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Bioethanol Production from Cassava and Sugar Cane Molasses

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Abstract—Bioethanol is produced from the fermentation of sugar. The process required sugar to produce ethanol derived from fuel or energy crops such as cassava, molasses, and sugar cane. Basically, ethanol is burned to produce carbon dioxide and water, releasing energy. The advantages of bioethanol over the conventional gasoline are higher volumetric energy density, higher engine compression ratios and cheaper price of gasoline produced. This study compares the production of bioethanol from cassava and molasses in terms of its retail prices, ease of accessible resources, global warming potential and dependence on fossil fuels. Besides, the effects of bioethanol production also were discussed in the related topic of food security, feedstock supply security, job opportunities, improvement of air quality, impact on deforestation, fuel price stability and stabilizing the income of farmers.

Keywords—bioethanol, cassava, molasses, biotechnology

7.1 Introduction

For centuries, human beings have depended solely on Mother Nature to sustain and keep living. Yet at the beginning of the twentieth century, modernisation happened, and the pattern changed as organic chemistry developed tremendous methods and technologies to manufacture products for living basics [2]. Many biotechnology firms continue to investigate the possibility and complexity of nature in terms of resources, techniques, and strategies to be utilised for human consumption and as well as its value-added benefits. The question strikes: what is biotechnology? And how does it work in adding value to the quality of human's life?

Biotechnology is an emerging technology focused on the application of cellular and biomolecular processes to create new technologies and products to provide a better living experience [3]. Biochemical pathways such as in fermentation, harnesses biocatalysts namely enzymes, yeasts, and other microbes as the miniature plants.

Biotechnology is helping to impact the world by:

a. Simplification of the chemical manufacturing processes for more than 80%.
b. Lower cleaning temperature for operation needed.
c. Improving efficiency of manufacturing processes and reducing costs by more than 50%.

d. Reducing dependency and usage on non-renewable petrochemicals.
e. Reducing fuel related emissions by more than 52% when biofuel is used.
f. Minimized waste produced.
g. Conversion of waste to wealth by tapping its potential.

Industrial biotechnology, also known as white biotechnology, involves the production of industrial goods, such as chemicals, plastics, food and beverages, agricultural and pharmaceutical products as well as energy carriers consumed by microorganisms and enzymes [4].

Renewable raw materials from agricultural and forestry wastes are often used to produce industrial products. This sector applies a greener approach to replace conventional and polluting technologies. The white biotechnology is used for metabolite processing, waste management, bio-control agent processing, biofuel production, and energy generation. It deals with the isolation of microorganisms from nature, screening of valuable compounds for drug creation, increasing drug yield, crop and disease maintenance, mass production through bioreactors and the recovery of products or services [2].

Biofuel is considered as renewable energy, unlike fossil fuels (petroleum, coal, and natural gas) as the feedstock resources can be easily replenished [5]. Any oil provided by the process of biomass, be it from plant, algae material or animal waste are known as biofuel or bio-based fuel. Three types of biofuels are bioethanol, biodiesel and biobutanol. Bioethanol for example is a fluid phase material (liquid) from many kinds of feedstocks including corn, wheat straw, soybeans, woodchips, and microalgae [6]. This biofuel is produced from acetone-butanol-ethanol (ABE) fermentation that is also oxygenated (35% oxygen). Due to this, the white biotechnology has great potential to reduce automobile emissions [6].

Hence, this study focused on bio-based fuel and energy production of bioethanol specifically in Thailand as the study case and with intention to review the appropriateness of application in Malaysia. Thailand is currently encountering a crisis regarding its overdependence on foreign oil purchases. The country is seeking an alternative way to boost their national energy protection by reducing their demands for foreign oil with their crude oil, gasoline, and diesel nearly reaching 100% imports [1]. The model developed by our neighbouring country could be used as a studied model for Malaysia.

The possibility of net ethanol income from the reduction of oil imports is the key driving force behind efforts to accelerate its development and usage in countries that are net oil importers such as China, Brazil, and the United States [7]. Indeed, one of the problems arising from the widening use of ethanol is its relatively high price over petrol. That scenario is also observed across Asia.

This study relies on a report carried out by Travis (2012). The history and sustainability analysis for both molasses and cassava-based ethanol is discussed here [1]. In 2018, a working paper of Stockholm Environment Institute by Matthew Fielding and May Thazin Aung, stated that sugarcane and cassava are the two main feedstocks for bioethanol production, with sugarcane dominating the market (70% of overall ethanol production) due to its lower utilisation [8]. However, which feedstock is more efficient to be used as bioethanol based is still debatable. Figure 1 sets out a timeline documenting the bioethanol development history in Thailand from 1985 to 2002.

1985

HRH King Bhumipol requested a study of the cost of producing alcohol from sugarcane for alternative fuel, and an ethanol facility opened in the Royal Chitralada Palace. However, the cost of bioethanol production was found to still be much higher than CG.

1994

Royal Chitralada Project (RCP)

This project investigated ethanol production from sugarcane with a capacity of 900 liters/batch and 15 automobiles of various makes and models. They found that 10% ethanol could be run without changing anything.

1996

HRH Princess Mahajakree Sirindhorn opens first gasohol, E10, filling station in the Palace.

1999

Dr. Dennis Shuetzel, Director of Ford Motor Company, visits the Minister of Science and Technology to discuss a collaborative effort in research of ethanol as a transportation fuel. The National Metal and Materials Technology Center is requested to test with Ford the viability of E10 gasohol in light trucks.

2001

The National Ethanol Committee is established under the Ministry of Science and Technology (MOST) and then transferred to the Ministry of Industry (MOI), now known as The National Biofuels Committee under the Ministry of Energy (MOE).

2002

The Thai government sets up the specifications for commercialization of gasohol.

Figure 1: Timeline of bioethanol production in Thailand [1]

In addition, the government of Thailand also set out three measures to fix its issue regarding the oil import in 2003:

a) Improve the performance of fuel renewable and its usage.
b) Secure the alternative resources of oil.
c) Raise the value added of energy sources.

Besides, stepping into 2022, The Ministry of Energy (MoE) has drawn up a Bioethanol Production Plan. The information of this strategy is set out in Table 1.

Table 1: Bioethanol production plan of Thailand (2008-2022) [1]

	ML/Day, Short Term				ML/Day, Medium Term	ML/ Long
	2008	2009	2010	2011	2012-2016	2017-
Production Target	3	3	3	3	6.2	[illegible]
On-Line Plants Capacity	1.6	1.7	2.9	N.A.	N.A.	N.
Actual Production	0.9	1.1	2.5[V]	N.A.	N.A.	N.
[V] Average production capacity during Jan-Apr 2010						

7.2 An Overview of Bioethanol Processing

In the world of bioethanol production, Thailand ranked ninth after the United States, Brazil, European Union, China, India, and Canada with 420 million gallons bioethanol produced [9], as shown in Figure 2.

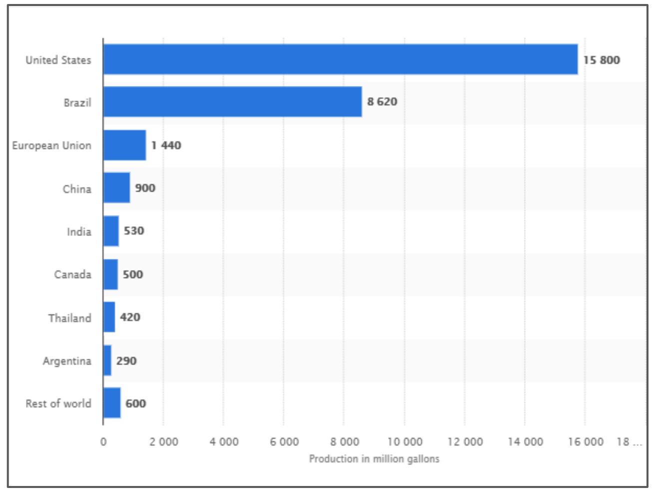

Figure 2: World-ranked bar chart on bioethanol processing in 2019 [9]

Between 2001 until 2011 (Figure 3), Thailand's production of biofuels shows a ten-fold increment starting from 2007 with the share of bioethanol goods in the Asia pacific region increased from 6% to 19% in 2007 and 2010 respectively [10]. The production of bioethanol in Thailand majorly involves the fermentation process of molasses and cassava (tapioca). Bioethanol production is called 'gasohol' which is a blend of ethanol with gasoline (petrol) [11].

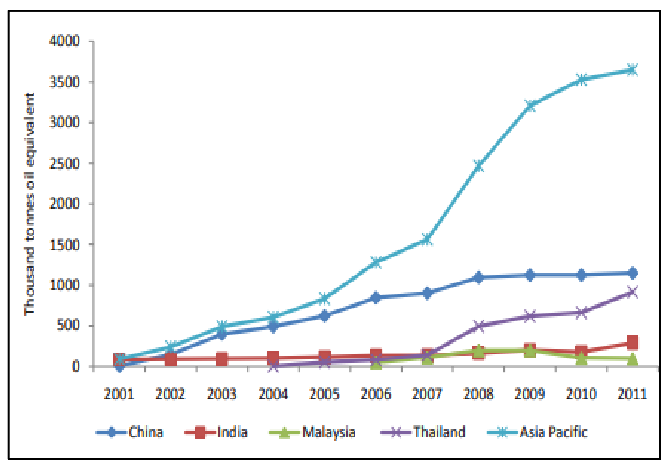

Figure 3: Biofuel production in the Asia Pacific [10]

As previously mentioned, molasses and cassava are the base crops in bioethanol production. Sugarcane can also be used in bioethanol production as it can be directly used, whereas molasses, the by-product during sugar production, is fermented with yeast to produce ethanol [12].

Molasses fermentation is a process in preparation of ethanol at the industrial scale. It is a residue begotten from sugarcane processing, a mother liquor left after crystallization of sugarcane juice [13] and it is also a microbiological energy source that helps in growing yeast, bacteria and molds as it is the most cost-effective method.

Sucrose from molasses is converted into cellular energy. Molasses is both fermentable and non-fermentable sugars that contain traces of nitrogen, phosphorus, dense sludge, and ash. Fermentable sugars are used directly during molasses fermentation, whereas non-fermentable sugars such as starch, cellulose, or pectin can only be used after hydrolysing. Ethanol is produced with the aid of enzymes and the reaction is reversible [14].

There is much research and information about gasoline production in Thailand with the comparison between cassava and molasses, and conventional gasoline. Moreover, which molasses and cassava are giving the most efficient production to be used as gasoline with several experiments is also being discussed. Apart from the reliance of this country on foreign oil, they are eager to find various ways to produce their own fuel. One of the main advantages of producing bioethanol is it can reduce the net emission of greenhouse gases by up to 3.9% for gasohol E10. Ethanol also helps in reducing the depletion of the ozone layer through blend with petrol in the ratio 85:15 [15] [16].

Even though currently the production of gasoline is quite expensive compared to conventional gasoline being a newly developed technology, is it predicted that soon, it will be preferred as the market price of gasoline will be significantly cheaper than the conventional gasoline.

7.3 The Use of Biological Process and Technology to Solve Problem or Make Useful Product

The article by Travis (2012) discussed the comparison between molasses and cassava feedstocks in terms of its background and sustainability. Figure 5 and 6 represent cassava and molasses respectively. Cassava is a long tuberous starch root that is an essential ingredient in many Latin American and Caribbean dishes. They are eaten, pounded, added to the stews, and used to make bread and chips. Cassava, also known as yuca, must be fried, or pressed before it is consumed due to its poisonous ingredient (cyanide) in its raw form [17].

Figure 5: Cassava [17]

The molasses or black treacle is a viscous liquid arising from sugar cane or sugar beet extraction. The molasses varies by the volume of sugar content, the process of extraction and the age of the plant [18].

Figure 6: Molasses [18]

As the biggest source in manufacturing and providing cassava, Thailand contributed almost 70% from a planted field of 1.24 M hectares producing 18.73 metric tons of roots per hectare [19]. Yucca is grown continually as this plant requires least irrigation, chemical and insects' controls. This edible plant can be transformed into bioethanol throughout the year because of the unbridled timeline of the crop for growing and processing. Next, its capacity to be preserved in large volumes as dried chips makes it accessible all the time especially in low harvest seasons [1].

Differ from cassava, sugarcane is a perennial grass type plant from the family *Poaceae*. It is a sensitive plant towards climate change, soil-type, drainage, fertilizers used, insects, pest prevention, varieties and harvesting seasons. Thailand contributes 38% of the overall planted territory even though sugarcane has a very limited harvesting season [1][20]. The quantities of different biofuel production feedstock in Thailand during the period 2006 – 2011 is displayed in Figure 7 [21].

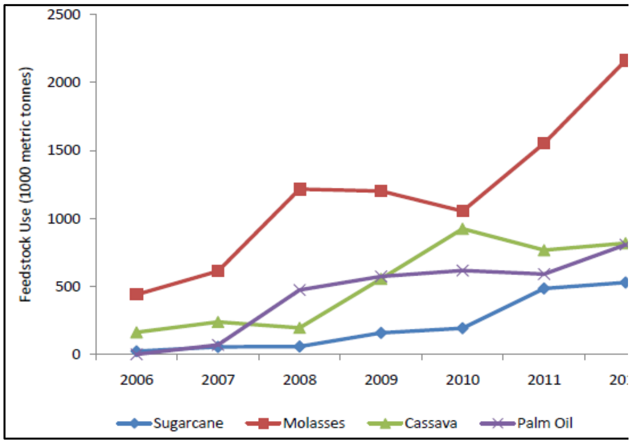

Figure 7: Usage of feedstocks in Thailand for ethanol and biodiesel production [21]

Biofuel production improves energy efficiency, agricultural employment and decreases) emissions of greenhouse gases, but concerns linked to water and land use and security of food remain critical considerations for its wide-ranging use. At present, E10 (10% of ethanol blended in 90% of gasoline) or called as gasohol is available at the refuelling pump in Thailand [22].

Development of bioethanol can be either from conventional or innovative biofuel technology based on the polymerisation state of sugars.

The prevalent method for bioethanol extraction is the fermentation of sucrose from sugar crops such as cane sugar, beet sugar and sweet sorghum [22]. As a first-generation of bioethanol, it was derived from sugar or starch and is categorized under traditional technology.

Sugar cane crops' rotation usually spans within 2 to 5 years. One new planting followed by one to four bunches. Land set up, seeding, maintenance of crops and harvesting were included in this phase. As this is the country's main sugar cane manufacturing area, power, material inputs, and labour specific information was checked and confirmed based on data gathered in the central region of Thailand (CRTh) [23].

Based on the biofuel policy of the government, ethanol is provided to buyers in gasohol 10, a blend of 10% ethanol. All processes and sub processes, included in the molasses-based gasohol system boundary are shown in Figure 4. The major processes are sugar cane manufacturing, sugar or molasses manufacturing, ethanol conversion, transport or distribution and burning of fuel in automobiles. The program's sub-processes involve agrochemical processing, human-labour lifestyle support, coal mining or refining and crude oil or refining. The figure also shows the general information regarding essential inputs / outputs correlated with the manufacturing / harvesting of 1 ton cane stalks

In Thailand, in order to expedite the growth of sugarcane, farmers were asked to fertilize the sugarcane with different formulas of nutrients. It results in higher production of N input than P and K. Diesel is used mainly for the fuelling of tractors for land planning, partly for planting, maintenance of crops and harvesting or loading of sugarcane crops [24]. Diesel consumption for all transport operations shall be determined based on round-trip distance travel. This helps in determining the limits of conventional gasoline and gasoline [25].

Almost in every stage of sugarcane farming, human labour input is required as it is important to analyse how energy-efficient a plant-based fuel production system is, i.e. whether or not the amount of energy being produced is higher than being consumed.

These assessments and further interactions with other states at different mechanization rates enable the inclusion of human labour. The solar energy obtained and stored in the biomass, considered to be secured, has not been counted. It must be stated, however, that without it there would be no biomass and therefore no biofuels.

EFE in 2007 stated that with a fuel of estimated 2.27-barrel tonne oil, cane trash is known to be a reliable fuel supply for fossil fuels or other natural sources of energy. Furthermore, free, or low-end applications have been wasted as an essential biomass fuel resource in Thailand or anywhere else in the world.

Consequently, the primary energy source for the sugar sector is a bagasse [26]. Rice husk is an additional source of energy for both transforming ethanol and sugar milling. In comparison, wood waste is another possible source of green energy that will continue to reduce the use of fossil fuels.

As an inexpensive and equally usable supply of energy, coal, is used in boilers to produce steam and electricity used in the process of refining ethanol. It provides most of the distillery energy required which is 59%, followed by rice husk which is 39%. The pre-civilization from anaerobic treatment, resulting in biogas storage of spent wash or stilling in up flow anaerobic

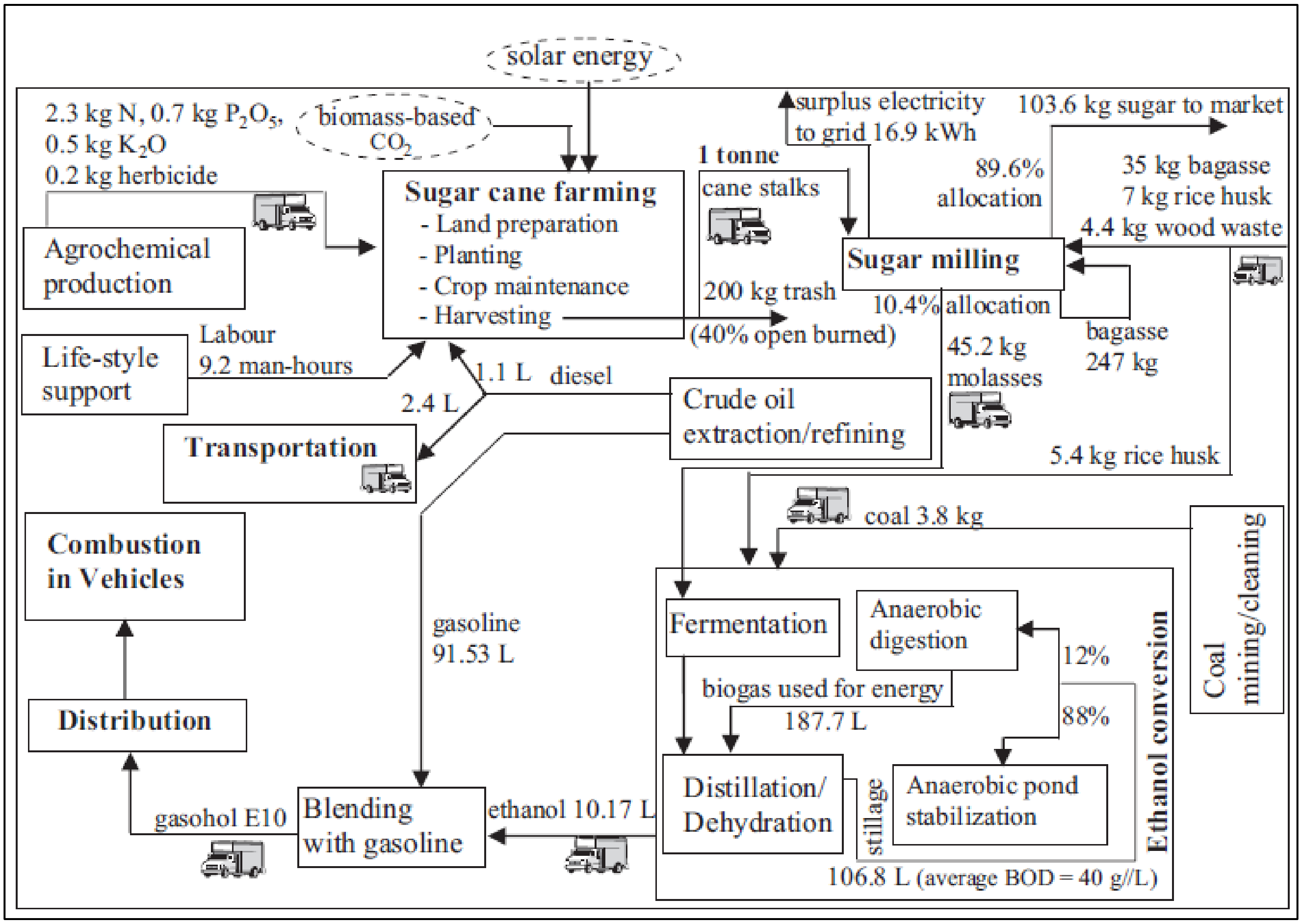

Figure 8: System boundary for the molasses-based gasohol life cycle [7]

sludge blanket (UASB) reactors contributes just 2%. Electricity generated in excess of the demand for the mill is sold to the grid.

The limited capacity of the UASB at the facility showed low contribution as it is qualified to handle only 12% of the waste generated. The remaining 88% are to be returned to normal anaerobic pond. The alcohol sector is responsible for addressing its high demand for biochemical oxygen, and making sure it fulfills the effluent requirements for discharge into local waterways or sewage [27][28].

As mentioned earlier, the process of producing the molasses-based E10, is by fermentation process. Microbes (mostly *Saccharomyces cerevisiae* yeast varieties) that are inoculated into the feedstock convert sugar (glucose, fructose or other monosaccharaides) to ethanol in the fermentation process.

Monosaccharaides are derived either specifically from disaccharides decomposed by invertase enzymes or through starch hydrolysed by amylase enzymes [29]. It also contains water and carbon dioxide, in addition to ethanol.

The corresponding equation represents the glucose-to-ethanol reaction:

$$C_6H_{12}O_6 + 2Pi + 2ADP \rightarrow 2C_2H_5OH + 2H_2O + 2CO_2 + 2ATP$$

Sugar milling demands a variety of process steps, like grinding, cleaning, heating, seeding and centrifuging, for the manufacturing of cane sugar crystals. A molasses as the sticky black syrup, the other a straw-like residue called a bagasse is processed and leaves behind two key co-products. Currently, sugar mills burn bagasse to generate steam and energy to function and export excess power to the grid.

The next step is the ethanol conversion. This process involves two important steps. The first is molasses after yeast fermentation produces dilute alcohol. The second, the fermented mash is passed via the distillation and then dehydration system to generate 99.5% in strength anhydrous alcohol.

The stillage, for production of energy, could be used as fertilizers, feed for animals or further refined into biogas. Nguyen et. al. (2008) clarified that the plant uses co-generation technologies from their work in the MoE factory to produce both vapour and electricity to meet plant reliance on fossil fuels. Coal is a big part of the energy needs for distillery (59% followed by 39% rice husk and 2% biogas). 12% anaerobic digestion in UASB (Upflow Anaerobic Sludge Blanket) reactors was produced from the 2% biogas portion. The remainder of the stilling is then contained in an anaerobic pond [1].

As the sugarcane produced more efficient gasohol in Thailand, the best method to ferment bioethanol by examining the percentage of mixture or raw sugar and molasses under 6 circumstances including 0:100%, 20:80%, 40:60%, 60:40%, 80:20% and 100:0% [24]. It was divided into three experiments which are:

Experiment 1: Combination of raw sugar and a specified percentage of molasses.

Experiment 2: Mixture of raw sugar and molasses with a specified ratio added with invertase (enzyme) to boost yeasts' ability to absorb and convert sugar as alcohol [30].

Experiment 3: Combination of raw sugar and molasses added with invertase and di-ammonium phosphate nutrient (DAP) and urea to improve raw sugar nutrition [29] [30].

It was important to monitor fermentation requirements in a batch reactor, with aeration rate at 0.5 1.0%, pH at 4.2 -4.5 and fermentation temp at 30 – 35 ^{o}C, to achieve a good and sufficient starter for fermentation. A continuous blend of the starter (500 g) was combined with dried yeast or powder yeast (*Saccharomyces cerevisiae*).

The experiment defined proportions of fermentable sugar (% FS) of molasses and raw sugar to 48% FS and 60% FS respectively, with final weight of 11,000 g fermentation broth content.

However, the addition of invertase from % FS which was appropriate for turning sucrose into single-molecule sugar should be considered. In the case of fermentation with 0 % raw sugar, the amount of DAP and urea will be associated with nutrients in solution.

Fermented sugar solution properties such as pH, Brix %, specific gravity, % residual sugar (% RS) and % alcohol were examined every 3 hours until there is less than 1.50%RS of the solution was analysed [30]. The methods for the study can be seen in Table 1.

The ethanol derived from the fermentation process also contains a considerable amount of water that should be extracted. This is done by a fractional distillation process.

The distillation process operates by boiling a mixture of water and ethanol. Because ethanol has a lower boiling point which is 78.3 ^{o}C than water, ethanol can be condensed and separated in the vapour state [24].

Hydrolysis and fermentation of the sugar will create ethanol from the biomass. The biomass waste contains a complex mixture of plant cell wall carbohydrate polymers such as hemicellulose, lignin and cellulose.

The is then pre-treated with acids or enzymes in order to generate biomass sugars, then to shrink the feedstock size and to free up from the plant's structure. Decomposition of hemicellulose and cellulose into sucrose starch by distilled acids or enzymes, which were then processed into ethanol. Typically, lignin was used as fuel for the boilers of ethanol processing plants. For removing sugars from biomass there are three primary methods which are concentrated acid hydrolysis, dilute acid hydrolysis and enzymatic hydrolysis [33].

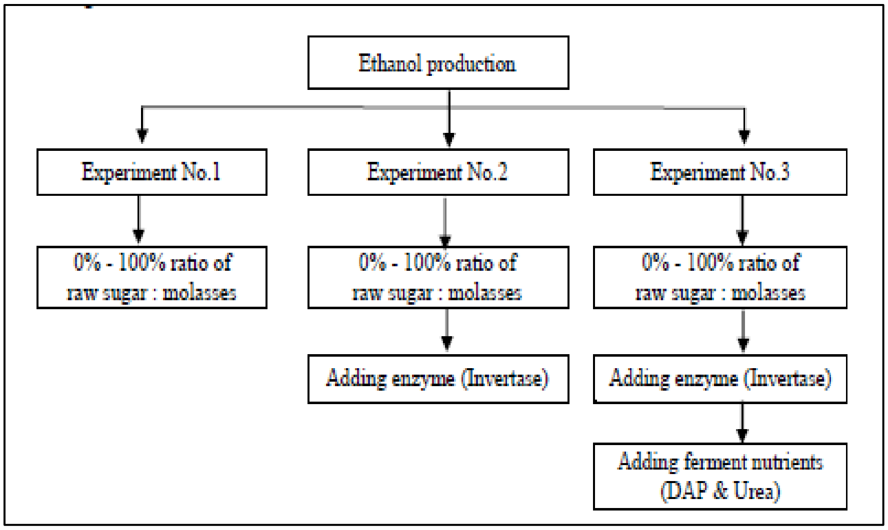

Figure 9: Experimental models for ethanol production from mixed raw materials of raw sugar and molasses [24]

Table 1: Fermented solution property measurement [24]

PROPERTIES	ANALYSIS METHODS
pH	pH meter
% Brix	Refractometer
Specific Gravity	Hydrometer
% Residual Sugar	Titration with Fehling's Solution using Methylene blue as an indicator
% Alcohol	Ebulliometer

7.4 Advantages of Bioethanol Compared to Conventional Gasoline

Some of the benefits were the ability of ethanol to deliver octane while replacing other potentially damaging materials of gasoline.

Other studies indicate that the use of ethanol will lower global warming. Reducing gasoline and crude oil imports decrease Thailand dependence on international oil. The rapid increase in the use of fossil fuels as markets expand and the close depletion of these fuels has sparked the hunt for substitutes, worldwide. Biofuels have arisen as a replacement for fuel oil, particularly for states that depend on oil and serve a variety of purposes [33].

Thailand is considered to be a bigger fuel ethanol market in Asia after China and India. Presently, in Thailand gas stations, 10% of the ethanol available is mainly from a molasses fermenter. As reported by 2008, there are 12 sugar-based ethanol plants with a combined capacity of 1,925 million litres (ML) per day in Thailand.

Another advantage of gasohol (E10) is it can be used directly in similar behaviour vehicles as to conventional fuels, no modification to the engine of the vehicles needed. Moreover, with the high-octane rating in bioethanol, it enables high engine compression ratios which increases engine efficiency and performances.

Differing from diesel, conventional gasoline has a lower volumetric energy density which translates directly into vehicles that need more bioethanol per kilometre. To effectively convert a traditional spark-ignition motor vehicle into a pure bioethanol motor involves changing the timing and installing a larger fuel tank due to the less energy content of the gasoline. The lower proportion of bioethanol blends (up to E10) can be used by almost all conventional gasoline engines without any changes, and it can even slightly enhance their efficiency.

In addition, the price of ethanol is affordable compared to gasoline as according to a survey by the Defour Company, E10 saves customers on average 4 cents per gallon. Ethanol losses were also greater relative to diesel petrol. More and more car makers are now endorsing the premium quality of E10 due to its high-octane efficiency, which is necessary for highly efficient engine technology. Greater ethanol blends offer similar octane benefits as premium but save the consumer significantly in terms of price per gallon. Table 2 shows the comparison of conventional gasoline and bioethanol in terms of fuel properties.

These advantages comparison between molasses and cassava are being made in Thailand to determine which feedstock is more efficient as bioethanol.

7.4.1 Comparison between Cassava and Molasses

7.4.1.1 Retail Prices

The Government of Thailand has established to raise its affordability through tax incentives and subsidies. Ethanol manufacturers are provided with a 6.39 Thai Baht (THB)/L tax exemption on refineries and are subsidized through the Oil Fund. Thus, the wholesale cost of fuel extracted from 85% ethanol (E85) is reduced by 30% and hence yields the prices of E10 between 22% - 26% less than conventional gasoline.

Table 2: Contrast between bioethanol and conventional gasoline in fuel properties [33]

Fuel Properties	Gasoline	Bioethanol
Molecular weight [kg/kmol]	111	46
Density [kg/l] at 15°C	0.75	0.80-0.82
Oxygen content [wt.-%]		34.8
Lower Calorific Value [MJ/kg] at 15°C	41.3	26.4
Lower Calorific Value [MJ/l] at 15°C	31	21.2
Octane number (RON)	97	109
Octane number (MON)	86	92
Cetane number	8	11
Stoichiometric air/fuel ratio [kg air/kg fuel]	14.7	9.0
Boiling temperature [°C]	30-190	78
Reid Vapour Pressure [kPa] at 15°C	75	16.5

7.4.1.2 Easily Accessible Resources

Conventional gasoline (CG) happens to be a non-renewable resource because it is extracted from crude oil. Even though current gas reservoirs can be maintained for several years, it will reach its end point soon.

Variety of resources are used in the bioethanol production such as crop wastes and plants that are grown specifically for the fuel. So, cassava and molasses are used in the production of bioethanol in Thailand, as it is renewable and is unlikely to run out soon because these crops can be replanted again.

In addition, Thailand is in Southeast Asia where its tropical weather is well suited for the growth of sugarcane production. Hence, there is no issue to get the raw materials for the bioethanol production compared to conventional gasoline (CG).

7.4.1.3 Minimize Dependence on Fossil Fuels

Perhaps more appropriate energy productions are required to decrease the reliance on fossil fuels, as crude oil prices hit the sky high, harnessing plant such as sugarcane as an effective way of maintaining any economy and avoiding over-reliance on fossil fuel imports such as oil and gas, since the cassava and molasses-based bioethanol production reduce fossil fuel use than conventional gasoline.

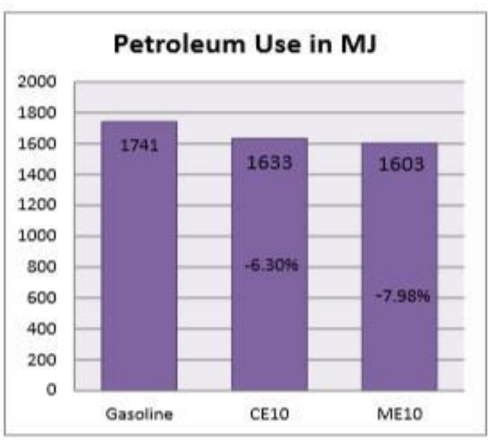

Figure 10: Petroleum used of cassava and molasses-based E10 bioethanol [1]

Figure 10 shows that conventional gasoline used more petroleum than cassava and molasses-based E10 bioethanol. Sugar sector is more mature and more advanced in research than the cassava sector. That is why ME10 uses less petroleum than CE10.

7.4.1.4 Global Warming Potential

In this case study, it reveals the potential for a reduction in global warming compared to conventional gasoline (CG). The global warming potential is therefore closely related to the use of coal as a main source of energy. Some studies showed that either cassava or molasses are being burned, the global warming potential is much lower than when coal is burned [33].

To have a lower global warming potential reading than conventional gasoline (CG), the use of coal in the power production for either cassava or molasses should be reduced or eliminated.

7.4.2 Cassava

7.4.2.1 Lower Air Emission

From this case study, it showed that cassava-based E10 (CE10) produced lower air emission rather than molasses-based E10 (ME10) compared to conventional gasoline (CG). A carbon dioxide produced by a vehicle when the ethanol was burned is offset by the carbon dioxide captured when the feedstock crops are grown to make ethanol. This varies from gasoline and diesel that are being extracted from earth-fuel petroleum. The nitrogen oxides, carbon monoxide, particulate matter, and unburned hydrocarbons are the substances created when gasoline was burned, no emission is offset.

7.4.2.2 Enriching the Nutrients

The nutrient enrichment is synonymous with fertilizer used, but unlike acidification, one option always stands out irrespective of the processing's power source. Cassava is a better option in terms of nutrient enrichment as opposed to molasses. Ethanol is combusted more completely than conventional gasoline, that is why CE10 proves slightly better than conventional gasoline.

7.4.3 Molasses

7.4.3.1 Renewability

Renewability is known as ratio of net bioenergy outputs or net fossil fuel feeds. If the

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renewability is more than 1, that means the bioethanol fuel produces an energy return on its investment in fossil fuel. Meanwhile if the renewability is less than 1, the bioethanol fuel requires more energy than it eventually can provide. In this case study, it shows that even at optimal operating circumstances, the renewability of the manufacturing of molasses is greater than in cassava. This may be mainly related to the fact that for steam production, the bioethanol from cassava plants is burning coal while the molasses plants are not.

7.4.3.2 Water and Land Utilization

Studies reveal that it is not going to be easy for the Thailand government to step up bioethanol development and at the same time maintain the land use at constant rate. Silalertruksa et al. (2008) reported Thailand will be expected to increase the area invested on cassava and sugarcane to the production of bioethanol.

Figure 11 shows the water and land use of cassava and molasses. The info provided for molasses is computed on the basis of growing sugarcane for the production of bioethanol from molasses and sugar. The allocation ratio is used to account for the overall amount of land and water being used by sugarcane, which would be associated with molasses-based bioethanol production.

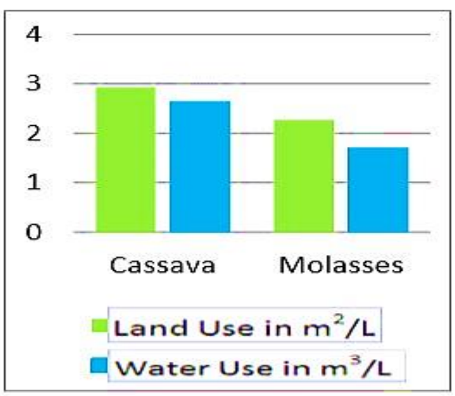

Figure 11: Cassava and molasses used in land and water [1]

The land and water use for cassava and molasses reveals that molasses-based bioethanol production demands less land and less water compared with cassava-based ethanol.

7.5 Effect of The Bioethanol Production from Cassava and Molasses on The Society

Nowadays, bioethanol production has become popular in order to reduce the dependency of fossil fuels. This is because nobody knows how long the world's petroleum supplies will last. Bioethanol is preferred to be used in order to replace conventional gasoline (CG) because it can be produced from a variety of crops such as cassava and molasses, which can be easily accessible compared to conventional gasoline (CG).

Having said that, we must keep in mind that there is still a big room for investigation of the pros and cons for bioethanol production that can give good or bad effects to the society that need to be considered.

7.5.1 Food Security

The development of the biofuel (bioethanol) sector has generated several trade-offs, new relations and competition among the various sectors or areas of the economy like agriculture and energy. To prevent threats through biofuel (bioethanol), but it also poses threats to food security.

Based on the other case study, the impact of enforcing Thailand's AEDP biofuel goals would lead to higher prices for those crops and food crops [26]. So, poorer households will also have to spend a slightly higher proportion of their earnings on more expensive food.

7.5.2 Feedstock Supply Security

Potentials for feedstock supply were evaluated depending on three situations for yield improvement which is low, moderate and high yield improvement.

Only the high yield enhancement situation could lead to a stable and adequate supply of cassava and molasses to meet long-term demands for bioethanol and some other sectors. Hence, to optimize the yield of existing feedstocks and to promote the production of agricultural residue-derived biofuel are crucial.

Other than that, as Thailand is one of the largest suppliers and exporters of various food products in the world, the food security crisis has an impact not just on domestic supply as well as in the worldwide food supply chain.

7.5.3 More Job Opportunities

Not many countries in the world have a huge reserve of crude oil. The need to purchase the oil creates a huge dent in the economy. A country is capable of reducing its dependence on fossil fuel when more individuals start to move towards biofuels.

More plantations of sugarcane are needed with a rising biofuel (bioethanol) industry. As a result, more manufacturing plants for ethanol fuel are built up, which develops into more job opportunities. In addition, the unemployment rate in the community will also decrease.

7.5.4 Improved Air Quality

Relentless emission of harmful greenhouse gases resulting from fossil fuel consumption could lead to global warming. Global warming is having terrible consequences including changes in weather patterns, rising sea levels and extreme heat.

Bioethanol combustion results in cleaner emissions which produce carbon dioxide, steam, and heat. Plants consume carbon dioxide and then processed through photosynthesis to help the growth of the plant.

This cycle of generation and combustion of energy means bioethanol might probably be the source of carbon free fuel and does not raise the atmospheric concentration of CO_2.

7.5.5 Deforestation

Since bioethanol is produced from plants like sugarcane, large farmland areas will be used to grow the plant and other crops used in the production of bioethanol.

Deforestation is another environmental problem caused by bioethanol because the forests are replaced with new farming lands, which will then be used to produce sugarcane for bioethanol production.

This way, the agricultural land is used for fuel production instead of being used for food production, and the forest disappears. Deforestation will lead to habitat loss, which further will destroy the ecosystem. In addition, deforestation also can cause flooding since trees avoid runoffs of sediments and forests hold more water than farmland.

7.5.6 Fuel Price Stability

Decreasing reliance on fossil fuel imports and deriving fuel from a variety of biomass feedstock could stabilize the country's transport costs. The widespread availability of biofuels in the fuel industries in Thailand may help shield customers from significant volatility in crude oil prices.

7.5.7 Stabilizing the Income of Farmers

Farmers will gain more profits t due to the higher demands for bioethanol production from crops such as cassava and molasses. When the demands for the crops become higher, more planting areas for the crops are needed. So, these situations will give advantage to the farmer.

This is especially for farmers with more surplus production to sell will gain much more than farmers with little surplus to sell. Therefore, in several contexts, farmers with more land tend to be better off than farmers with only a small area of land, so it seems that poorer farmers would not earn the bulk of the benefits from rising food prices.

CONCLUSION

As a conclusion, the serious issue that Thailand was facing is their dependency on foreign oil imports which is almost 90% of their crude oil, diesel and gasoline being imported. Perhaps the most essential thing about our transport fuel status is that nobody knows how many years the world's petroleum supplies would last.

So, starting in the late 1970s and further emphasized in the early to mid 2000s, Thailand noticed a need to create a process for the production of domestic fuel for transport. One of the most interesting biofuels due to its positive impact on the environment is bioethanol. Thus, the country came up with an idea of production of biofuel which is bioethanol from cassava and molasses in order to boost their national energy security by reducing their foreign oil demands.

Nevertheless, there is still a discussion on which feedstock must be selected to power the bioethanol industry in the country. Besides, in 2003 the government of Thailand implemented three strategies to increase the efficiency of renewable fuel and use, secure alternative fuel sources and improve performance added from power generators.

It is complicated to reach a good decision on the best option of feedstock for production of bioethanol in Thailand. This is because there are many pros and cons in the use of cassava and molasses for the purpose of producing the biofuel in Thailand. There are many aspects that need to be considered.

Firstly, even though cassava uses a lot of water than molasses, it is more versatile in the places it can be planted, making it more suitable for a bigger planting area. Deforestation will occur to make new farmland. As a result, flooding can easily happen especially during the rainy season because the forests that hold more water are being replaced.

In addition, molasses uses fewer crude oil compared with cassava per volume of ethanol manufactured that promotes energy security of the country. However, cassava-based ethanol also has its own benefits such as it is environmentally friendly, because of its benefits in nutrient enrichment and lowered photo-oxidation.

Lastly, as with other sustainability problems, the method of weighing up each of the sustainability dimensions will decide which option is eventually considered to be the best.

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