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UNDERLYING FACTORS INFLUENCING BIODIESEL PRICE INCREASE AND POSSIBLE SOLUTIONS

Ivie Ibuemi Otasowie

ABSTRACT

Biodiesel is a renewable alternative fuel that can help mitigate dependence on fossil fuels. However, barriers to the commercialization of biodiesel have led to increasing fuel, food, and biodiesel prices over the years. This study aimed to identify the root causes of biodiesel price hikes and offer solutions to encourage biodiesel production and commercialization. The biodiesel supply chain and production process were analyzed to pinpoint limiting factors like feedstock availability, logistics challenges, food crop competition, and regulatory uncertainties. Figures demonstrated rising biodiesel, diesel, and food prices from 2012-2022. Proposed solutions emphasized utilizing non-edible crops, strategic refinery locations, feedstock waste recycling, and technological innovation. Overall, this research highlighted critical obstacles hampering the biodiesel industry and provided feasible recommendations for growth. With refined policies, expanded production efficiency, and optimal use of resources, biodiesel can become a sustainably priced, scalable renewable fuel. Further analysis of logistics optimization, emerging feedstocks, conversion processes, infrastructure systems, and environmental impacts is warranted.

The key findings, objectives, and recommended next research steps are clearly summarized while emphasizing the paper's focus on addressing real-world issues in the biodiesel field. Revising and condensing this further could make an effective abstract to give context for the full research paper.

CHAPTER 1. INTRODUCTION

1.1 Introduction

The transportation, industrial, and energy sectors are expanding, which has put pressure on the pricing and supply of fossil fuels. The quest for alternative energy sources has also been aided by a rise in academic and general knowledge of global warming and the effects of greenhouse gas (GHG) emissions (Puri et al., 2012). Biobased energy is regarded as a critical sector in the international energy market by the energy industry and policymakers in both emerging and industrialized economies. This is mostly due to rising energy consumption, the introduction of new renewable energy sources, and the increase in price volatility that has resulted from the formation of alternative energy markets (Uddin et al., 2021). Over the years, there has been a rising need to increase biofuel production and reduce the use of fossil fuel. Fossil fuels are non-renewable energy sources that emit pollutants and have been connected to rising temperatures, climate variability, and even some terminal illnesses (Aransiola et al., 2014). The widespread use of a fossil fuel has a number of detrimental effects on the environment, society, and the economy (Ekener-Petersen et al., 2014; Uddin et al., 2021)

In recent years, substantial research has been conducted to find a viable replacement for fossil fuels. Renewable diesel, biodiesel, renewable jet/aviation fuel, and renewable heating oil are examples of biofuels with comparable physical qualities to petroleum distillate fuels and applications for which they can be utilized (U.S. Energy Information Administration, 2022)

The diesel engine was created in 1897 by Rudolf Diesel, who also examined using vegetable oil as the fuel in diesel engines. Because it is mostly utilized in diesel engines, the fuel generated from animal fats and vegetable oils that we now refer to as "biodiesel" bears his name (as does petroleum diesel fuel). Since biodiesel meets with American Society for Testing and Materials (ASTM) specification D6751, it can be mixed with petroleum diesel or distillate (U.S. Energy Information Administration, 2022).

1.2 Overview of Biodiesel fuel

Biodiesel is a type of biofuel. It is a fatty acid of methyl or ethyl ester (FAME or FAEE) which can be applied as substitute for diesel engine fuel. It is manufactured through the process of trans-esterification of vegetable oils extract and animal fat with catalyst in the form of methanol or ethanol. Biodiesel is non-toxic, renewable, and biodegradable; it contains no sulfur and is a better lubricant. Algae are currently regarded as one of the most promising non-edible oil sources for biodiesel. Due to downstream processing issues, a 'one size fits all' strategy to biodiesel synthesis may not be feasible. Advances in heterogeneous catalysts derived from natural resources or biomaterials may be helpful alternatives to traditional catalysts for commercial-scale biodiesel production (Aransiola et al., 2014; Madaan & Suneja, 2018).

In July 2022, the average B20 commercial fuel costs within the United States increased to 4.8 dollars per equivalent gallon of gasoline. In contrast, normal diesel fuel costs $5.02 USD. B20 fuel is a diesel mixture that contains 20% biodiesel. The price of fuel on the retail market increases with the amount of biodiesel it contains. In July 2022, B100 was marketed for an average selling value of 5.48 dollars, which is around 70 cents more than B20 diesel. As of October 2017, B20 was the least expensive choice (Sönnichsen N., 2022). Maize, vegetable oil, and sugar are the main feedstocks, also known as raw materials, used in biofuel production. While the production of biofuels has massively increased, raising hopes for viable alternatives to oil-based energy, there are growing issues about how rising raw material costs may affect the world's food supply chain (William T. Coyle, 2007).

The most significant element enhancing the efficiency of renewable fuels is the increase in oil prices. Original price declines below $50 per barrel are not predicted by projections. Strong demand-side variables, such as strong economic development and increasing oil consumption from quickly expanding middle-income economies, are the factors driving the present oil price (William T. Coyle, 2007).

The aim of this research is to identify the root causes of the significant biodiesel price increase and suggest solutions to reduce or eradicate them. This research might eventually help to alleviate the burden on fuel and food prices.

1.3 Statement of the Problem

According to a recent USDA analysis, the average price of biodiesel and petroleum diesel in some Midwestern parts of the United States rose from $3.93/gallon and $3.34/gallon, respectively, in December 2012 to $7.35/gallon and $5.75/gallon, respectively, as of July 2022. Depending on the feedstock utilized in production, biodiesel is now priced between 70% and 130% higher than fossil fuel on the wholesale market. It is thus imperative to identify the root causes of the alarming biodiesel price hike and offer ways to minimize or eliminate them. This study would ultimately help to mitigate the pressure on fuel and food prices.

1.4 Objectives of the study

The following objectives are highlighted to achieve the stated aim to:

i. To understand the processes involved in biodiesel production.

ii. To identify limiting factors to biodiesel commercialization

iii. To offer workable solutions to biodiesel fuel, and food price increment.

CHAPTER 2. LITERATURE REVIEW

2.1 Overview of Biofuel Supply Chain

The production of biomass feedstock, collecting, gathering, preserving, and transfer of the feedstock to the biorefinery, conversion of the biomass to fuel there, distribution of the fuel to end consumers, and usage of the fuel are all steps in the biofuel supply chain. Biomass is obtained from a variety of habitats, each with a unique set of production and collection expenses. A variety of economic expenses for feedstocks and sustainability result from these various environments. The economics of manufacturing biofuels, the economic impacts on other sectors, and the environment could all change with each new step of their production and use (National Academies Press, 2011). On the biofuel supply chain, there are few steps involved in the production before it gets to the consumers as seen in fig 1. The steps include feedstock production, feedstock logistics, biofuel production, biofuel distribution and biofuels end use.

Feedstock production

The crop's selection to grow is the first step in feedstock production. The productivity of a crop in a particular area of choice should influence the feedstock selection. In various parts of the world, some crops grow more successfully than others. Therefore, the farmer must research the climate of his chosen landmass to get the maximum yield of the chosen crop. Growing feedstock is the next phase in feedstock production.

Biomass production, or plant growth, is influenced by a variety of agronomic, environmental, and other factors. Some of the most crucial factors include soil moisture, soil and air temperature, air humidity, photoperiod, light intensity, soil fertility, or the availability of soil nutrients, and genotype (Amir Tajer, 2000).

2.2 Feedstock logistics

The process of the feedstock's logistics includes four basic steps: harvesting, storage, preprocessing, and delivery or transportation.

Harvesting and Collection: For the bioenergy feedstock supply system to have access to more resources, it is essential to collect renewable carbon sources. The timing and method of collection may have an impact on the quality properties that result, such as the resource's chemical composition and structural characteristics. The effectiveness and price of managing, storing, and transporting data downstream can be influenced by the collection format (Energy Efficiency & Renewable Energy, n.d.).

Storage: Controlling moisture content, material loss, and microbial deterioration are necessary for maintaining feedstock quality. Existing transportation infrastructure can be used to move resources and feedstocks by truck, train, or barge (Energy Efficiency & Renewable Energy, n.d.)

Pre-processing: Biomass is stabilized for longer-term storage through dehydration and densification, which also enhances performance and durability during handling, transit, and transformation. The physical and chemical variability of raw biomass can be reduced through blending and formulation for more dependable, predictable, and effective performance in downstream processing. Mechanical, thermal, and chemical preprocessing techniques can be used in combination or separately at different locations throughout the logistics chain. Depending on the situation, a different set of feedstock supply chain operations may be the most effective and efficient option (Energy Efficiency & Renewable Energy, n.d.).

Handling and Transportation: Moving renewable carbon sources from the field, the forest, or the waste facility to the preprocessing location is necessary, as is delivering preprocessed feedstocks to the conversion reactor's throat. Resources and feedstocks can be moved using the current transportation network via truck, train, or barge. Renewable carbon sources are converted during preprocessing operations into stable, standardized feedstocks with physical and chemical properties that meet the quality requirements of conversion facilities and can be moved using current, high-volume transportation and handling systems (Energy Efficiency & Renewable Energy, n.d.)

2.3 Biofuel Production

This process involves the conversion of feedstock into biofuel. To make biomass into liquid or gaseous fuels, biofuels must be converted from their original form. The most basic way to do this is through fermentation of crops that are high in sugar (starch) or fat into ethanol, which can be mixed directly with gasoline to power cars (USDA, n.d.). Advanced biofuels are often produced through a multi-step process, such as cellulose ethanol and renewable hydrocarbon fuels. The biological components cellulose, hemicellulose, and lignin, which are securely bonded together in the plant cell wall's strong, stiff structure, must first be broken down. Either high temperature deconstruction or low temperature deconstruction can be used to achieve this (USDA, n.d.-a).

In high-temperature deconstruction, solid biomass is broken down into liquid or gaseous intermediates by applying intense heat and pressure. This pathway uses three main routes: Gasification, pyrolysis, and hydrothermal liquefaction (USDA, n.d.-a).

In the process of **pyrolysis**, biomass is heated quickly at high temperatures (500°C–700°C) without any oxygen present. Biomass is converted into pyrolysis vapor, gas, and char by heat. Following the removal of the char, the vapors are cooled and condensed into a liquid "bio-crude" oil (USDA, n.d.-a).

The process of gasification is somewhat similar, but biomass is heated to a higher temperature (>700°C) while still having some oxygen present to create synthesis gas (also known as syngas), which is mostly a mixture of carbon monoxide and hydrogen (USDA, n.d.-a).

Hydrothermal liquefaction is the ideal thermal method for working with wet feedstocks like algae. In this process, water is used to transform biomass into liquid bio-crude oil under elevated pressures and moderate temperatures (200°C–350°C) (USDA, n.d.-a).

Low-Temperature deconstruction

Chemicals or biological catalysts called enzymes are frequently used in low-temperature deconstruction to break down feedstocks into intermediates. The physical structure of plant and algal cell walls are first opened during a pretreatment process on biomass, which increases accessibility to sugar polymers like cellulose and hemicellulose. The hydrolysis process subsequently breaks down these polymers chemically or enzymatically into the building elements of simple sugar (USDA, n.d.-a).

To create a completed product after deconstruction, raw intermediates like syngas, sugars, and other chemical building blocks must be improved. This process can be biological or chemical. To create a completed product after deconstruction, raw intermediates like syngas, sugars, and other chemical building blocks must be improved. Processing on either a biological or chemical level can be used in this step. Microorganisms can ferment sugar or gaseous intermediates into fuel blend stocks and chemicals, including bacteria, yeast, and cyanobacteria. As an alternative, sugars and other intermediary streams, such bio-oil and syngas, may be treated using a catalyst to get rid of any unwelcome or reactive substances and enhance storage and handling qualities. The upgraded final products may be fuels or bioproducts that are ready for commercial sale (USDA, n.d.-a).

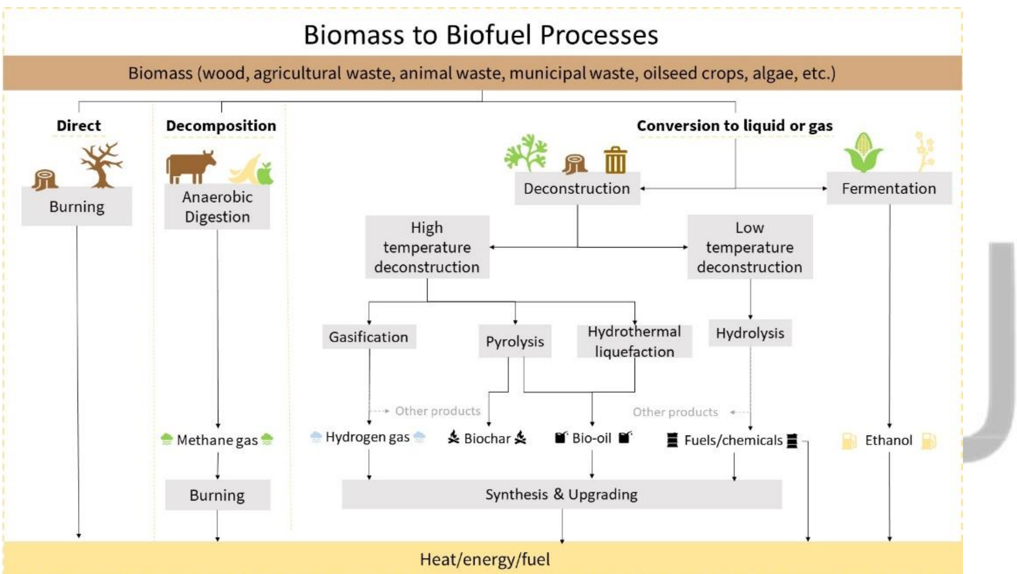

Figure 1: Biomass to Biofuel Process (USDA, n.d.-b)

2.4 Biofuel Distribution

Biofuels are first delivered to the mixing stations where they are blended with fossil fuel. In the United States, ethanol is produced close to the feedstocks that are used to make it. The main cause of this is that refineries must be built close to reliable sources of bio feedstocks because of the high weight of ethanol feedstocks relative to the weight of finished ethanol. Since most domestically manufactured ethanol is made from maize, most refineries have been constructed in the great Lakes region, one of the nation's corn-growing regions (Frank Rusco, 2012).

Currently, rail is the primary mode used to transport biofuels to massive liquid fuel terminals for mixing and delivery to refueling stations. Because ethanol is a potent solvent that has the potential to cause pipeline corrosion as well as the deterioration of seals and other pump parts, it cannot normally be transported in multi-fuel pipelines that are currently in use. Ethanol also absorbs water and disperses leftovers from other fuels left in the pipelines (Frank Rusco, 2012). Because of this, ethanol transported through pipelines could reach a terminal with a specification that is not within the range of acceptable. This is a problem at ports where ethanol will be combined with gasoline carefully prepared to fulfill stringent carbon emissions standards. Because rail transportation is so important, biofuel refineries are constructed alongside existing rail lines (Frank Rusco, 2012).

2.5 Potential Oil Crops for Biodiesel Production

Humans have historically benefited from oil-producing plants. For many millennia, hunter-gatherers had been harvesting wild plants with oil-bearing seeds or fruits before agriculture was invented and plants were domesticated. In addition to having calorie-dense and nutrient-rich meals, the oils from such plants were used for a variety of non-edible purposes, such as illumination, fuels, lubricants, and even some sorts of cosmetic use. Among the first plants to be tamed and raised as crops were those that produced oil. A variety of well-known oil crops have been grown for more than 7,000 years. These include annual oilseed plants like sesame as well as perennial fruits with high oil content from tree crops like olive or oil palm (S.K. Gupta, 2012).

Numerous oilseed crops and animal fats can be used to make biodiesel. The feedstocks used for biodiesel production can be grouped into four categories: edible oils, inedible oils, oils from microorganisms (e.g algae) and animal fats (Sales et al., 2022).

Rapeseed oil is the main feedstock for biodiesel in Europe. Soybeans are the most common biodiesel feedstock in the US (Farm Energy, 2013). Various agricultural crops, such as corn, sugarcane, wheat, and edible oils, such as rapeseed, sunflower, soybean, and palm, have been used to manufacture biodiesel as the feedstock for the first-generation biofuel. However, the use of edible oil and agricultural crops to make biodiesel has highlighted the possibility of a "food vs. fuel" conflict. The biodiesel market does not intend to compete with the food sector; hence, it is vital to emphasize the significance of those that are not edible. Because edible oils are highly valued, there is pricing competition, which drives up the cost of these products (Sales et al., 2022). The world's population is expanding quickly, and people are consuming large amounts of edible oils, which can lead to major issues like famine in developing nations. Non-edible oils thus become a category that seems highly viable as a replacement source for the generation of biodiesel (Sales et al., 2022). Non-edible vegetable oils have been suggested as a raw material to reduce the number of food crops diverted for biodiesel production, but there are still issues with their availability to adequately feed the biofuel industry. However, if methods such combining conventional esters (obtained from edible oils) are used, shortages in the supply of inedible oils may be addressed. Additionally, by adding non-edible ester to the mixture, the proportion of edible sources can be decreased. Examining unconventional oilseeds may reveal the potential for large yields at the conclusion of the biofuel production process (da Silva et al., 2020).

2.6 Background of some Oil crops grown in USA

Pennycress

Pennycress, often known as French weed or stinkweed, is a winter annual plant in the Brassicaceae family. Although there have been recent attempts to grow it, it has historically been a weed in the Midwest. The plant can be used in a summer to winter rotational cycle to complement current agricultural productivity as opposed to replacing traditional commodity crops (like maize or soybeans). Field pennycress is a non-food crop that can grow in unused land, has a high oil content (up to 36% oil), and works with standard farm infrastructure (Tao et al., 2017). In the bulk of the midwestern United States, pennycress can be planted in the fall after the corn harvest and harvested in the spring using conventional agricultural equipment. Field pennycress does not contain any food and doesn't require much in the way of fertilizer, pesticides, or water. It also tolerates marginal sites that are unsuitable for traditional agriculture (Moser et al., 2016).

Camelina

In west central Minnesota, a state in the north central United States, camelina (*Camelina sativa L.)* performs admirably as an oilseed crop. Camelina is an annual flowering plant in the Brassicaceae family, which also includes the well-known oil crops rapeseed, canola, and mustard. It is often referred to as fake flax or gold-of-pleasure. Camelina is superior to other oilseed crops in terms of oil content (around 35% oil), drought resistance, and water use efficiency (yield vs. evapotranspiration). These characteristics make camelina an excellent biofuel crop for the dry western states, which frequently have few opportunities to cultivate biofuel feedstock. Camelina grows using the same technology as wheat and requires no agricultural input, thus it could replace fallow, provide an energy crop, and not compete with the production of food crops (Tao et al., 2017).

Rapeseed

Rapeseed is an annual herb that grows well in cool, humid regions (Jaime et al., 2018).The USA's south-eastern and pacific northwest regions have recently produced the most rapeseed. In 2020, the average yield of rapeseed was 1,971 pounds per acre. Rapeseed does well in a variety of well-drained soil types, favoring pH values between 5.5 and 8.3, and is only moderately tolerant of saltwater soils (AGMRC, 2022). Since antiquity, people have used rapeseed oil, one of the primary biofuel sources, to cook food and light their homes. The most popular rapeseed oil is canola because it has less erucic acid than other rapeseeds. In addition to being a biofuel, canola provides food for people and animals. Canola is an exception due to its low saturated fat content, which hinders the formation of ice crystals. Canola does not burn poorly, even though most biodiesels generated from plants do not due to the highly saturated lipids, especially in cold conditions. Canola contains more oil overall than other vegetable oils (Sharon Omondi, 2019). A series of canola types known as winter canola require fall planting and mature by early to mid-summer. Spring canola is sown in the early spring and harvested in the second half of the summer, just as spring wheat. In Missouri, both spring and winter canola have been studied, but winter canola has clearly proved superior due to higher yields and fewer insect problems. Winter canola's earlier harvest also makes it possible to double-crop after canola harvest with a second crop like soybeans or sunflowers (Rob Myers, 2018). The market for industrial rapeseed is fairly developed. However, there is a likelihood that as attention on renewable resources and biodegradability grows, demand in raw materials such high erucic oil rapeseed may rise. But because there is now a tiny market for it, rapeseed should be grown on contract. On a farm, biodiesel can be produced using canola or rapeseed (AGMRC, 2022).

Sunflower

The plants are quickly gaining popularity as feedstock crops for biodiesel due to their similarities to other crops like canola and soy. Since the seeds of the sunflower plant have a high oil content of up to (Sharon Omondi, 2019). Sunflower yields in arid settings typically average 1,300 pounds per acre, while yields of more than 2,000 pounds per acre under irrigated or frequently rained circumstances are not common. Oil typically has a content of 40–42%. From one acre of sunflower seeds, 35 to 80 liters of oil are produced. The growth environment, how the seed was treated after harvest, and whether it was done chemically or mechanically all affect how much oil is extracted from the seed (Farm Energy, 2019).

The seeds themselves can be processed into biodiesel, or the plant waste from the plants can be used as biomass to fuel businesses and power plants. According to research by the National Sunflower Association, one acre of sunflowers can provide up to 600 pounds of oil. The amount of oil extracted from sunflower seeds varies depending on several factors, including the growth environment and methods used to extract the oil (Sharon Omondi, 2019)

2.7 Biodiesel Supply chain challenges

2.71 Feedstock Production Challenges

The two main challenges limiting growth in the biofuel renewable fuel market are:

Feedstock supply limitations: The rise of the generation of renewable fuels is causing a demand surge for feedstocks that is unprecedented. The capacity of renewable diesel in the US is expected to double in future. The increase in capacity will be more than the total supply of fats, used cooking oil, and greases on the domestic US market. To identify feedstocks to support the expansion of the renewable diesel and sustainable aviation fuel industries, buyers will need to broaden their search both geographically and in terms of materials (Fast Markets, 2022).

Legislative uncertainties: Market instability has previously resulted from small refinery exemptions and delays in mandate releases, and future market instability could result from calls for mandate rollbacks. The former trading environment was unstable due to small refinery exemptions (SREs) and delays in the release of renewable volumetric obligations (RVOs). Concern over international biofuel mandates is now being raised because of the prospect of high grain and oilseed costs as well as government pressure related to food insecurity. In order to satisfy current production and usage estimates, biofuels producers and buyers must act swiftly, assuming that regulation governing blending regulations in the US won't undergo significant modifications (Fast Markets, 2022).

One on the recent research by (Fast Markets, 2022) discovered that the projection for feedstock production continues to increase year over year. A best-case scenario for the production of raw materials should ideally presume that sustained, long-term increases in output and imports will support feedstock supply. This is not the case though. Increases in yield will be used to expand the supply of feedstocks, but the rate of technological advancement required to enhance oil output for both oilseeds and waste-based products is significantly faster than that of the renewable sector. Buyers will therefore want to import more feedstocks, however rising local demand may shorten supply in the near future. the expansion of feedstock supplies from the meat-packing industry is threatened by high feed costs, which are partly caused by the drought and a wide range of supply chain problems. The gathering of waste-based feedstocks may be slowed down by the greater costs of raw materials, such as soybean oil for cooking (Fast Markets, 2022).

2.72 **Feedstock logistics challenges**

Since the places where biomass is typically gathered and collected, as well as the locations of the plants that turn it into energy, are not always the same, transportation efforts are necessary, which have an influence on both the environment and society (Amit Kumar et al., 2006; Gold & Seuring, 2011).

Logistics distances, or the proximity of the biomass source and the conversion facility, are strongly correlated with transport emissions. Emissions are heavily influenced by the manner of transportation. For instance, compared to truck transportation, long-distance shipping emits far less CO2 per unit of length (Gold & Seuring, 2011).

Frequent truck transfers that cause traffic jams may readily elicit resistance from the residents of impacted towns. Pipeline transportation would limit these kinds of detrimental effects of biomass transportation on the neighborhood because it would require fewer loads, which would improve the situation (Amit Kumar et al., 2006; Gold & Seuring, 2011). However, keep in mind that carrying biomass by pipeline renders it incompatible with combustion for the purpose of converting it into energy because the carrier fluid considerably limits the biomass's ability to heat up (Gold & Seuring, 2011; Searcy & Mentzer, 2003).

CHAPTER 3. METHODOLOGY

3.0 **Methodology**

To carry out this research, it is necessary to first comprehend the many steps in the manufacture of biodiesel and then pinpoint obstacles to its commercialization. Then, we may suggest practical strategies to encourage the production and sale of biodiesel.

At every stage of their development and use, biofuels have greenhouse gas emissions. Some impacts are obvious, like odors emanating from an ethanol plant. Others are less obvious, such as those that originate from actions taken throughout the biofuel supply chain (for instance, nitrate seeping into surface waterways because of nitrogen fertilization on corn fields) and others that might take place outside the supply chain due to economic impacts (for example, loss of biodiversity upon land-use change induced by higher corn prices). On a regional, local, national, or international scale, several consequences may manifest. While some of these effects are simple to evaluate, others are more challenging (*Renewable Fuel Standard*, 2011).

3.1 Biodiesel Production Process

Using transesterification process, vegetable or animal lipids are combined with alcohol to create biodiesel (Knothe G et al., 1997; Romano SD et al., 2006; van Gerpen J et al., 2004). This chemical process converts vegetable oil or animal fat into biodiesel. Biodiesel is created by purifying a mixture of fatty acid methyl esters (FAME). Depending on the catalyst used, transesterification can be enzymatic, basic (commonly used at all production scales), acidic (less frequently used in manufacturing output, occasionally used as the first stage with very acidic raw materials), or both (less used; the enzymes are usually lipases). Although transesterification—which produces a mixture of esters—is the most crucial step in the production of biodiesel; additional processes are necessary to make a product that meets the international standard. (Meher LC et al., 2006; Romano SD et al., 2006). Once the chemical reaction is complete, and the two phases (mix of esters and glycerin) are separated, the methyl esters mixture must be filtered to reduce the concentration of pollutants to acceptable levels. These include unused catalysts, extra water, and methanol, which is frequently added to the raw materials in excess to improve the transesterification reaction's conversion efficiency (Romano & Sorichetti, 2010).

3.11 Stages of Biodiesel Production (Romano & Sorichetti, 2010)

i. Treatment of raw materials

The quantity of free fatty acids, water, and non-saponifiable molecules are crucial factors in achieving high thermal efficiency in the transesterification reaction. If the triglyceride (FFA) concentration is under 2%; basic transesterification is feasible. As the acidity of the oil rises, the reaction's efficacy falls. To reduce the amount of FFAs to 2%, acid conversion is necessary as a preliminary step in the case of extremely acidic raw materials (animal fats from cows, poultry, and swine; vegetable oils from cotton, coconut, and most extensively used oils, etc.)(Romano & Sorichetti, 2010; Tomasevic AV & Marinkovic SS, 2003).

ii. Alcohol-Catalyst Mixing

Before infusing the oil, the catalyst and alcohol required to produce biodiesel must be combined. The mixture is kept going until the alcohol and catalyst are fully dissolved. Alcohol should not include any water; it should be emphasized (anhydrous). The most popular kinds of basic catalysts are sodium and potassium hydroxide salts. Commercially accessible sodium, potassium, or methylates can be used for industrial-scale manufacturing (Romano & Sorichetti, 2010).

iii. **Chemical Reaction**

The chemical reaction is brought about by the combination of oil and alkoxide (alcohol–catalyst mix). This necessitates timing, temperature, and stirring demands (Freedman B et al., 1984; Meher LC et al., 2006). The chemical reaction is typically carried out under pressure and at an elevated temperature because alcohols and oils do not interact at ambient temperature (Romano & Sorichetti, 2010).

Catalysts

Catalysts for triglyceride transesterification can be classified as basic, acidic, or enzymatic (Ma F & Hanna MA, 1999; Vicente G et al., 2004).

Sulfonic acids, sulfuric acids, and hydrochloric acids are examples of acid catalysts; less research has been done on how to use these Enzymes, titanium silicates, alkaline earth metal complexes, and anion exchange resins are a few examples of based catalysts that have been studied for the synthesis of biodiesel (Bayense CR, 1994; Peterson GR & Scarrah WP, 1984; Vicente G et al., 2004). Lipases are the enzymes that are most frequently used in the synthesis of biodiesel (Romano & Sorichetti, 2010).

iv. Separation of the Reaction Products

Due to their distinct densities, fatty acids methyl esters (FAME) separate from glycerin to create two phases, which start to form as soon as the mixture's agitation is halted. This method of separating reaction products is known as decantation. Most of the catalyst and excess alcohol will accumulate in the lower phase (glycerin) because of their differing chemical affinities, whilst most of the mono-, di-, and triglycerides will focus solely on the upper phase (FAME). The two solutions may be differentiated once the interphase has been established in full and with clarity. It should be noted that decantation will take several hours to complete if it happens because of gravity alone (Romano & Sorichetti, 2010).

v. Purification of the Reaction Products

To meet the set performance criteria for biodiesel, the mixture of fatty acids methyl esters (FAME) produced by the transesterification reaction must be refined. FAME needs to be cleaned, neutralized, and dried as a result. Methanol, catalyst, and glycerin residue are all removed through repeated washings with water because these pollutants are water soluble. Emulsions must be carefully avoided during the washing procedures because they would reduce the procedure's effectiveness. The initial washing procedure is finished with acidified water to balance the esters mixture. The latter two washing procedures simply use water. The last step is to dry the material to remove any remaining water. Once it has dried, the refined product is prepared to be labeled as biodiesel in accordance with international regulations (Romano & Sorichetti, 2010).

3.2 Limiting Factors to Biodiesel Commercialization

Several barriers to the commercialization of biodiesel have led to an annual increase in the price of fuel and biodiesel (U.S. Environmental Protection Agency, 2022). The difficulties in achieving the RFS2 standards for biofuel consumption can be divided into three groups: market-based, technological, and regulatory (Frank Rusco, 2012). In terms of lifecycle water use, criterion air pollutants, land use effects, and greenhouse gas emissions, various biofuel feedstocks and production methods have varying consequences. Therefore, any policy aimed at these more general problems may alter, which could affect the production and usage of biofuels (U.S. Environmental Protection Agency, 2022).

Land availability & Proximity to Refineries: Numerous crops that would typically be utilized directly for human consumption or indirectly as animal feed are included as biofuel feedstocks (U.S. Environmental Protection Agency, 2022). The conversion of these crops to biofuels may increase the amount of land used for agriculture, the amount of polluting inputs used, and the cost of food (U.S. Environmental Protection Agency, 2022). Additionally, cellulosic feedstocks may compete with food production for resources like land, water, and fertilizer. Because of this, some studies contend that biofuel production may result in many unfavorable changes (U.S. Environmental Protection Agency, 2022).

To determine the impact of the need for ethanol on local agriculture, researchers from ERS examined farmers' plant choices in relation to the development and expansion of ethanol refineries in their area. The researchers used annual crop data to analyze the impacts of ethanol refineries on areas where maize was grown in 12 states between 2006 and 2010. The findings demonstrate that the presence and capacity of an ethanol refinery nearby had a statistically significant and widespread impact on maize growers. In 2006, a 1% gain in a neighborhood's capability for refining typically led to a 1.5% increase in the area used for growing maize and a 1.7% increase in all agricultural land. In other words, the cultivation of an additional 67 acres of maize within a

100-kilometer radius of a refinery was a result of a refinery's capacity increase of 1 million gallons (about 3785410 L) in 2006. Increased corn plantings and total agricultural land, particularly in areas near ethanol refineries, call attention to the expanding ties between farming and the energy market as well as the obvious effects of the biofuels business on rural economies and habitats.

Environmental Impacts: Modifications in land use practices may increase greenhouse emissions by discharging terrestrial carbon stocks into the atmosphere (Searchinger et al., 2008). GHG emissions from the production of tropical biofuel feedstocks like soybeans in the Amazon and oil palm in Southeast Asia, which are grown on land cleared of tropical forests, are especially high (Fargione et al., 2008). GHG emissions from the production of tropical biofuel feedstocks like soybeans in the Amazon and oil palm in Southeast Asia, which are grown on land cleared of tropical forests, are especially high (Melillo et al., 2009). The production and processing of biofuels may release GHGs (Green House Gas) using certain methods. Nitrous oxide, a potent greenhouse gas, is released when fertilizer is administered. Most biorefineries use fossil fuels to power their operations. Some studies indicate that GHG emissions from the development and use of biofuels, including those from passive land use change, could be higher than those produced by fossil fuels depending on the time of the investigation (Aline Mosnier et al., 2012; Melillo et al., 2009).

According to research on non-GHG environmental consequences, the expansion of biofuel feedstocks, particularly agricultural crops like maize and soy, may lead to an increase in environment degradation from fertilizers, pesticides, and silt (National Research Council, 2011). As ethanol production and irrigation rise, aquifers may become depleted (National Research Council, 2011). The impact of biofuels on tailpipe emissions and the additional emissions emitted at biorefineries, which together could lead to higher conventional air pollution, could cause air quality to worsen in some locations (National Research Council, 2011).

Higher Food Prices: Although there is a wide variety of estimates in the literature, economic models demonstrate that the usage of biofuels may lead to increased crop prices. For instance, estimates for the impact of biofuels on maize prices in 2015 ranged from a 5 to a 53 percent increase, according to a 2013 study (Zhang et al., 2013). Several analyses found a 20–40% increase in maize prices from biofuels between 2007 and 2009, according to the National Research Council's (2011) study on the RFS. According to a working paper from the National Center for Environmental Economics (NCEE), 19 studies on average showed a 2 to 3 percent increase in long-term corn prices for every billion additional gallons of corn ethanol production (Condon et al., 2013) Higher agricultural prices result in higher food prices, however, the effects on US retail food are predicted to be minimal (National Research Council, 2011). In poor nations, rising crop prices can result in higher rates of malnutrition (Günther Fischer et al., 2009; Mark W. Rosegrant et al., 2008)

Laws and Policies: The policies and legislation provide parties interested in developing, constructing, and running biodiesel production plants with information on federal environmental activities and the responsibilities of federal, state, and municipal agencies. The United States Environmental Protection Agency and its state partners carry them out. There may be standards for air, water, hazardous waste, accident prevention, and release reporting. Operators of biodiesel facilities must evaluate all applicable laws and rules (United States Environmental Protection Agency, 2008). Every state has different regulations regarding the manufacturing of biodiesel, so it's necessary to know what to do and who to talk to. Some policies governing production are as follows; National environmental policy act, clean water act (CWA), Safe drinking water act, clean air act, Emergency planning and community Right to know act (EPCRA), Resource Conservation and Recovery Act (RCRA), and Toxic Substances Control Act (TSCA).

Technological Challenges and Biofuels Infrastructure: The future mix of biodiesel available in the market will depend on the nature and speed of technological advancement and will require expansion and potential changes to the modes of liquid fuels transportation and distribution, and the motor vehicle fleet. However, until the path of technological innovation through to commercialization is clear, making infrastructure investments will be fraught with risk (Frank Rusco, 2012).

Biomass-based diesel can be made from vegetable oils or animal fats, and the production scale is limited by competition for land to grow feedstocks, land that has alternative uses, including growing food crops. If biomass-based diesel is to expand much, the infrastructure needed to support this will primarily be associated with new production facilities and additional rail capacity. Beyond that, there is the issue that not all biodiesel is mutually compatible, and to the extent that biodiesel use expands, additional storage and blending infrastructure may be required to avoid blending incompatible fuels (Frank Rusco, 2012).

Other power train alternatives to fossil liquid fuels, such as electric vehicles or hydrogen fuel cell technologies could overtake advanced biodiesel technologies, obviating the need for additional biodiesel infrastructure and making some existing infrastructure obsolete (Frank Rusco, 2012).

Large infrastructure investments in development, transport, marketing, and auto manufacturing will be necessary to expand biofuels use and production. For the market for fuel sources to effectively incorporate rising amounts of biofuels, coordination of all these investments will be necessary. Further, investors' capability of financing this will primarily depend on how eager customers are thought to be to adopt new technology and fuels (Frank Rusco, 2012).

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CHAPTER 4. RESULTS AND DATA ANALYSIS

4.0 Results/Data Analysis

According to literature data, the cost of biodiesel, fuel, and food keeps rising every year because of several barriers to its commercialization. Fig 4.1 shows a chart of the biodiesel price increment from 2012 to 2022.

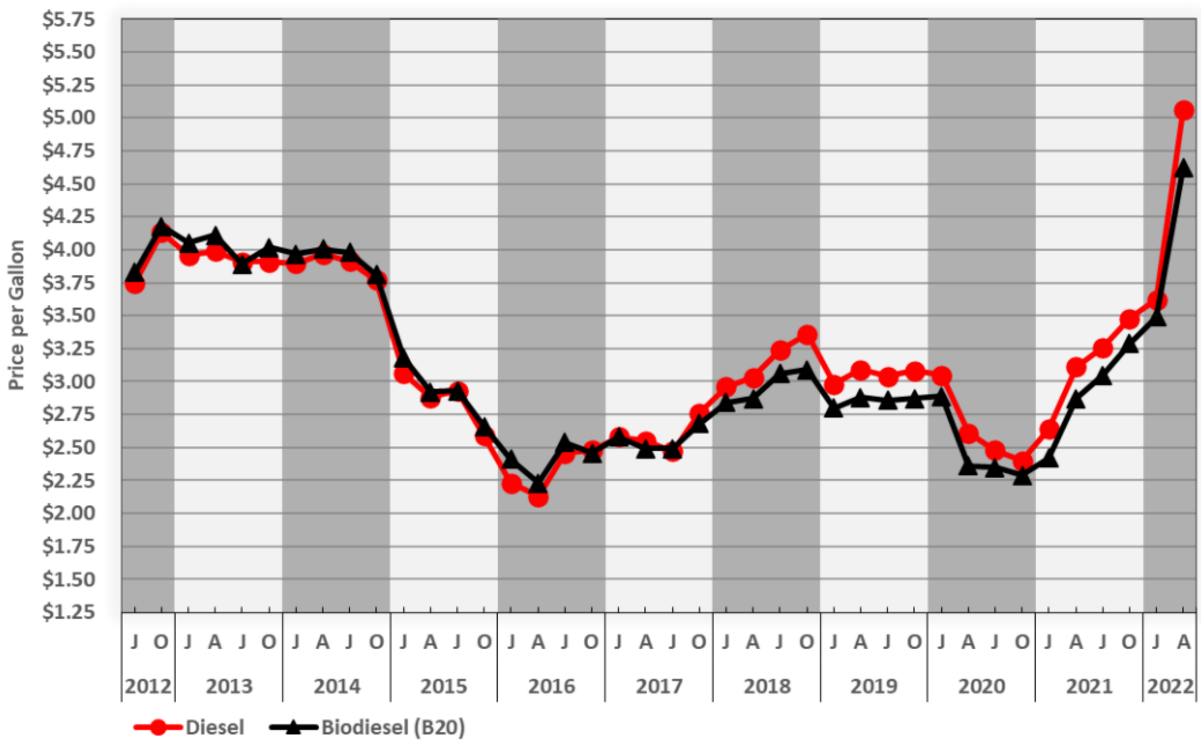

Fig 4.1 Biodiesel (B20) Prices Versus Diesel (U.S Department of Energy, 2022)

It is clear from Fig. 4.1 that from 2016 to 2019, the cost of diesel and biodiesel increased steadily. The COVID-19 epidemic in 2020 caused biodiesel and fuel prices to fall; however, towards the start of 2021, prices began to rise again.

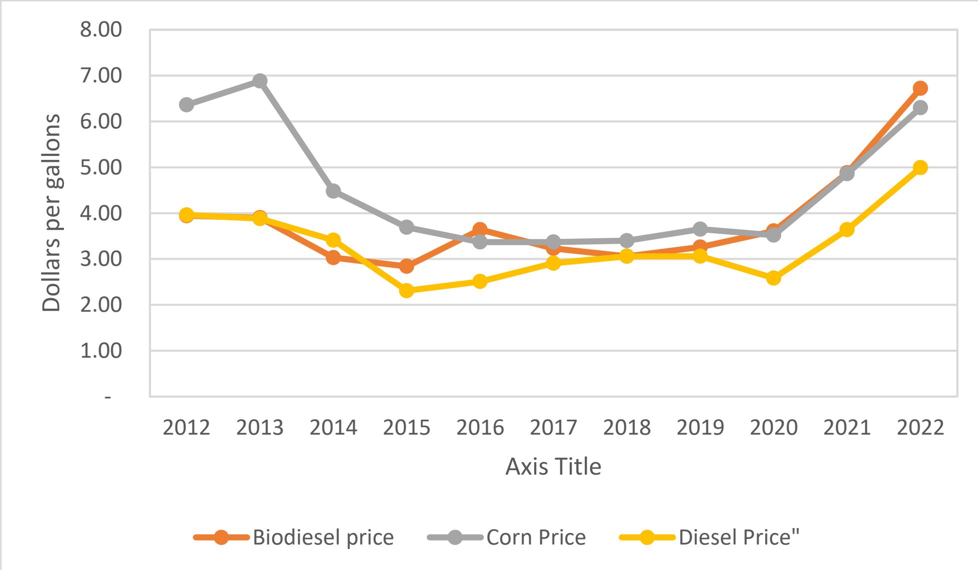

Fig 4.2 Biodiesel price against food price(USDA, 2022)

A graph showing the price of biodiesel in relation to the price of food from 2012 to 2022 is shown in Figure 4.2. The data used to plot figure 4.2 was gotten from (USDA, 2022). Figure 4.2 shows that, following the drop in 2013, the price of food (corn) increased again. Due to the increased demand for corn for use in the production of biodiesel, corn prices continued to rise from 2016 to 2022. If the appropriate steps are not taken, food prices will keep rising in the future.

The findings from Figures 4.1 and 4.2 show that, although being a cleaner source of energy, biodiesel production has not been entirely beneficial to the US economy. Consequently, commercialization has its limitations.

Under the titles, "oil extraction from feedstock, closeness to refineries, and usage of feeds from extracted oil seed," several feasible solutions to the biodiesel and food price hikes will be covered. Because of the intense competition between energy production and human consumption, food crop prices have increased. To lower the cost of food crops, non-edible crops should be used to produce biodiesel.

Additionally, refineries should be situated close to areas used for the cultivation of oil crops used to make biodiesel. This will lower the cost of moving oil from the fields to the refineries, which will lower the price of making biodiesel and encourage its commercialization.

Typically, the residues left over after oil extraction from oil crops are regarded as waste. Instead, you should think of other strategies for extracting the remaining oil from these feeds before using them. Increasing the overall amount of oil utilized to produce biodiesel will encourage its commercialization.

CHAPTER 5. DISCUSSION

The goals for improved biodiesel have not been reached recently. Although technology is developing, mass production of advanced biodiesel does not seem to be imminent. Technically better options for diesel fuel continue to pose a threat to expanded biodiesel production and use. Other climate and environmental factors, as well as alternative uses for land and water, present difficulties in increasing domestic biodiesel production. It will be exceedingly challenging to reach an agreement among all parts of the liquid fuel value chain over the form and rate of infrastructure investment due to its significance. The degree of regulatory and technological uncertainty these factors create regarding the future of biodiesel. This study identified the challenges to the commercialization of biodiesel and offered workable solutions. In this study, some of the workable solutions to biodiesel and food price increase were discussed under oil extraction from feedstock, proximity to refineries, and utilization of feeds from extracted oil seed.

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