International Journal of Scientific Research & Engineering Trends
Volume 8, Issue 4, July-Aug-2022, ISSN (Online): 2395-566X

# Biofuels-Recent Advances and Case Studies

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**Abstract- Biofuels are essentially the fuels that are generated by the living or dead organisms and which are mostly in the form of the co-metabolized substrates or they are the products of the microbial metabolism. Biofuels include the bio-diesel as well as the bio-CNG which stands for the compressed natural gas that has been produced from the biological sources. Biofuels are needed in the modern world as we need the alternate renewable sources of energy which are less polluting than the fossil fuels and which can also be degraded by the microbes present in the environment. In this report the current state of the biofuels industry is described with the purpose of reviewing the recent advances that have been made in the biofuel industry as well as discuss the future prospects of the biofuels' usage in various industries. Some case studies have been discussed to highlight the issues faced and the advantages that the biofuel usage has over the usage of the conventional fossil fuels, and also to analyze the practical utility and economic sustainability of the biofuels' usage at the large scale as well as the individual consumer scale.**

**Keywords- Bio CNG, conventional fossil fuels etc.**

## I. INTRODUCTION

The biofuels are the energy sources that are derived from the biomass over relatively short time intervals and they are mostly derived from the agricultural harvest, wood from the forests, or from the organic waste streams. The biofuels currently manufactured on the large scale are either liquid forms of the biodiesel, which are produced from the fat cells of animals, re-used wax or from vegetable oils, or ethanol, which is produced from the fermentation of the sugar or the other starch crops by yeast or other microbes.

The need for the biofuels is to replace the traditional sources of the transportation energy, the fossil fuels. The biofuels are biodegradable mostly as they come from the organic sources and thus they do not pose the risks of the long term environmental degradation, which is the problem in many of the crude oil refinery, oil well and oil storage sites all over the world as the oil and the fuels derived from it like petrol and diesel are non-biodegradable in nature and also are toxic to living organisms.

Such problems of widespread contamination are not prevalent for biofuels. Also the biofuels can be derived from a wide variety of sources and thus they have the ability to developed indigenously and thus the costs of the fuel are also lesser. The biofuels have lesser emission of Sulphur dioxide and particulate matter into the atmosphere but the emissions of the nitrogen oxides ($NO_x$) are higher. They are also renewable and thus the biofuels allow the development of the sustainable transport sector and also the biofuels do not need a lot of modification to the existing manufacturing process or the existing engine technology for their usage, which is an issue that the electric vehicles face. The existing infrastructure itself can be used to develop the transport sector based on the biofuels.

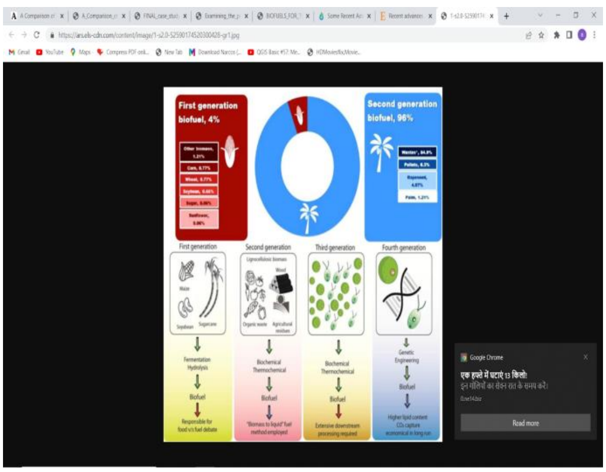


Fig 1. Categorization of the biofuels and overview of the processes through which they are made. The actual source distribution of the various kinds of biofuels is also shown. Adapted from Shweta *et al* (2021) [ 1]

The biofuels are already used as the enhancers of the fossil fuels through blending as the other boosters like the methyl-tert-butyl ether (MTBE) are recalcitrant pollutants and thus their usage is being reduced and banned in many regions of the world. Biofuels are divided into 4 categories, generation 1 to 4. The first generation biofuels are the ones that are derived from the sugars, oil and starch rich plants. Mostly these are derived from the plants that

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are also food sources and thus they have an impact on the food security.

The second generation biofuels are produced from the lignocellulose materials which are obtained from agricultural or forest residues. The third generation biofuels are the ones that are obtained from the microalgae and the fourth generation biofuels are obtained through the genetically engineered cyanobacteria and the biofuels are produced with the better characteristics and higher yields through metabolism and action on the substrates. Shweta *et al* (2021) [ 1]

## II. METHODS OF BIOFUEL EXTRACTION AND MANUFACTURE

The biofuels can be generated by the action of the yeast or the other fungi on the lignocellulose sugars which leads to their conversion to these sugars to the lipids, bioethanol and bio-butanol. The lipids can be converted to the products like the alkanes. These products can be used as the biofuels in their clean form or as the blends with fossil fuels. Biofuels need to have the good power output and also less polluting potential as compared to the fossil fuels. The biofuels are mostly manufactured in the liquid form as the liquid biofuels need the less land area, water, and transportation and storage costs and give better economic viability as compared to the solid or the gaseous biofuels.

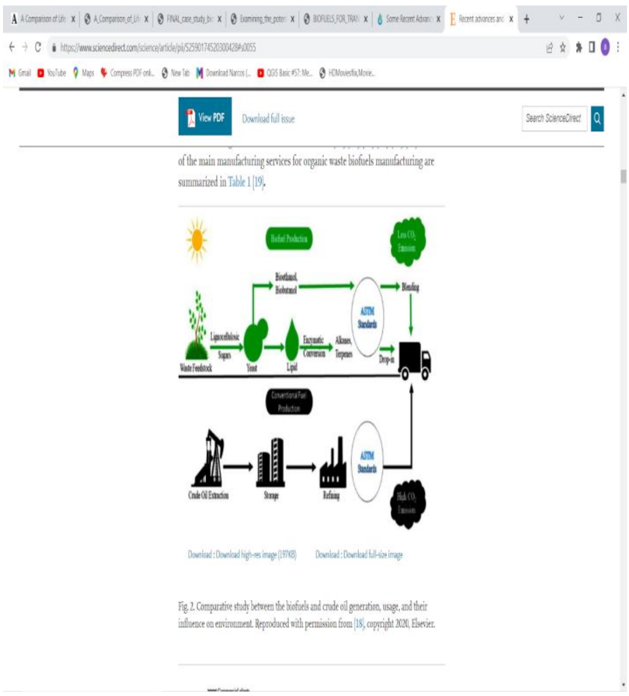

Fig 2. The comparative representation of the biofuel and conventional fuel production and their respective impacts on the environment.
Adapted from Shweta *et al* (2021) [ 1]

The feedstock for the biofuel production varies depending on the availability; type of biofuel needed and market forces. Many times the organic wastes like the food and yard waste, livestock waste, agricultural or logging residues, etc. are used but this is only used as a mechanism to deal with the organic waste and is not the mainstream method for the generation of the commercial biofuels as the products are not of standard quality and the fuel energy efficiency is also low. Shweta *et al* (2021) [ 1]

The first generation biofuels that are generated from the oil, starch and sugar rich plants are mostly generated through the action of the fungal species like the yeast on the plants. The plants used here are wheat, maize, corn, barley, and potatoes. The starch-degrading fungal species used in this process are Saccharomyces cerevisiae and Rhizopus sp.

The bioethanol is made from the fermentation of the natural corn and sugarcane by the starch and the sugar degrading bacteria and the biodiesel is made from the sunflower and the soybean plants. The main mechanism for the generation of these biofuels is the enzymatic hydrolysis of the sugars and the starch present to the bioethanol. Biodiesel is generated through the conversion of the oils, which have the triglycerides into the fatty acid methyl esters and the glycerol through the reaction of the oils with the methanol. The alcohols produced in this process are separated from one another through the distillation. The second generation biofuels are generated from the lignocellulose materials via the same mechanism. The third generation biofuels are generated from the micro-algal biomass through the action of the cellulolytic bacteria and they produce the biodiesel and can also be the carbon dioxide fixers. The fourth generation biofuels are generated through the metabolism of the post-genomic engineered micro-algal species. Shweta *et al* (2021) [ 1]

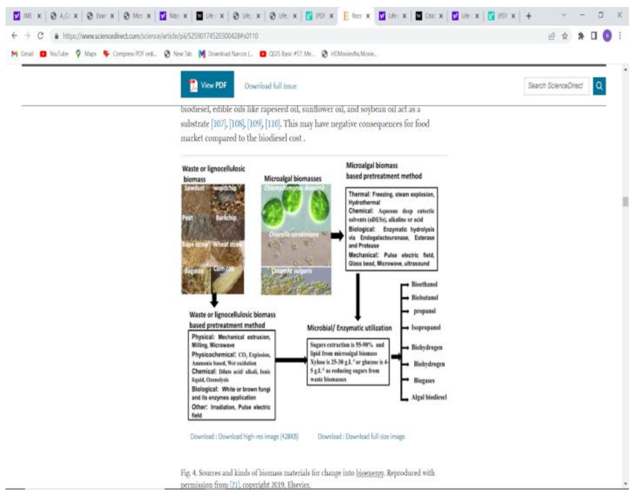

Fig 3. The distribution of the sources of the biofuels and the schematic of the biofuel manufacturing process and the biofuels that are manufactured in the industry.
Adapted from Shweta *et al* (2021) [ 1]

The micro-algal species used to create the biomass for the third generation biofuels have to be of high oil producing capability and high growth rate. The biomass is simply trans-esterified and the biodiesel is produced. The residual algal biomass that is left after the biodiesel extraction has occurred also is a good producer of the biogas through the anaerobic digestion process. The microalgae can also produce the wide array of the hydrocarbons which will then be converted to the fuels like the diesel and the kerosene.

An example of such species is *Botryococcus braunii* that is a freshwater microalga and the hydrocarbons produced are deposited outside the cell and thus the extraction of these bio-hydrocarbons is also easier. Some microalgae produce the hydrogen from water and sunlight and this hydrogen is the promising fuel for the future transportation as there is no dangerous pollutant emission. Some examples of the hydrogen producing microalgae include the purple non-sulphur microalgae that derive the hydrogen from the organic sources and the green microalgae that derive the hydrogen from the hydrogen sulphide.

The micro-algal biomass gasification in the presence of the oxygen yields the mixture of the gases which contains methane, carbon monoxide, hydrogen, and some water vapour and this is called the bio-syngas and it can be burnt in the boilers to generate electricity and can also be used in the manufacture of other hydrocarbons. Tiwari *et al (2018)* [7].

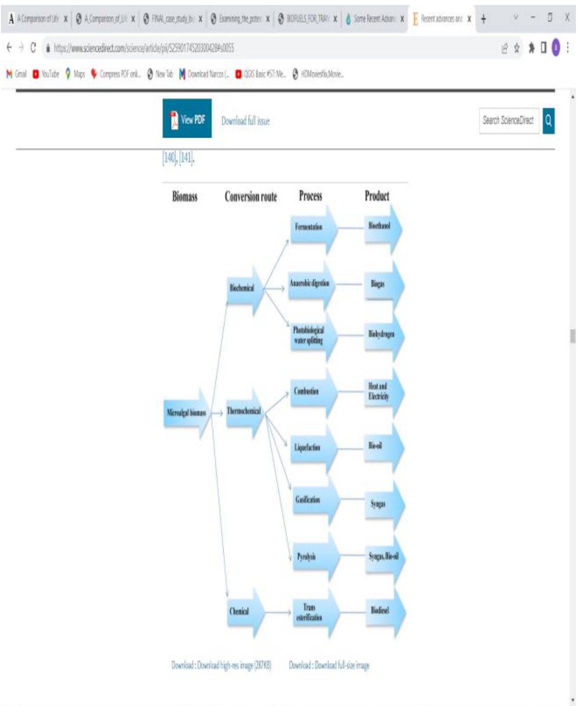


Fig 4. The processes that can be done on the micro-algal biomass and the fuels that can be generated through these processes. These are all third generation biofuels. Adapted from Shweta *et al* (2021) [ 1].

## III. LIFE CYCLE ANALYSIS AND CASE STUDIES OF BIOFUEL USAGE IN VARIOUS APPLICTIONS

For the assessment of the actual advantages or the disadvantages of any technology the life cycle analysis methodology is used. In this technology, there are four stages, the goal and scope definition, inventory analysis, impact assessment and the interpretation. The goal definition is given so as to state the reason why the study is supposed to be done and the hypothesis or the proposition that the study is intended to verify.

The scope definition includes, drawing the flowchart of the system which is the starting point of the study and shows all the processes involved in the system and their internal connections, choice of the functional unit and the reference flow which describe the flowing quantities and their units that are being studied in the system and they are used to compare multiple functionally equivalent systems and they also are used to analyse the system performance in a quantitative way, impact assessment methods that include the assessment of the direct impacts on the environment and also the indirect impacts on the human health, ecosystem health and the resources, the system boundaries that define the limits of the study that define the processes that are internal or external to the system as well as the time duration and geographical limits to the study, and the allocation problems that arise when the one or more inputs or the outputs are associated with multiple processes.

Generally, in the LCA the allocation problems are supposed to be avoided and when the same input or the output can undergo or come from many processes then these processes are considered to be the alternatives and then one alternative is chosen as the representative of the whole system and the other processes' emissions or reference flows are considered as the emissions that are saved and they are subtracted from the net overall emissions of the system. The second step in the LCA is the inventory analysis and this includes the process construction based on the defined system boundaries, the data logging about the inputs and the outputs of the various production processes and the assignment of the environmental burden that each of these processes sets on the environment.

In the third step of the LCA analysis, the impact assessment, the environmental consequences of the loads assigned in the second step are described and the important steps are the classification, where the emissions of the processes are assigned to the various impact categories and then the characterization step converts these impacts on the human health and the environment to the representative factors based on the science based conversion rules and this allows us to compare the inventory results of the various impact categories.
The last phase of the LCA is the interpretation phase of the LCA and in this phase the findings of the LCA are analysed and the conclusions are reached about their

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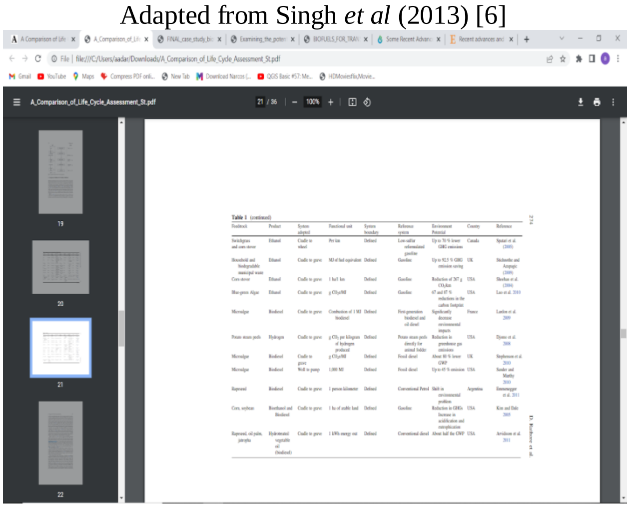
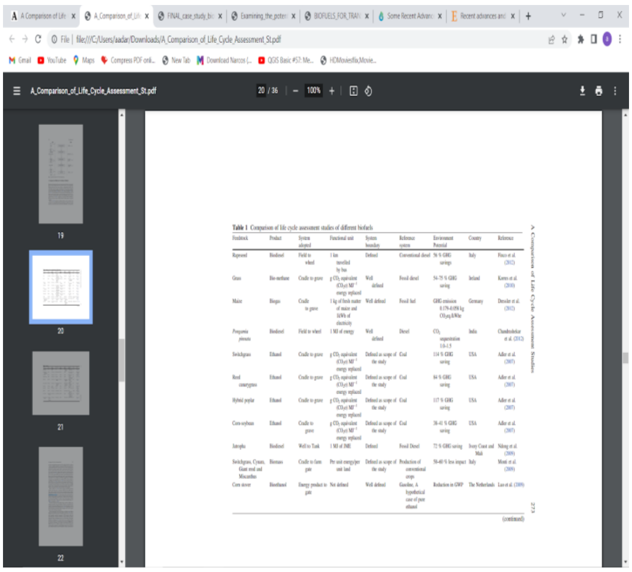
environmental or the economic performance and recommendations about improving the performance of the product of interest in the parameter of interest are also given. Here the various kinds of the biofuels from the wide variety of sources are compared based on the LCA analysis and some of the biofuels that represent the sample space are analysed in detail.

The LCA analysis has been done through the various software but the detailed workings of each of them is not within the scope of the report. But the process LCA steps are all described in detail and thus the usage of different software does not affect the results by much and this assumption is used to analyse some of the LCA case studies of various biofuels. Finco *et al* (2012) [2]

Table 1. A comparison of LCA studies for various biofuels, their environmental potential and LCA study conditions and assumptions.
Adapted from Singh *et al* (2013) [6]





**1. LCA Analysis of Greenhouse Gas Emissions from Rapeseed Biodiesel Compared with Conventional Diesel:**

The rapeseed biodiesel is the most produced biodiesel in Europe and is often mixed with the soy and the sunflower biodiesel. The goal of the LCA analysis was to Greenhouse gas emission savings obtained by the replacement of the conventional diesel by the pure rapeseed biodiesel.

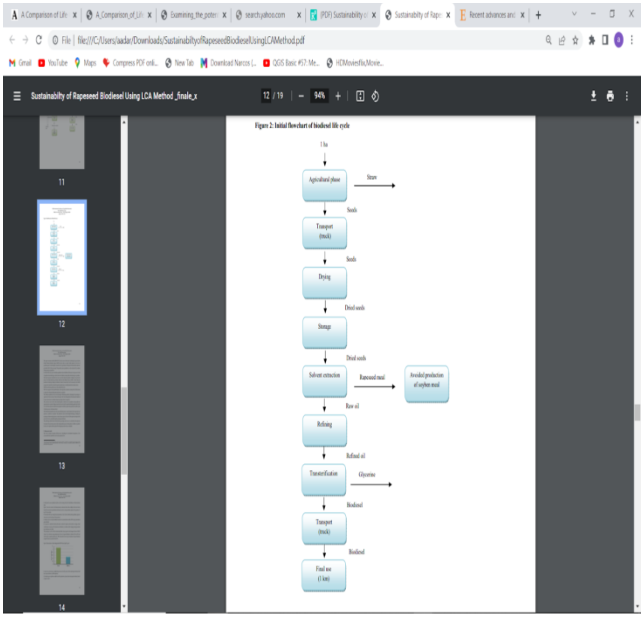


Fig 5. Initial life cycle flowchart of biodiesel.
Adapted from Finco *et al* (2012) [2]

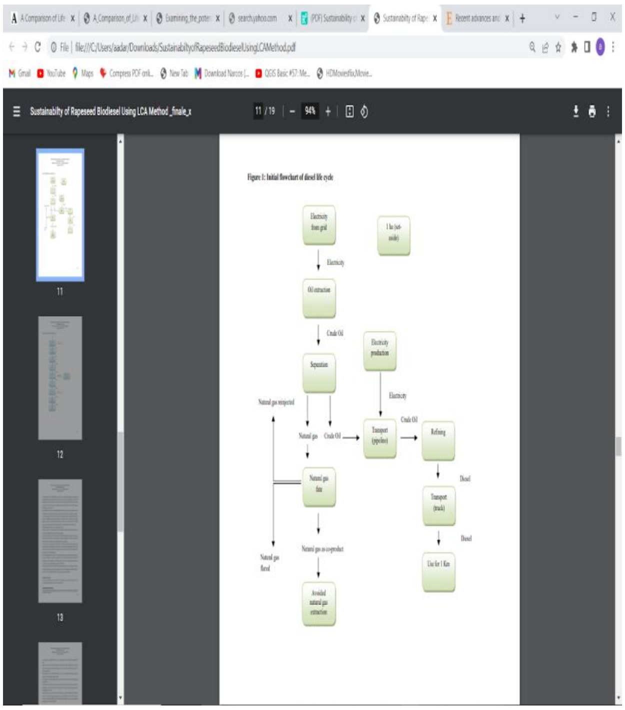


Fig 6. Initial life cycle flowchart of conventional diesel.
Adapted from Finco *et al* (2012) [2]

The functional unit for the analysis is the distance of one kilometer travelled by a bus. In the diesel production system, the assumptions include that the diesel is extracted

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through the offshore processes, then it is transferred to the refineries via pipelines for the distance of 100 kilometers, then the refined diesel is carried to the gas stations in the trucks with 40 Tons capacity for 100 kilometers, and that for the functional unit 0.3 kg of the diesel is needed.

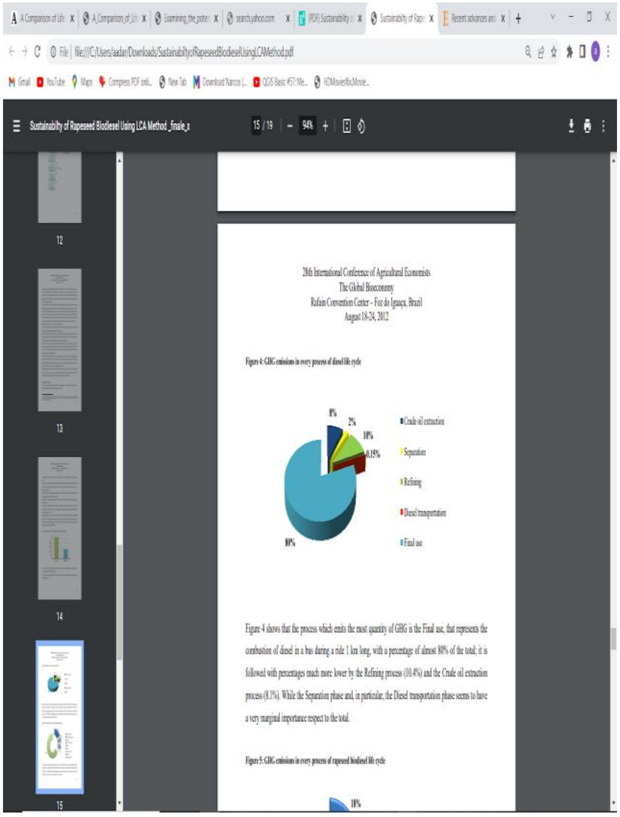

Fig 7. Distribution of the greenhouse gas emission sources and their percentage contributions to the total emissions in the whole life cycle of conventional diesel.
Adapted from Finco *et al* (2012) [2]

For the rapeseed biodiesel, the process assumptions include 1 hectare of agricultural land where the rapeseed crop is cultivated and this land is maintained in the set aside manner and the environmental impacts of the land use changes are not considered here, the raw seed is taken in the trucks of 7.5 Tons capacity to the nearby transesterification plant and this is a negligible environmental burden process, the biodiesel is extracted from the rapeseed through the usage of the hexane as the solvent and then this biodiesel is carried to the gas stations in the 40 ton trucks by travelling 100 kilometers and in the analysis the tailpipe emissions of the carbon dioxide are considered zero as the assumption is that the rapeseed plant biodiesel is emitting the carbon dioxide into the atmosphere in the amount that is equal to the amount of the carbon dioxide that the plant removed from the atmosphere over the course of its lifetime. Since the biodiesel has no Sulphur the Sulphur dioxide emissions are also considered zero and the final assumption is that the quantity of the rapeseed biodiesel needed for the functional unit is 0.4 Kg. Finco *et al* (2012) [2]

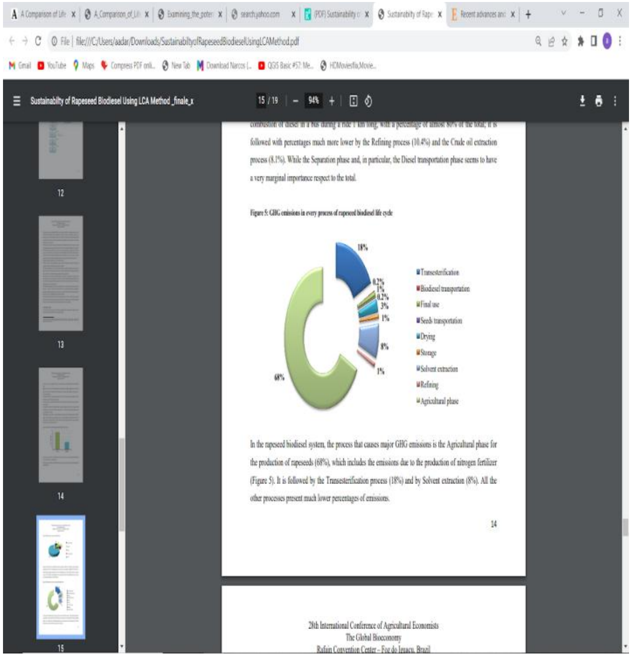

Fig 8. Distribution of the greenhouse gas emission sources and their percentage contributions to the total emissions in the whole life cycle of rapeseed biodiesel.
Adapted from Finco *et al* (2012) [2]

The result of the LCA for the greenhouse gas emissions is that the lifecycle emissions of the biodiesel for the functional unit was 0.48 Kg of Carbon dioxide equivalents while the lifecycle emission of the conventional diesel was 1.1 Kg of the carbon dioxide equivalents. In this LCA the effect of the land use change that would have caused the increase in the carbon dioxide emissions and the associated increase in the biodiesel greenhouse gas emissions was not considered.

The result of the LCA is that the use of the biodiesel in place of the conventional diesel will cause the decrease of the greenhouse gas emissions by 56 percent. The processes that are involved in the biodiesel and the conventional diesel life cycle and their contributions to the overall life cycle emissions as the percentage are shown in figure 8 and figure 7 respectively.
Finco *et al* (2012) [2]

**2. LCA of Greenhouse Gas Emissions During Biogas Production from Maize and the Conversion of Biogas into Electricity:**

In this study, the life cycle analysis of the biogas production and the energy generation is done for three districts of Gottingem, Celle and Hildesheim and these are compared and analysed to gain the insight into the sustainability of the biogas production from maize and also to study the variations of the LCA in the three districts. The goal was to study the effect of the regional parameters on the LCA analysis of the production of the

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biogas from the maize feed-stock and the subsequent usage of the biogas produced to generate the electricity.

The whole life cycle analysis is a cradle to grave analysis and thus the burden of all the processes used in the inputs of the system is included. These inputs whose burdens were included the cultivation of the maze, its transportation to the biogas plants, the production and the usage of the biogas to generate the electricity and the disposal of the output sludge. The burden of the infrastructure build-up so as to facilitate the biogas production is not included in the life cycle analysis. This is justified as these burdens only account for four percent of the total environmental burden. There are two functional units used in this study and they account for the agricultural output (maize produced) and the bioenergy output (electricity produced from the biogas) as both these processes are followed by one another thus the two functional unit usage is justified.

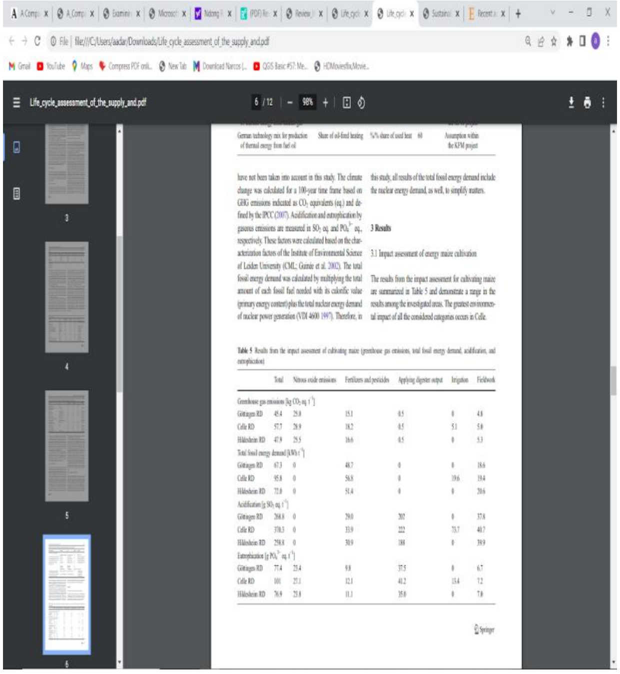
The functional units are the one Kilogram fresh matter of maize and the one kilowatt-hour of energy generated through the biogas burning in the combined heat and power reactor. Some of the issues that the biogas production causes are the nutrient flows and the acidification of the soil or the water bodies of discharge. These effects especially hold true for the anaerobic digester sludge disposal.

The study has looked at the various environmental impact categories like the global warming potential, acidification potential and the eutrophication potential. The climate change, acidification and the eutrophication have all been calculated for hundred years and they all are obtained from the greenhouse gas emissions expressed as the carbon dioxide equivalents, the acidic gas emissions expressed as the sulphur dioxide equivalents and the nutrient emissions expressed as phosphate ion equivalents.

The fossil fuel energy demand is obtained by adding the nuclear energy demand to the sum of the products of the calorific value of the fossil fuel and the total amount of each fossil fuel. The results from the impact assessment of the maize cultivation are given in table 2. The greenhouse gas emissions in each of the districts is seen to be from 45.4 to 57.7 Kg of carbon dioxide equivalents per ton of the fresh maize and the main share of the greenhouse gas emissions is due to the emission of the nitrous oxide from the soil which accounts for 50-56 percent of the total greenhouse gas emissions.

The total fossil fuel energy demand for the production of the fresh maize is 63.7 to 95.8 Kwh per ton of the fresh maize. Acidification that is caused by the cultivation of the fresh maize in the soil ranges from 258.8 to 370.3 g SO2 eq./t of fresh maize and the eutrophication emissions range from the 76.9 to 101 phosphate ion equivalents per ton of fresh maize. Dressler *et al* (2012) [3]

Table 2. Results from the impact assessment of cultivating maize.
Adapted from Dressler *et al* (2012) [3]



gaseous emissions are measured in $SO_2$ eq. and $PO_4^{3-}$ eq., respectively. These factors were calculated based on the characterization factors of the Institute of Environmental Science of Leiden University (CML; Guinée et al. 2002). The total fossil energy demand was calculated by multiplying the total amount of each fossil fuel needed with its calorific value (primary energy content) plus the total nuclear energy demand of nuclear power generation (VDI 4600 1997). Therefore, in

3 Results

3.1 Impact assessment of energy maize cultivation

The results from the impact assessment for cultivating maize are summarized in Table 5 and demonstrate a range in the results among the investigated areas. The greatest environmental impact of all the considered categories occurs in Celle.

Table 5 Results from the impact assessment of cultivating maize (greenhouse gas emissions, total fossil energy demand, acidification, and eutrophication)

| | Total | Nitrous oxide emissions | Fertilizers and pesticides | Applying digester output | Irrigation | Fieldwork |
|---|---|---|---|---|---|---|
| Greenhouse gas emissions [kg $CO_2$ eq $t^{-1}$] | | | | | | |
| Göttingen RD | 45.4 | 25.0 | 15.1 | 0.5 | 0 | 4.8 |
| Celle RD | 57.7 | 28.9 | 18.2 | 0.5 | 5.1 | 5.0 |
| Hildesheim RD | 47.9 | 25.5 | 16.6 | 0.5 | 0 | 5.3 |
| Total fossil energy demand [kWh $t^{-1}$] | | | | | | |
| Göttingen RD | 67.3 | 0 | 48.7 | 0 | 0 | 18.6 |
| Celle RD | 95.8 | 0 | 56.8 | 0 | 19.6 | 19.4 |
| Hildesheim RD | 72.0 | 0 | 51.4 | 0 | 0 | 20.6 |
| Acidification [g $SO_2$ eq $t^{-1}$] | | | | | | |
| Göttingen RD | 268.8 | 0 | 29.0 | 202 | 0 | 37.8 |
| Celle RD | 370.3 | 0 | 33.9 | 222 | 73.7 | 40.7 |
| Hildesheim RD | 258.8 | 0 | 30.9 | 188 | 0 | 39.9 |
| Eutrophication [g $PO_4^{3-}$ eq $t^{-1}$] | | | | | | |
| Göttingen RD | 77.4 | 23.4 | 9.8 | 37.5 | 0 | 6.7 |
| Celle RD | 101 | 27.1 | 12.1 | 41.2 | 13.4 | 7.2 |
| Hildesheim RD | 76.9 | 23.8 | 11.1 | 35.0 | 0 | 7.0 |

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For the second stage of the process, that is, the usage of the biogas to produce the electricity the greenhouse gas emissions range from the 0.248 to 0.281 carbon dioxide equivalents per Kwh of the electricity generated. The biogas production in the anaerobic digester may have the heat recycling and the usage of the sludge as the fertilizer and the credits for the saved emissions in these categories has to be subtracted from the calculated greenhouse gas emissions and the net result for the biogas usage comes out as 0.058 to 0.179 Kg carbon dioxide equivalents per kwh of electricity generated.

The fossil fuel energy demand for this process is 0.468 to 0.543 equivalents of carbon dioxide per kwh of the electricity generated from the biogas. The acidification ranges from the 1.62 to 1.94 grams of the sulphur dioxide per kwh of the energy generated and the largest share is accounted by the disposal of the anaerobic digester sludge. The eutrophication nutrient emissions range from 0.330 to 0.397 equivalents of the phosphate ion per kwh of the electricity generated. Thus the finding is that the actual ton of the maize produces 605.56 $m^3$ of the biogas and the electricity yield is 2.14 kwh per $m^3$ of the biogas and thus the 1 ton of the maize gives 1295.9 kwh of energy and thus the total emissions in this process from the 1 ton of maize processing is 205.11 Kg or carbon dioxide equivalents per ton of the maize on average and the net acidic gases emission from the process is 2.621 Kg of sulphur dioxide equivalents per ton of ton of the maize. The of the greenhouse gases per ton of the coal used in the coal fired power plants is 1860 Kg of the carbon dioxide

equivalents and the acidic gas emissions stand at 14.14 Kg of the sulphur dioxide equivalents per ton of the coal used. Now, the energy yield of the biogas electricity is roughly 0.65 of the yield of the coal and thus adjusting the emission levels to the energy equivalent ratio gives 1209 Kg of carbon dioxide emissions as opposed to the 205.11 kg of carbon dioxide equivalents, which is the net reduction of 83.03 % per kwh of energy and the reduction in the sulphur dioxide emissions is 71.4 % and thus we can conclude that the usage of the biogas from the maize is an environmentally sustainable process and there are significant environmental gains to be made if the biogas replaces the coal in the production of the electricity, especially in the developing countries like India.
Dressler *et al* (2012) [3]

**3. LCA of Greenhouse Gas Emissions During Hydrogen Gas Production from Potato Steam Peels:**

The purpose of this study was to assess the sustainability of the hydrogen production from the potato peels through the LCA analysis and the alternatives that are compared for the usage of the potato peels were the direct animal feeding of the peels and the hydrogen production from the peels and then feeding the protein rich by-product to the animals. The functional unit chosen for the overall system analysis was the 1 Kg of the potato steam peels used and the functional unit for the two stage bio-reactor evaluation that will produce the hydrogen gas from the peels is 1 Kg of the hydrogen gas produced.

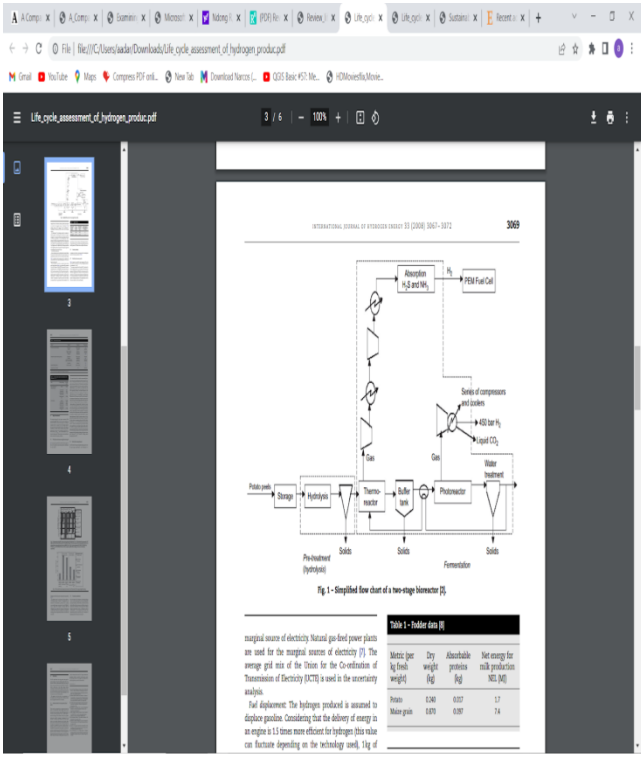

Fig 9. Flowchart schematic of a two-stage bioreactor Adapted from Djomo *et al* (2008) [4]

The system boundary starts once the potato peels are produced as the by-products of the potato processing industry and the burden of the hydrogen production in the two stage bioreactor, the replacement of the fuels by the hydrogen, and the replacement of the traditional fodder by the protein rich by-product and the land use burden for the animal fodder production are included but the burden of the potato cultivation and the generation of the capital goods are not included. Also the assumption is that the bio-reactor is very close to the potato processing plant and thus it gets the feedstock from this plant and the transportation costs are negligible. Djomo *et al* (2008) [4]

In the bioreactor the potato peels are introduced at the flow rate of 800 Kg per hour and then they are hydrolysed to the protein rich fraction and the glucose rich fraction that is 400 Kg per hour and the glucose rich fraction then goes to the thermo-reactor with the thermophilic bacteria and they generate the hydrogen and then the liquor is clarified and the supernatant is taken to the photo-reactor where the photo-heterotrophic bacteria convert the organic components to the hydrogen and the carbon dioxide. The gaseous phase contains mostly the hydrogen as the carbon dioxide is in the liquid phase. The total hydrogen yield from both the processes is 57 Kg per hour and the protein rich substrate yield is 500 Kg per hour. Per Kg of the hydrogen produced, the 330 MJ of the energy is needed and 20 Kg of emissions are caused.

Table 3. Results from the impact assessment of hydrogen production in the 2 stage bioreactor from potato peels. Adapted from Djomo *et al* (2008) [4]

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### 4. LCA of Greenhouse Gas Emissions and Non-renewable Energy Consumption of Jatropha Bio-diesel and Conventional Diesel:

The main goal of the study is to compare the actual greenhouse gas emissions that are caused during the whole life cycle of the Jatropha biodiesel extraction and the usage process and the conventional biodiesel production and the usage process and also analyse the non-renewable energy that is consumed in both the processes. The functional unit is the 1MJ of JME or the conventional gasoline lower heating value. The function of the system is to deliver the biodiesel or the conventional diesel to the road vehicles and all the processes.

The well to tank scheme is used and the GHG emissions by the end product combustion is not included but this is compensated as the carbon dioxide absorbed by the plants during their life is also not included in the analysis and these two values are assumed to be similar and thus are both ignored but the diesel combustion is assumed to be complete in this study.

The impact assessment of the land use change when the energy crops are cultivated may be indirect when the energy crops replace the active carbon sinks like the forests or the other woodlands or indirect, when the energy crops are replacing the food crops and the other areas where carbon sinks are there are replaced by the food crops. Now, in the study, the Jatropha replaced the carbon crops and thus as the Jatropha stores three times the carbon within its body as compared to the cotton, the land use change can be safely assumed to tilt the environmental balance towards the Jatropha. But due to the lack of the incomplete data and the associated complexity of this analysis this LUC burden is not included in the LCA but the effect is only positive and thus ignoring it does not have the detrimental effect on the sustainability study of the Jatropha.

The environmental impacts of the Jatropha are there like the acidification and the eutrophication effects but they were not included in the study. The greenhouse gas emissions which were composed of the methane, nitrous oxide and carbon dioxide were converted to the carbon dioxide equivalents for the 100 years using the global warming potentials of the IPCC (intergovernmental panel on climate change). Energy consumption was measured in the MJ of the non-renewable energy. The JME in the study stands for the Jatropha methyl ester, which is the chemical name of the biodiesel that is produced from the Jatropha, which is in the form of the methyl esters.

Henceforth, the JME will be referred to as the biodiesel. Now, the energy yield of the biodiesel production process is 4.7 which mean that the 1 MJ of the non-renewable energy usage results in the production of the 4.7 MJ of the biodiesel energy. The usage of the non-renewable energy as the percentages in the various processes of the biodiesel production is shown in figure 11. The non-renewable energy usage is the most in the transesterification step. Ndong *et al* (2009) [5]

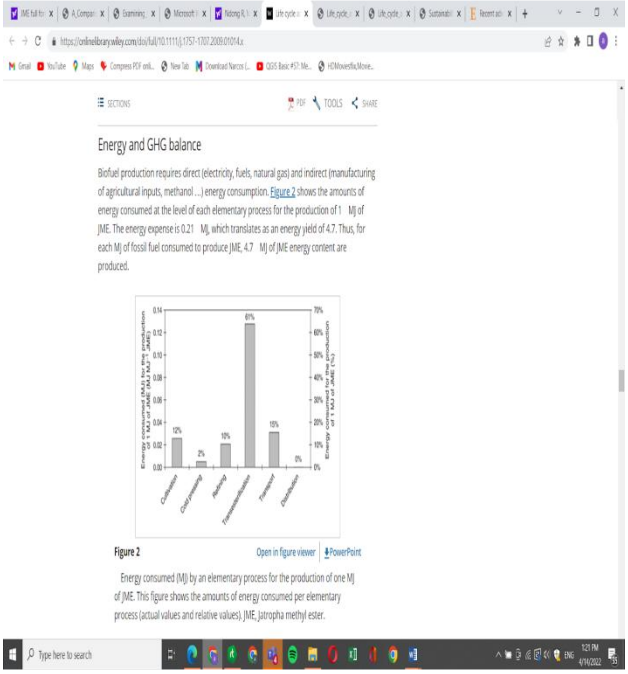


Fig 10. The non-renewable energy consumed by various processes in the production of the 1 MJ energy worth of Jatropha biodiesel (Jatropha methyl ester, i.e. JME). The non-renewable energy consumption is shown in the absolute units as MJ and also as the relative units, i.e. the percentage of the total non-renewable energy consumption in LCA 1 MJ worth of JME.
Adapted from Ndong *et al* (2009) [5]

The greenhouse gas emissions are the most in the cultivation and the transesterification reactions as the cultivation has the large quantities of the fertilizers required and their manufacture causes a lot of emissions while the energy usage for the transesterification is high as the methanol is needed in the large quantities and the process is very energy intensive. Now, for the overall process, the Jatropha biodiesel produces 23.5 g of carbon dioxide equivalent of the greenhouse gas emissions per 1 MJ of energy delivered.

This include all the emissions for the functional unit of the 1 MJ of energy content, ranging from the production process to the combustion and the transportation processes, both for the oil seeds and the produced biodiesel. The GHG emissions of the conventional diesel per MJ of the energy delivered, including all the production, transportation and the combustion processes is 83.8 g of carbon dioxide equivalent. Thus the replacement of the conventional diesel by the conventional diesel caused a 72 percent reduction in the greenhouse gas emissions and a total elimination of the tailpipe sulphur dioxide emissions.

International Journal of Scientific Research & Engineering Trends
Volume 8, Issue 4, July-Aug-2022, ISSN (Online): 2395-566X

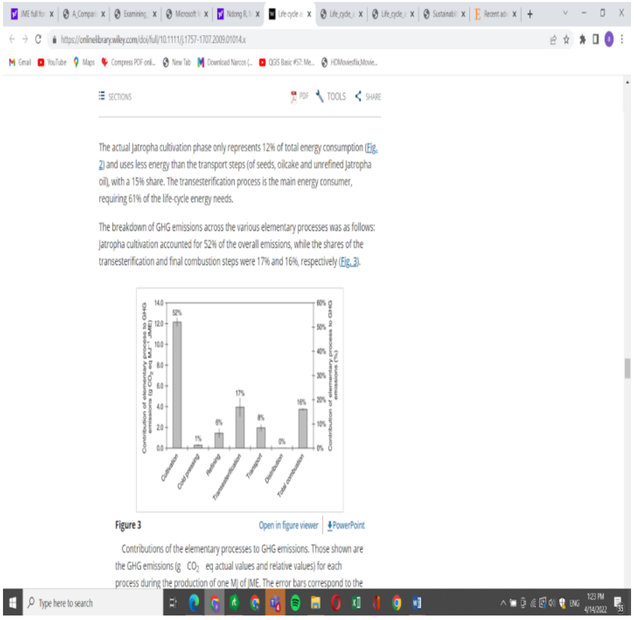


Fig 11. The Greenhouse gas emissions of various processes in the production of the 1 MJ energy worth of Jatropha biodiesel (Jatropha methyl ester, i.e. JME). The greenhouse gas emissions are shown in the absolute units as grams of carbon dioxide equivalents and also as the relative units, i.e. the percentage of the total greenhouse gas emissions in the LCA of 1 MJ worth of JME. Adapted from Ndong *et al* (2009) [5]

## IV. ADVANTAGES AND DISADVANTAGES OF USING BIOFUELS

The main advantages of the biofuel usage is the cleaner environment and biosphere as the production processes do not produce the dangerous recalcitrant carcinogenic species and thus the cancer and gene mutation prevalence in the population goes down. The biofuels also do not emit the hazardous gases like the carbon monoxide and the sulphur dioxide during their combustion and thus they reduce the air pollution. The biofuels are eco-friendly, bio-degradable and non-toxic and also don't have the sulphur or the aromatics and also they have the high oxygen content (over 50 percent) and thus they undergo complete combustion and are environmentally beneficial.

The disadvantages of the biofuels usage are the huge labour costs, the large land area that is needed to grow the crops for the biofuels, the large area needed to store the feedstock and also the large transportation costs and the large water requirement for the production of the energy crops as well as in the processes to create the biofuels. The biofuels are also much more viscous than the diesel and also are not that easily fluidized in the fuel tanks and thus the ignition efficiency of the biofuels is low and they so, they still have not been utilized on the large scales, in spite of their favourable environmental impacts. Shweta *et al* (2021) [1]

## V. CONCLUSION

As we can see in the case studies, many of the biofuels have the favourable environmental impacts as compared to the fossil fuels and they also give good energy yields when they are used in their pure forms also, but the problem that most of them face is the large capital investment that is needed to produce the biofuels and also they don't have very favourable engine dynamics, which means that they don't give the same energy output per Kg as compared to the fossil fuels and they can also increase the maintenance costs of the engines and thus they have not been able to capture the market of the transportation fuels. Research is ongoing to produce the fuels that have better physical properties and can compete with the fossil fuels in the engine dynamics.

Also the biofuels also have higher running costs as compared to the fossil fuels and the economic viability is also something that reduces the biofuel penetration in the fossil fuel market. There is the need for the governments around the world to encourage the biofuel usage through the subsidies on the capital investments so that the transportation sector greenhouse gas emissions can reduce and the sector becomes sustainable, for which the transition to the biofuels is a major step.

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