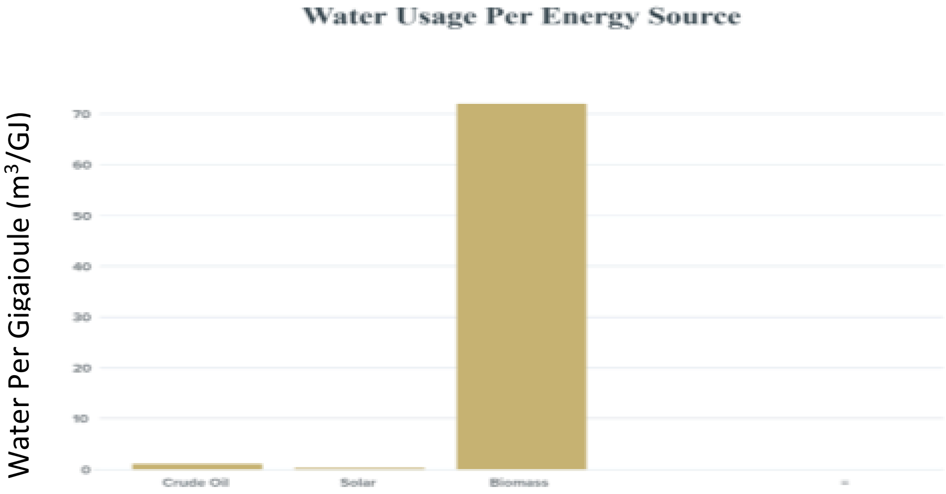
The integration of Bioethanol conversion and Hydrogen separation via a thin-film Palladium-based ceramic membranes has been analyzed and presented. The results of the permeation tests show a considerable impact of concentration polarization for the empty, packed and fluidized bed configuration.

DISCUSSION

The current Bioethanol Industry has turned a blind eye to the production and procuring cost of obtaining the most widely used raw materials for Biofuels – Corn and Jatropha. Humans have advanced to alternative sources of energy such as Solar Energy. A study suggests that photosynthesis, that occurs in Corn and Jatropha; is an incredibly inefficient way to turn sunlight into usable energy. The energy efficiency of Photosynthesis is usually under 1% for plants meaning on average plants can capture about 1% of sunlight (Corn being 0.25%). In contrast, with photovoltaic solar cells, humans have the ability to capture 12-20% energy [10].

The downside of using fertilizers is that they can have harmful effects on the surrounding environment and may cause water pollution. Fertilizers contain nitrogen and phosphorus. They can be washed away from soil to nearby lakes, rivers or ponds [11]. Biofuel is less suitable for use in low temperatures. It is more likely to attract moisture than fossil diesel, which creates problems in cold weather. It also increases microbial growth in the engine that clogs the engine filters [11]. If the land is used to grow a biofuel feedstock, it has to be cleared of native vegetation, which then leads to ecological damage. The native forest is almost always better at removing CO2 from the atmosphere than a biofuel feedstock partly because the CO2 remains trapped and is never released by burning as with fuel stock. Estimates have shown that deforesting native land can actually produce a carbon debt that can take up to 500 years to repay.

Finally, changing land to an agricultural status almost always means fertilizers are going to be used to get the most yields per area. The problem is runoff and other agricultural pollution [11]. The water consumption from these sources of fuel can be seen as a potential risk of water scarcity in the area of production.



Graph 1: Water usage Per energy source

(Figure by author [12])

The Biofuel Industry requires 240 times the amount of water than solar and Is 48 times less efficient than solar at converting sunlight into energy

The use of Coffee bean grounds as the primary source for Bioethanol has a raw material input of zero. This is because, coffee grounds are deemed as waste and dumped into landfills, hence an incentive to collect the grounds from coffee shops, breweries, subway stations, corporate offices, etc. will potentially collect millions of tons of waste that can be turned into fuel. The calorific value of Bioethanol is the only hindrance during this process as seen in the table below:

Table 1: Calorific Values of Fuels

Types of Fuel	Net Calorific Value (MJ/Kg)
Ethanol	26.8 – 28.9
Petrol	42.0 – 43.5
Hydrogen	120

(Table by author [3])

Studies have shown that Coffee grounds are also high in calorific value in comparison to that of Corn and Jatropha. While they can't be eaten, this means that they are a potential energy source. From the image below, we can infer that the Bean belt lies in countries where the* *economy is highly dependent on Oil and Natural Gas as a primary source of Income.

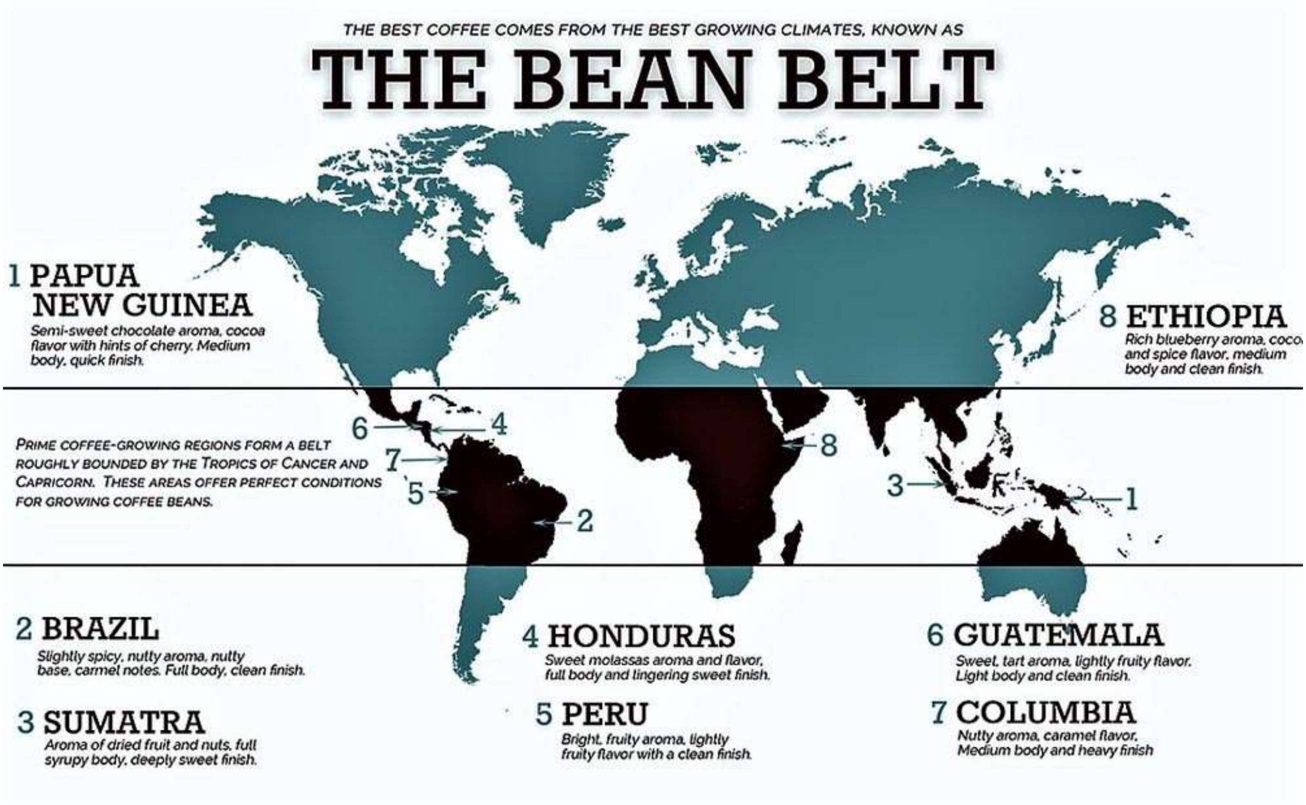


Figure 9: Distribution of Coffee

(Figure by [13])

Coffee grounds burn "20% hotter and longer" than dry wood fuels. They also have a lower carbon footprint when compared to traditional fossil fuels [2]. We can acknowledge the abundance of Coffee production present in the world.

Hence by shifting the trend of their dependance on fossil fuels to producing fuel from waste will make the environment around us sustainable and carbon-neutral.**Conclusion**

We have studied a Bioethanol – hydrogen blend energy generation using fuel cells and their utilization in hybrid vehicles was conducted. The studies have shown that Hydrogen fuel cells will play a significant role in the energy industry and the transportation industry in the near future. With such a high calorific value, the demand and supply are hoped to increase in the future. As demand and supply for fuel cells, increase their price is estimated to reduce when producing fuel cells in large quantities and commercializing them. With the increase in use of Biofuels, the durability of the engine increases and the carbon emissions significantly decrease.

When it comes to the economic effects of using Bioethanol (Derived from Coffee-grounds) – Hydrogen blend, is currently the cheapest and most effective alternative source of energy. With a negligible procurement cost and a less labour intensive, this model seems to be an ideal alternative to fossil fuels. With future advanced research and improvement in technology, the science and engineering in the process can be significantly improved.

ACKNOWLEDGEMENT

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[15]

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