ENERGY AND CO_2 ESTIMATION IN PRODUCING BIODIESEL FROM USED COOKING OIL

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ABSTRACT

The world is undergoing energy and environmental crises, new energy sources are needed, biodiesel from used cooking oil is a renewable energy source and it is a source of clean fuel. It can be combusted more efficiently than petroleum diesel therefore reducing carbon-dioxide emissions, one of the causes of global warming. However, a degree of energy expenditure and carbon-dioxide emissions during biodiesel production are noticed. This research is aimed to clarify every step in the entire biodiesel production process. Used cooking oil purchasing and biodiesel production were studied. The study reveals that biodiesel production is classified into four processes, substance Reaction, Separation of glycerol, Rinsing, and salt filtration. Energy expenditure and carbon-dioxide emission during each step were calculated.

KEY WORDS: RENEWABLE ENERGY/ BIODIESEL / USED COOKING OIL / CARBON-DIOXIDE / GLOBAL WARMING

78 pages

การหาค่าพลังงานและ CO_2 ที่ใช้ในกระบวนการผลิตไบโอดีเซล จากน้ำมันปรุงอาหารใช้แล้ว

ENERGY AND CO_2 ESTIMATION IN PRODUCING BIODIESEL FROM USED COOKING OIL

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บทคัดย่อ

ในปัจจุบันโลกเกิดภาวะวิกฤตทางด้านพลังงานและสิ่งแวดล้อม มนุษย์จึงจำเป็นต้องมีการค้นหาพลังงานรูปแบบใหม่มาทดแทน พลังงานทางเลือกหนึ่งคือน้ำมันไบโอดีเซลจากน้ำมันปรุงอาหารใช้แล้ว เนื่องจากเป็นพลังงานที่สะอาด มีการเผาไหม้ที่สะอาดกว่าน้ำมันดีเซล จึงช่วยลดการสะสมคาร์บอนไดออกไซด์ในอากาศ ซึ่งเป็นสาเหตุของสภาวะโลกร้อน แต่อย่างไรก็ตามในกระบวนการผลิตไบโอดีเซลนั้น ก็ย่อมมีพลังงานที่สูญเสียไปในการผลิต รวมถึงยังมีการปล่อยค่าคาร์บอนไดออกไซด์ออกมาด้วย ดังนั้น วัตถุประสงค์ของงานวิจัยนี้ ก็เพื่อศึกษากระบวนการผลิตน้ำมันไบโอดีเซลจากน้ำมันปรุงอาหารใช้แล้ว โดยทำการศึกษาตั้งแต่กระบวนการรับซื้อ จนถึงกระบวนการผลิต จากการศึกษาพบว่า น้ำมันที่ปรุงอาหารใช้แล้วที่นำมาผลิตเป็นไบโอดีเซลนั้นนำมาจากโรงงานอุตสาหกรรม และแหล่งชุมชน ส่วนในกระบวนการผลิตนั้น แบ่งออกเป็น 4 ขั้นตอนหลักๆประกอบด้วย ขั้นตอนการทำปฏิกิริยา, ขั้นตอนการแยกกลีเซอรีน, ขั้นตอนการล้างน้ำ และขั้นตอนการกรองเกลือ จากนั้นผู้วิจัยคำนวณการใช้พลังงาน และค่าการปล่อยคาร์บอนไดออกไซด์ ที่เกิดขึ้น

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CHAPTER I

INTRODUCTION

1.1 Background and Problem Statement

Fuel is an important part of economic development. In Thailand, fuel consumption increases considerably according to the continuously growth of economics and industries. The graph shows Thailand's energy consumption for different fuel types.

However, price of fuel rises up and fluctuates over time. Consequently, Thailand is also affected significantly because imported fuel is worth several hundred million per year. With the current energy crisis, fuel is limited to replace and likely to decline accompanying with environmental aspect both pollution and global warming. All mentioned factors cause renewable energy to be replaced. One of those replacements is energy from biofuels such as biodiesel, ethanol, biomass and biogas. The advantages of biofuels are renewable with plantation and friendly to environment.

Biodiesel is alternative energy making from natural plants and animals. It is produced by the reaction of vegetable and animal oils with methanol as the catalyst. As a result, biodiesel is generated with glycerin as by product. In Thailand, many oily plants can be used as raw materials such as palm oil, jatropha, including used cooking oil. From the survey data, used cooking oil each year especially from industrial factories including communities and households had found to contain high amounts of several hundred million litres. This used oil is eliminated by disposing to nature which is wasted. The corrective measure is to use them as raw materials for biodiesel production. In 2007,Bangchak Petroleum Public company had initiated the used cooking oil purchasing project from any markets via Bangchak gas stations in order to feed as raw materials for biodiesel producing unit.

Another advantage of biodiesel is able to decrease green house effect. Emissions from combustion do not make carbon dioxides accumulation in atmosphere, does not pollute air because of cleaner combustion than diesel, and does not emit sulfur compound. Therefore, biodiesel is the right choice for the use of renewable energy. But in terms of the energy efficiency, the energy used in producing it is higher or lower than the energy used to produce the diesel from crude oil. It is very interesting that the energy used to produce it. More or less energy to get out.

1.2 Objective

The proposes of this thesis are:

1.2.1 To study the biodiesel production process from used cooking oil and diesel production process from crude oil

1.2.2 To find the energy used and CO_2 produced in biodiesel production processes from used cooking oil

1.2.3 To compare the energy consumption and CO_2 emission between biodiesel production and diesel from crude oil

1.3 Scope of the Study

Although there are many factories produce biodiesel from used cooking oil, but due to the time constraint, the study is limited to the processes used of the Bangchak. This is the guide for estimating the energy efficiency of the biodiesel from used cooking oil.

1.4 Study Area

The data used in the research from refinery plant of Bangchak Petroleum Public Co., Ltd, located at 210 Sukhumvit 64 Bangkok.

1.5 Expected Results

1.5.1 Knowing the biodiesel production processes from used cooking oil and diesel production processes from crude oil.

1.5.2 Knowing the energy used and $C0_2$ produced as a result of biodiesel production process from used cooking oil.

CHAPTER II
LITERATURE REVIEW

2.1 Definition of Biodiesel

Biodiesel is a renewable energy of diesel. It can be made from the reaction of vegetable oils (there are Rapeseed, Sunflower, Sesame, Cottonseed, Peanuts, Soybeans, Castor, Jatropha, Coconut, Palm and Used cooking oil) and alcohols such as Methanol or Ethanol by using alkali as a catalyst. The obtained product feature as ester of fatty acid called “Fatty Acid Methyl Ester” This process is chemical process named as Transesterification Process. (Mittelbach and Remschmidt, 2004)

2.2 Raw material in biodiesel production

2.2.1 Rape seed

Rape seed is a granule similarly to sesame. It is an annual crops in weed-type found generally in Europe. The scientific name is Brassica napus. In 1982, Transesterification is researched with rape seed at Institute of Organic Chemistry, Graz, Austria. Presently, rape seed is used as raw material mostly in biodiesel manufacturer in Europe. The 80% share of production is used over other raw materials. Germany is regarded as a leader of replacing of biodiesel for diesel and a leader of innovating rape seed as raw material in biodiesel production. In addition, France and Spain also used rape seed. (Bangchak, 2009)

Figure 2.1 Rape seed

2.2.2 Soybean

Soybean is vegetable oil used as raw material in biodiesel production especially in USA. Production volume of soybean reaches over 30 million tons per year. Furthermore, Italy also uses soybean to produce biodiesel. (Bangchak, 2009)

Figure 2.2 Soybean

2.2.3 Palm oil

Palm oil is vegetable oil which is used popularly as raw material in biodiesel production in Thailand because it has higher potential to produce fuel than other vegetable oil. It possesses lower cost with higher productivity. Its productivity is 5 times higher than rape seed mainly used in Europe and 10 times higher than soybean mainly used in USA. The reason is that Palm is perennial and withstand to natural disasters.

Palm can be harvested up to 20 years. The result is that the demand of palm oil in Thailand tends to rise up considerably in the near future. It is planted mostly in Malaysia. For worthwhile planting in according to Department of Agriculture Extension, Palm has high yield up to 4,000 baht per year. Consequently, farmers are promoted to plant palm instead of other low yield plants. (Bangchak, 2009)

Figure 2.3 Palm oil

2.2.4 Jatropha

Jatropha is one type of vegetable oil which government has promoted communities to plant for using as raw material in biodiesel production because it's easily grown without much care, resist to drought and flood conditions, and can be planted in all cultivated regions even in less utilized agriculture area. It cans yield when palm has been planted for 1 year and lasted for 30 years. Extractable oil can fill directly in low-cycled diesel engine for agriculture purpose instead of diesel. Most people probably do not know Jatropha although it was planted in Thailand more than 200 years. The portugese imported into Thailand since the late Ayutthaya period for plantation and then purchased seeds back to Portugal in order to extract its oil for producing soap.

Figure 2.4 Jatropha

Jatropha is one type of suitable alternative vegetable oil which agricultural expert stated that if seed has been developed with care in suitable cultivated condition, it could have yielded more than 300 litres per year. Nevertheless, if it has been planted naturally, it could have yielded only 100 litres per acres per year. At the time, palm could have yielded 600 litres per year after planting for 3-4 years. Another advantage is that Jatropha can't be eaten dissimilar to others. This causes its price not fluctuating. Its price stays around 3-4 baht per kilogram. The extraction needs 4 kilograms seeds for 1 litres extractable oil. Cost of Jatropha is 12-16 baht per litre still lower than palm oil which price fluctuated around 14-22 baht per litre.

Exceptionally for using as renewable energy, Jatropha also grows as cover crops to prevent soil erosion from wind and water including help improving the quality of the soil to be able to use for other agricultural crops.

2.2.5 Used cooking oil

In the period of expanding the cultivated area to get enough palm oil, other types of raw material which should be supported to produce biodiesel is used cooking oil. Not only renewable energy can acquire but also environmental problem can be reduced. During 20 years past record, the global average rate in vegetable oil consumption increases 4% per year resulting in today vegetable oil consumption reach 100 million tons per year. This comes from living style changing to enjoin fast food which is cooked by frying. Consequently, lots of used cooking oil from cooking need to manage, eliminate, or recycle these wastes without environmental problems.

For Thailand, vegetable oil is consumed more than 800,000 tons per year and evaluated that used cooking oil becomes wastes more than 100 million litres per year. By this amount, some parts are recycled as raw material in soap production or as filler in animal feed while some parts are disposed into public canal causing environmental problems, or illegally sell as cheap oil to be used repeatedly. The repeatedly used cooking oil has been deteriorated both physical and chemical properties, can accumulate in liver cell and kidney, and may cause cancer too.

In 2007, Bangchak Petroleum Public Co.Ltd. had initiated the used cooking oil purchasing project from any markets via Bangchak gas station in order to feed as raw materials for biodiesel producing unit which had capacity of 50,000 litres per day and located at Sukhumvit 64 road. (Bangchak, 2009)

Figure 2.5 Used cooking oil

2.3 Biodiesel production process

Transesterification / alcoholysis as a reaction to the triglyceride molecule. This is the main component of vegetable oil / animal grease is the new ester or mono-alkyl ester and glycerol by reaction with small molecule alcohol by the reaction has a catalyst. (Bangchak, 2009)

The reaction is following:

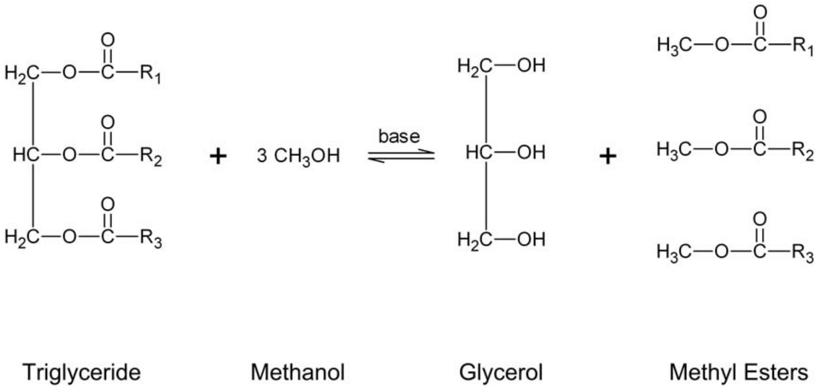

Figure 2.6 Transesterification

2.4 Form of transesterification

2.4.1 Alkali catalyzed transesterification

Transesterification catalyzed with alkali can be achieved more quickly than catalyzed with acid in the same amount, and also more popular. But, alkali is more expensive than acid. It can be seen from most industries that alkali is usually be used, such as Sodium Methoxide (CH_3ONa), Potassium Methoxide (CH_30K), Sodium Hydroxide (NaOH) and Potassium Hydroxide (KOH). From study, we found that catalyst as KOH is the most efficiency and NaOH, CH_3ONa and CH_30K are second, third and fourth respectively. A catalyst which is popular in industries is NaOH and KOH because it's cheaper. Catalyst reaction generates Methoxide ion in 2 ways, that is, methoxide salt and reaction between methanol and hydroxyl group of alkali hydroxide. Methoxide ion acts as strong nucleophile and attaches carbonyl group to become alkyl ester. Oil which is catalyzed by alkali must have low free fatty acid not exceeding 0.5%. According to the result of catalyst amount comparison , NaOH is used less than KOH and CH_3ONa because lowest molecular weight. In term of concentration, CH_3ONa is used less than NaOH and KOH. Biodiesel can achieve the highest yield with CH_3ONa as catalyst. Alkali catalyst in transesterification must be anhydrous condition. KOH (NaOH) preparation must use methanol anhydrous in order to generate CH_3ONa and water. Water will react with triglyceride and Na+ to form soap. The reaction should loss some triglycerides while CH_3ONa give CH3O- and Na+ without water interference. When NaOH or CH_3ONa is used, upper layer will be a liquid of ester and lower layer will be high viscous glycerol with soap conglomeration. When KOH is used, there are only 2 layers which is easier and more convenient. That's why industries usually use KOH.

According to alkali catalyst's price, NaOH is the cheapest and KOH, CH_3ONa is second and third respectively. In conclusion, NaOH is suitable either cost or usage amount. (Rashid and Anwar, 2008)

2.4.2 Acid catalyzed transesterification

Advantage of transesterification with acid catalyst is capable to react with moist raw material and high free fatty acid, for example, it cans react with cooked vegetable oil which has free fatty acid almost 6%. Acid catalyst can accelerate both transesterification and esterification. Acid is saver than Alkali. However, it is 4,000 times slower than Alkali and must use higher temperature in accelerate animal grease or used grease, for example, acid catalyst cans react with R/M with 0.1% moisture but if R/M has 5% moisture, the reaction will inhibit completely. In addition, acid catalyst can yield slower if it reacts with high polar compound because hydrogen ion will be caught up by polar compound instead and polar compound will interfere any ions in catalyst. Moreover, separation layer may occur with acid catalyst. However, it can be solved with solvent filler. R/M with high free fatty acid cans bedigested with acid catalyst and then transesterification with alkali catalyst.

Transesterification can give high yield of biodiesel with high cost and price as well. Mechanism of reaction with acid catalyst is to protonate carbonyl and oxygen which increase electrophilicity of carbon atom to have strong nucleophile for collision. The importance factor is structure of carboxylic and alcohol which may interfere esterification of palmatic acid using ethanol or methanol as catalyst. From the study, methanol is better than ethanol. There are many kinds of acid catalyst but the most popular is sulfuric acid (H_2SO_4). Hydrochloric acid (HCl), Trifluorideboron acid (BF_3) , Phosphoric acid (H_3PO_4) and Sulfonic acid are the second, third, fourth, fifth respectively. Acid usage may create water in reaction which adversely affect the production of biodiesel because ester are hydrolyzed to free fatty acid once again. However, the water also has advantage. Acid will react with water more than with alcohol which causes water to encircle acid protons, prevent triglyceride from acid collision, and inhibit transesterification. The surrounding protons in acid catalyst affect transesterification more than esterification which has bigger and less polar molecules due to the polar of carboxylic group of free fatty acid and bonding capability of hydrogen and water.

Even though the usage of liquid in the catalyst is effective in accelerate the reaction, there are some disadvantages too. Contamination and neutralization are problems of liquid catalyst. Furthermore, it’s difficult to extract or separate the product which waste time and lose cost. Solid catalyst is easier to separate and able to recycle that solid catalyst. The use of acid solid is better than alkali solid because it's resistant to corrosion, less effect to environment, easier to purify, and cheaper. The suitable solid catalyst should be in continuous packed bed which is easier to separate and purify including reduce waste. The use of solid catalyst must study more about the connection of a large hole, acid concentration of the reactants, and hydrophobic surface. One example of solid catalyst is Zirconium Sulfate which is strong acid with acceleration ability to any reactions such as alkylation, isomerization, trans-esterification, etc., is active in the reaction of long chain hydrocarbons under moderate conditions. Zirconium Sulfate is prepared from dissolving $ZrOCl_2.6H_2O$ in water, precipitating with ammonia, rinsing, filtering to remove chloride ion out, $Zr(OH)_4$ separating and drying, immersing in H_2SO_4 for 24 hrs., filtering and drying at 823 kelvin for 3 hrs. (He et al**.,** 2007)

After transesterification of used cookig oil and methanol with acid solid catalyst, accelerator will be separated in order for re-using. The methyl ester will have high level of stability. The use of acid solid catalyst with used cooking oil having high free fatty acid will get better efficiency than alkali solid catalyst because of higher reactivity and rapid reaction rate. But, alkali solid catalyst has high reactivity to water and free fatty acid in raw material. So, alkali solid catalyst must use with high quality of raw material in order to avoid deactivation. But, acid solid catalyst can use with moist R/M and high free fatty acid in oil. Commonly, acid solid catalyst has very low reactivity. Acid solid catalyst is suitable for oil having free fatty acid because it makes catalyst stable. In addition, there is one type of transesterification. This type use Zirconium Sulfate with hydrogen gas at high temperature. After finishing this reaction, cooling down must be done to prevent any conglomerate in oil. After that, filtering to remove solid out and analyzing in GC. Zirconium Sulfate will catch up protons from metal surface in order to accelerate the long chain hydrocarbon. Hydrogen gas which is added will compensate for the hydrogen that comes off from surface of Zirconium Sulfate.(Charusiri and Vitidsant, 2005)

2.4.3 Enzymatic transesterification

Enzyme Lipase or Glycerol ester hydrolase or Acyl glycerol hydrolase is catalytic enzyme for accelerating hydrolysis of triglyceride molecules to give fatty acid and glycerol. Moreover, enzyme lipase can be applied in synthetic process in some industries, for example, food industry use enzyme lipase to create odor and taste, leather industry use enzyme lipase to remove scraps of meat or unwanted fat from raw material, or the use of enzyme lipase to treat waste water from communities, etc. Enzyme Lipase comes from 3 sources; Animal (pancreas), Plant (wheat, oats, soybeans, cotton), and microorganisms (some species of fungi and yeast)

Enzyme Lipase from microorganisms is mostly used because it grows and populates more quickly, can adjust suitable conditions for the population of enzymes that are easier to culture than plants. Biodiesel production with enzyme lipase is the fuel production process which has no adverse effects on the environment. The production process is cleaner, safer for consumer and lower pollution emission level comparing with chemical production process. The use of enzymes has high cost due to expensive enzymes. However, enzymes in today have been developed to form immobilized lipase which causes enzymes' price decrease because immobilization process is easy and no purification process required. Furthermore, enzymes' stability is rather high. Lipase can be used for accelerating transesterification of triglyceride with high efficiency both in system with water and without water. Biodiesel can be extracted easily. Moreover, biodiesel by this enzymes can achieve higher yield than alkali catalyst because the enzyme has high specificity to precursors both functional groups and stereo specificity. Notwithstanding, in industrial level, the use of enzyme still has higher cost than alkali catalyst and immobilized enzyme is used only for capability to recycle repeatedly. (Woravut, 2005)

2.4.4 Non-catalyzed transesterification

Non-catalyzed transesterification is process without catalyzed and uses uttermost methanol instead. It is the one-step method for converting vegetable oil to biodiesel by transesterification at 350 ^{o}C and 20-50 MPa respectively. Methods have 2 sub-steps ; hydrolysis the used cooking oil with the water and then react with uttermost methanol as methyl-esterification at moderate temperature and pressure --

less than 300 °C and -20 MPa respectively-- which is more difficult than alkali catalyst. Withstanding to heat of biodiesel is factor which should be considered especially in the sensitivity reaction of unsaturated fatty acid in vegetable oil such as oxidation, etc. There are seen in the result from FT-IR that in most used cooking oil has unsaturated fatty acid which has tendency not withstand to heat. Palm oil has saturated fatty acid which has ability to withstand to heat. The cis-trans isomerization effects to flow properties of biodiesel at low temperatures because trans-isomer has melting point higher than cis-isomer while the cloud point and the pour point are hardly different. For biodiesel made from the use of uttermost methanol, cloud point and pour point are gradually high at 350 °C /43 MPa especially in linseed oil and sunflower oil and found that, at 350 °C /43 MPa, biodiesel will decrease 50% accordingly to transmutation to larger molecules by polymerization and transmutation to gas. (Imahara, 2007) Viscosity of methyl ester is higher than diesel --D2-- and when reaction temperature increases, ester generate more (Demirbas, 2003)

2.5 Factor effecting to transesterification

2.5.1 Ratio of methanol-to-oil

Alcohol as accelerator has many classes such as methanol, ethanol, propanol, butanol, ethyl alcohol, etc. by which methanol and ethanol is used in lab-scale and large-scale. Because methanol is cheaper, and ethanol comes from agricultural products which can re-produce and is friendly with environment. So, ethanol is considerably renewable energy to produce fuel. Butanol's advantage is able to surpassing mix with vegetable oil. In addition, the use of large molecule alcohol will yield biodiesel having higher boiling point than small molecule alcohol. Consequently, it can be used at high temperatures at moderate pressure. Butanol will give the highest reaction rate. 1- Propanol and Ethanol is the second and the third respectively.

Although the reaction accelerated by methanol will give the lowest reaction rate, there are 2 factors affecting to compatibility of the reaction precursors ; increasing of the non-polar conditions and the active temperature. In theoretical study, increasing molecular weight of alcohol needs 3 moles of methanol per 1 moles of triglyceride in order to get 3 moles of methyl ester and 1 mole of glycerol. It means the ratio of methanol to oil should be 3:1. However, when pure oil is used, the 6:1 ratio of methanol to oil would get the highest yield. If amount of alcohol increase, reaction will occur quickly and completely including higher ester as well. But, the reaction will not complete if the ratio of methanol to oil is higher than 6:1. Not only incomplete reaction occurs but also the extraction between ester layer and water layer is difficult to be done, takes time and lose cost too. For used cooking oil, the ratio of methanol to oil should be 7:1 in order to get the highest amount of ester. The ratio is higher than pure oil because used cooking oil has higher viscosity which needs methanol to dissolve it and to increase more surfaces between oil and methanol. The amount of accelerator and the ratio of methanol to oil give much effect than temperature and time although the use of different alcohols will cause in its reaction mechanism and the amount of ester. (Meher, Dharmagadda, and Naik, 2006)

2.5.2 Temperature

Temperature is important factor in biodiesel production. High temperature in the reaction gives higher reaction rate. Temperature will help separation to decrease in each phase. The constant of reaction rate will increase and be more compatible with precursors and accelerator. This also helps decrease reaction time. The use of high temperature causes lower yield and higher soap in pure vegetable oil. But, in used cooking oil, the use of high temperature will increase viscosity of biodiesel, effect to soap generation, give lower yield, dissolve oil easier, and increase more contacting surface between oil and methanol creating more triglyceride. The overall reaction is better and faster but accelerates more soap too. In conclusion, the use of high temperature affects positive result to used oil and negative result to pure oil because it causes high viscosity. Temperature will relate with time. Temperature should not exceed the boiling point of alcohol because high temperature accelerates glyceride soap generation. (Meher, Dharmagadda, and Naik, 2006)

2.5.3 Time

Time period used for completely transesterification relates with temperature used in the reaction. In other words, if high temperature is used, time would be short. If low temperature is used, time would be long. For the mechanism of reaction, if time is used 15 minutes, reaction would go fast in the first 5 minutes which generates ester more than 90% and then the reaction go slowly until complete at 15 minutes, and if time is left over the period of 15-30 minutes, the amount of ester is hardly increased, but it decrease the biodiesel yield because ester will hydrolyze more as time passing on. When the amount of ester decrease, fatty acid will increase instead and finally, soap will generate more as time passing on and on. Therefore, time should be controlled not too long because it accelerates reversible reaction which causes lower yield. The concentration of methyl ester is higher as time passing on because more mixing time of precursors making methanol in oil distributing more (Attanatho, Magmee and Jenvanitpanjakul, 2004).

2.5.4 Concentration and type of accelerator

If concentration of accelerator is too low, it is not enough for accelerating. If concentration of accelerator is too high, product will come out lower because it generates soap instead causing viscosity of the solution to increase. When concentration of accelerator increase, concentration of methyl ester increase proportionally to each other because there is little mass transfer within low ratio of methanol to oil. Inversely, if within high ratio of methanol to oil, contacting surface between methanol and oil will increase and make the concentration of methyl ester increase as well. But the increment of methanol is too much; ester will generate more and interfere the separation process between methyl ester and glycerin because methanol will dissolve those two layers to become more homogeneous. Moreover, when product come out lower, solubility will increase at higher temperature which also reduce separation rate between methyl ester and glycerin. Reaction rate will increase when the amount of acid increase, but the acid will stimulate the ether from reaction of alcohol degradation. If using too much alkali, triglycerides are converted to soap with less ester in consequence. For example, when the concentration of NaOH is changed from 0.5% to 1.5%, the product will reduce because of soap generating causing dissolution of methyl ester in glycerol. The separation process is found difficulty since then. Furthermore, it also effects to accelerator removal process and soap removal process which will take time and lose cost afterwards The concentration of accelerator is more effective than temperature, time and the ratio of methanol to oil. (Attanatho, Magmee and Jenvanitpanjakul, 2004)

2.5.5 Stirring process

Stirring is also important factor to transesterification because it helps all precursors and catalyst in the reaction to touch or collide each other. In case of lacking of stirring process, oil and alcohol cannot be homogeneous in nature and both have different solubility causing the reaction occurring only in the joints of oil and alcohol. Therefore, stirring process helps the reaction to occur much easier and faster. However, if the round-per-minute of spinning exceeds one value of the reaction, it will not make the reaction faster anymore because that value is the exposure limit of oil with alcohol and the catalyst at the most. (Rashid and Anwar, 2008)

2.6 Features and Quality of Biodiesel

Specification of Biodiesel classifies into 2 standards; Std. of USA, ASTM D6751 and Std. of Europe, EN 14214. Both standards have different specifications. Biodiesel for commercial purpose has 2 features; the use of biodiesel for blending with diesel and the use of biodiesel for replacing diesel. Commercial Biodiesel has many grades by using B abbreviated for biodiesel and using the number following B for the proportion of biodiesel blending in diesel, such as B5, B20 and B100. For example; B5 means the homogeneous blending of biodiesel and diesel with proportion of biodiesel 5% and diesel 95%. B20 is used popularly in European countries such as Germany. (Ozsezen, Canakci and Sayin, 2008)

In Thailand, features and quality are specified by Department of Energy Business, Ministry of Energy. There are 3 specifications; B100, B5 for commercial purpose and B100 for communities. B100 is specified to be methyl ester of fatty acid which made from ethanol. B100 requirements has 23 inspection items such as % methyl ester, viscosity at ambient temperature, flash point, the anti-knock properties, water content, etc. B5 has the same inspection items as diesel exceptionally for the blue color of the B5. B100 for communities has 12 inspection items similar to B100 exceptionally for the violet color of the B100. (Anucha and Chaicharn, 2007)

Biodiesel has specific gravity 0.88 close to Diesel which has specific gravity 0.85. For density, it has been found that biodiesel has density 2-7% higher than diesel. Biodiesel made from methyl = 2-propyl> ethyl> butyl esters has kinematic viscosity 1.9-6.0 mm^2/sec, according to ASTM D6751 which specify to inspect at 40 ^oC. Viscosity depends on temperature. If temperature increases, viscosity decreases with higher yield of product. Viscosity of biodiesel is 2 times higher than diesel D2. The higher viscosity of biodiesel can save oil. Cetane number Index indicates good combustion control affecting to pollution emission decrement including cold start properties in which ASTM D6751 set Cetane Number Index at 48-60 depending on the amount of carbon chains. This value is higher than pure vegetable oil and diesel in comply with ASTM D675 (Rashid, and Anwar,2008;Demirbas,2003)

In consideration of flash point and burning value of biodiesel, it has been found that it is higher than diesel D2. These Parameters indicate arranging, storing and keeping safely and ignition temp, of oil. If these two values are high, it means possibility to decrease accidents. The use of animal grease in biodiesel production make flash point lower than biodiesel from vegetable oil. ASTM indicates flash point of biodiesel higher than diesel. The water content in diesel and biodiesel is less than 0.05%. If water in biodiesel is high, it has chance to generate fungi. Oxygen content in biodiesel proves better combustion than diesel. Voice of engines using biodiesel is less than engines using diesel. The durability of burns of biodiesel close to diesel which means oxygen helps to increase the maximum heat. Sulfur content, Hydrogen content and Carbon content is already specified in standard (Rashid, and Anwar, 2008; Ozsezen, Canakci, and Sayin, 2008).

Properties of diesel and biodiesel conforming to ASTM showed following in Table 2.1.

Table 2.1 Properties comparison of diesel and biodiesel according to ASTM (Lotero et al., 2005)

Descriptions in each item	**Diesel as ASTM D975**	**Biodiesel as ASTM D6751**
Inspection Items	Hydrocarbon (C10-C21)	Methyl ester of fatty acid
Viscosity(mm^2/s)	1.9-4.1 at 40 ^oC	1.9-6.0 at 40 ^oC
Specific gravity	0.85	0.88
Flash point (^oC)	60-80	100-170
Water content(%)	0.05	0.05
Carbon content(%)	87	77
Hydrogen content(%)	13	12
Oxygen content(%)	0	11
Sulfur content(%)	0.05	0.05
Cetane Number Index	40-55	48-60

In Thailand, the Ministry of Energy (2011) sets biodiesel standards for vehicles and agricultural tractor as shown in Table 2.2 and 2.3

Table 2.2 Quality of the biodiesel methyl esters of fatty acids

List	**Specs**	**High-low rates**		**Test**
1	Methyl Ester, % wt.	Not less than	96.5	EN 14103
2	Density at 15 ◦C, kg/m^3	Not less than And Not higher	860 900	ASTM D 1298
3	Viscosity at 40 ◦C, cSt	Not less than And Not higher	3.5 5.0	ASTM D 445
4	Flash Point, ◦C	Not less than	120	ASTM D 93

Table 2.2 Quality of the biodiesel methyl esters of fatty acids (cont.)

List	Specs	High-low rates		Test
5	Sulphur, %wt	Not higher	0.0010	ASTM D 2622
6	Carbon Residue , on 10 % distillation residue, %wt	Not higher	0.30	ASTM D 4530
7	Cetane Number	Not less than	51	ASTM D 613
8	Sulphated Ash, %wt	Not higher	0.02	ASTM D 874
9	Water, wt.	Not higher	0.050	EN ISO 12937
10	Total Contaminate, %wt.	Not higher	0.0024	EN 12662
11	Copper Strip Corrosion	Not higher	No. 1	ASTM D 130
12	Oxidation Stability at 100 °C, hours	Not less than	6	EN 14112
13	Acid Value , mg KOH/g	Not higher	0.50	ASTM D 664
14	Iodine Value , g Iodine / 100 g	Not higher	120	EN 14111
15	Linolenic Acid Methyl Ester , %wt.	Not higher	12.0	EN 14103
16	Methanol, %wt.	Not higher	0.20	EN 14110
17	Monoglyceride %wt.	Not higher	0.80	EN 14105
18	Diglyceride , %wt.	Not higher	0.20	EN 14105
19	Triglyceride , %wt.	Not higher	0.20	EN 14105
20	Free glycerin , %wt.	Not higher	0.02	EN 14105
21	Total glycerin, %wt.	Not higher	0.25	EN 14105
22	Group I metals (Na+K), mg/kg	Not higher	5.0	EN 14108 and EN 14109
	Group II metals (Ca+Mg),mg/kg		5.0	pr EN 14538
23	Phosphorus, %wt.	Not higher	0.0010	ASTM D 4951
24	Additive	Shall be in accordance with the approval of. Director General of the Department of Energy.		

Table 2.3 Quality of agricultural tractor

List	Specs	High-low rates		Test
1	Density at 15 ◦C, kg/m ^{3}	Not less than And Not higher	860 900	ASTM D 1298
2	Viscosity at 40 ◦C, cSt	Not less than And Not higher	1.9 8.0	ASTM D 445
3	Flash Point, ◦C	Not less than	120	ASTM D 93
4	Sulphur, %wt.	Not higher	0.0015	ASTM D 2622
5	Cetane Number	Not less than	47	ASTM D 613
6	Sulphated Ash, %wt.	Not higher	0.02	ASTM D 874
7	Water and Sediment, %vol.	Not higher	0.2	ASTM D 2709
8	Copper Strip Corrosion	Not higher	No.3	ASTM D 130
9	Acid Number, mg KOH/g	Not higher	0.80	ASTM D 664
10	Free glycerin, %wt.	Not higher	0.02	ASTM D 6584
11	Total glycerin, %wt.	Not higher	1.5	ASTM D 6584
12	Colour		purple	Visual inspection with eye
13	Additive	Shall be in accordance with the approval of. Director General of the Department of Energy.		

2.7 Advantage and Disadvantage of Biodiesel

Biodiesel made from plants or animals can replace for diesel with non-toxic, biodegradable, and never running out while diesel made from petroleum which will be out one day and will not be replaced or renewable. In addition, R/M in biodiesel production may use industrial wastes such as used cooking oil or scraps of animal grease. The advantage of the use of extractable plants such as soybean, palm, etc. is able to rise up that plant price for farmer's better life and able to reduce dependence on oil imported from abroad, and it is alternative option for farmers to plant the extractable crops. However, when planting too much, it reduces cultivated area of other food crops such as rice, etc. This may cause food crops face with crisis situation. Therefore, the cultivated area should be determined clearly to meet the balance between energy crops and food crops in order to create balance in both sides and to secure the energy of nation which can't produce fossil fuel by its own. (Anucha and Chaicharn, 2007)

2.7.1 Advantage of Biodiesel

Biodiesel help reducing pollution emission at exhaust intake such as carbon monoxide, black smoke and odor including toxic material as sulfur, long chain aromatics, etc. Smokes from biodiesel have short chain and high oxygen. So, it causes no soot and black smokes emit to environment. Soot and black smokes make any engines deteriorate and damage easily. One important advantage is that biodiesel has no carbon dioxide (CO_2) emission to atmosphere and not to damage global environment. Carbon dioxide in atmosphere can be absorbed gradually by plants for photosynthesis. It has been found that biodiesel is friendly to environment and can decompose naturally. It can be used with all unmodified diesel engines. Moreover, biodiesel has higher flash point than diesel causing safely usage including has high lubricity causing extending engine life longer and reducing frequency in changing spare parts. (Agarwal and Agarwal, 2006; Lotero et al., 2005)

2.7.2 Disadvantage of Biodiesel

The use of biodiesel can emit nitrogen oxide (NO_x) to global atmosphere, for example, biodiesel made from soybean can increase emission of nitrogen oxide 12% comparing with diesel. B20 --biodiesel 20% and diesel 80%-- can increase emission of nitrogen oxide 2-4 % comparing with diesel. Therefore, rules and regulations should be noted strictly to control the use of biodiesel, even though nitrogen oxide emission is in little amount. Although biodiesel can be used directly in unmodified diesel engines, it should be applied exhaust gas recirculation –EGR-- in order to reduce nitrogen oxide emission. EGR is the technical in reducing nitrogen oxide from diesel engines by using of CO_2 and steam to replace oxygen and nitrogen in combustion chamber. The recirculation of waste gas into engine causes increasing specific heat of the mixture and reducing oxygen content in mixture. Both factors reduce nitrogen oxide but increase carbon monoxide, hydrocarbon, dust and specific heat instead. Moreover, it effects to increase more smoke content, durability of biodiesel engines, and possibility of oxidation occurrence than petroleum fuel oil. This causes acidity and precipitation in biodiesel. Oxidation rate depends on structure of hydrocarbon, concentration of heteroatom, type of heteroatom, concentration of oxygen and time. (Agarwal, Sinha and Agarwal, 2006)

For another considering advantage is that biodiesel production by trans-esterification may generate toxic substances which may contaminate and pollute to environment if production process has no sub-step to eliminate efficiently , for example ; chemicals such as acid or alkali used as catalyst including chemicals used for extracting pure biodiesel, etc.

Table 2.4 The advantage and disadvantage of biodiesel (Anucha and Chaicharn, 2007)

Advantages	Disadvantages
1. Biodiesel can replace diesel at any time by making from plant oil, animal grease and used cooking oil.	1. Emit nitrogen oxide but can solve by waste gas recirculation system.
2. Emit toxic gas a little amount such as carbon dioxide, sulfur, soot etc.	2. Chemical residues remaining from trans-esterification may pollute environment and need to be eliminated efficiently.
3. Reduce dependence on oil imported from abroad resulting farmers to have better income.	
4. Biodiesel can apply with safe and extend life of engine.	

2.8 Crude oil refining process

Crude oil refining process is the decomposing process of hydrocarbons in petroleum compound to various groups or fractions with intricate and sophisticated distillation process. Crude oil in refinery is not only distilled to various fractions but also generated impurities such as sulfur. Refinery may produce oils , gases and chemicals more than 80 types of end-product in which the most important product is many fuels either from lighter fraction (such as gasoline , paraffin , kerosene , or benzene) or heavier fraction (such as diesel, lubricants, fuel oils). The remaining is some residues such as coke, bitumen, tar, and wax. Moreover, various gases such as propane, butane, etc is also come out. All these petrochemicals can be processed to more valuable downstream materials including many derivatives of fuel oils from fractional distillation process. (Pramol and Nurak, 2000)

2.9 The approach of crude refining

2.9.1 Fractional distillation

This approach is a basic distillation process which can refine crude oil to various fractions. Boiling point of each fraction is applied to be the process principle which captures each condensation point to classify its type. Crude oil is pumped into the furnace which has high temperature enough for boiling all fractions to become vapor. Vapors are lined into fractionating tower which is designed to have cylinder shape with height of 30 meters and diameter of 2.5-8 meters. Inside tower is separated to have many horizontal sections which partition as round tray. All section partitions is perforated in order for the coming vapors to pass through to the top of tower and lined with connecting pipes for carrying out the condensed vapors. When the hot vapors are submitted to the distillation tower, vapors will move up into the top of tower. While the vapors moving up, it will become colder and condensed in each section. Vapors will become liquid at each level depending on condensing temperature which differs by each type. The lighter fractions such as gasoline, paraffin with having low condensing temperature will be liquidized at the uppermost section of tower and captured in that section’s partition. The medium fractions such as diesel, gas oils, and light fuel oils will be liquidized in the same way as lighter fractions at each section along the middle of tower. The heavier fractions such as residues, heavy fuel oils, bitumen will settle down in the bottom of tower and be drained off at the base of tower. The disadvantage of fractional distillation is light fractions coming out in lower proportion than worth in economic value. (Pramol and Nurak, 2000)

2.9.2 Thermal cracking

This approach will get distillate as gasoline in the increment of 50%. Currently, this distillation process is run by cracking crude oil in reactor at 1,000 ^{o}F (Degree Fahrenheit) with more than 1,000 psi (pounds per square inch). At this high temperature and high pressure, the high molecular hydrocarbons seclude or split to light fractions or lighter molecular hydrocarbons with fewer carbon atoms in the chain. This light fraction will be submitted into the distillation tower in order to further distill any other condensed liquids. (Pramol and Nurak, 2000)

2.9.3 Catalytic cracking

This approach is developed continuously from traditional approach mentioned earlier. Both are for increasing distillate amount and their better quality. This approach introduces catalysts into medium fractions in order to be split or seclude more progressive without interfering chemical compounds in the fractions. Used catalyst is in form of platinum powder or clay with fine particle. Hot vapors in reactors will contact with catalysts and split or seclude into lighter fractions such as gasoline, and then be finally condensed. Carbon atoms and impurities will be absorbed in clay particles. The clay which is covered with carbon will be flowed out of the reactors into the regenerator in which carbons will be burnt into air. This distillation process forces chemicals to react with crude oil and accelerates the splitting process including extracts out the impurities such as sulfur compounds which has tang odor, aromatics and hydrogen sulfide. (Pramol and Nurak, 2000)

2.9.4 Polymerization

Whilst cracking improve gasoline quantity by splitting out the high molecular fractions, though, polymerization improve gasoline quantity by conglomerating the lightest fractions or gases which are commonly blew out as waste. These gases is fused to be larger molecular which can expand gasoline quantity and also heighten the octane content. (Pramol and Nurak, 2000)

2.10 Products refined from crude oil distillation

2.10.1 Liquefied Petroleum Gas, LPG

LPG or cooking gas is the uppermost distillate in tower. Among the distillates from natural gas, LPG has abundant low boiling point and will be in gas at ambient temperature and pressure. It should be stored in pressure control condition in order to condense it in liquid form which can be used conveniently and safely. LPG can use as fuel with high heating value and has clear flame without smoke. LPG itself has no color and smell. Many manufacturers usually favor some smell in LPG for the purpose of obvious detection when leaking. LPG is applied usefully as cooking gas, vehicle fuel and furnace fuel. (Pramol and Nurak, 2000)

2.10.2 Gasoline

Gasoline is vehicle fuel usually called as “Benzin”. It can be modified from distillate or be extracted from the separation of liquefied natural gas. Gasoline can be filled chemicals for suitable quality as using in each application. For example, heightening the octane number, antirust filler, corrosion proof in tank and pipe lines , etc. (Pramol and Nurak, 2000)

2.10.3 Aviation Gasoline

Aviation gasoline is for turboprop aircrafts. Its properties like vehicle gasoline exceptional in higher octane number as for the purpose of driving power. (Pramol and Nurak, 2000)

2.10.4 Jet Fuel

Jet fuel is for jet aircrafts as used regularly in many airlines. It likes kerosene but more pure and more advantage quality. (Pramol and Nurak, 2000)

2.10.5 Kerosene

Kerosene is known in Thailand since Rama 5 era. Originally, it's used for lamp ignition. Presently, various purposes have been applied such as ingredient in insecticide, solvent in lacquer, etc. (Pramol and Nurak, 2000)

2.10.6 Diesel Fuel

Diesel engine has differently basic combustion system with gasoline engine. Ignition in diesel engine uses heat that comes from high compressed air in a piston, metaphorically doesn't come from spark plug as gasoline engine. Diesel is used widely in many economy machine and tool such as truck, bus, tractor, etc. (Pramol and Nurak, 2000)

2.10.7 Fuel Oil

Fuel oil is for boiler, furnace or kiln in industrial facilities, large generator, marine engine, etc (Pramol and Nurak, 2000)

2.10.8 Bitumen

Bitumen is heaviest residue remaining from distillation. Processed bitumen is modified to meet some particular characteristics such as inert to chemicals and any substances, weather resistance, aging properties, impact resistance, toughness, temperature resilience. (Pramol and Nurak, 2000)

2.11 Global Warming

Global warming means changes in climate occurring from human action. The changes effect to the increment of average global temperature as we called 'Global warming'. Human actions which expand global warming are mainly from any actions that heighten greenhouse gases. For example, effect heightened directly by fuel combustion, effect heightened indirectly by deforestation. (Pisamai, 2005)

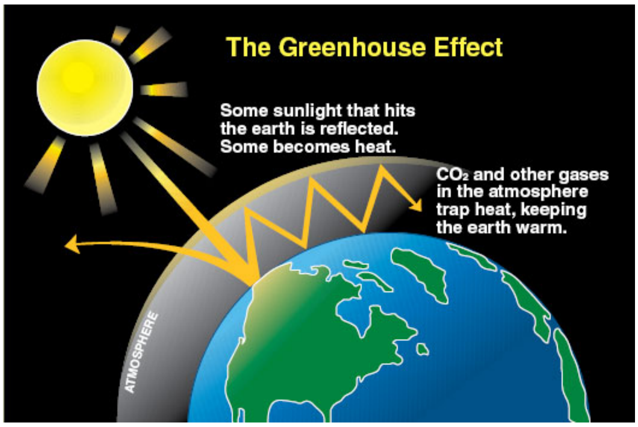

Figure 2.7 The greenhouse effect

The greenhouse effect means the Earth's atmosphere act as glass which allows short-wave radiation from the sun to pass through surface of the Earth and encloses long-wave radiation not to exude out of atmosphere. This phenomena cause world's climate to become very cold at night. The Earth's atmosphere implies as a big blanket covering the Earth. Gases that can induce the phenomena called the greenhouse gases.

The greenhouse gas is gases that possess ability to absorb thermal radiation or infrared rays. These gases are needed to maintain the temperature of atmosphere to be consistently. In case of no greenhouse gas as other planet being, it will cause world's climate become very hot at daytime and very cold at night. These gases can absorb thermal radiation at daytime and exude out gradually at night. World's climate with these gases will not change swiftly. Many gases possess this ability and are grouped as the greenhouse gases which are either from natural or from human action. The examples are steam, carbon dioxides, ozone, methane and nitrous oxides, CFC, etc. The greenhouse gases that are controlled by The Kyoto Protocol are only 6 types which are emitted from human action. There are Carbon dioxides (CO_2), Methane (CH_4), Nitrous oxides (N_2O), Hydro-fluorocarbon (HFC), Per-fluorocarbon (PFC), and Sulfur hexafluoride (SF6). However, there is CFC or Chlorofluorocarbon that is not controlled in The Kyoto Protocol, but is already controlled in Montreal Protocol. (Pisamai, 2005)

2.11.1 Origin of greenhouse gas

2.11.1.1 Degradation of the fossil

2.11.1.2 Industrial factory

2.11.1.3 Appliance in daily usage such as refrigerant in refrigerator / air condition

2.11.1.4 Utensil in daily usage such as propellant in spray cans

2.11.1.5 Paddy or any plants that have to retain water

2.11.1.6 The burning of fossil

2.11.1.7 Applications that have combustion of charcoal, oil, natural gas

2.11.1.8 Various combustion such as fuel consumption in factory or vehicle

2.11.1.9 Burning of forest for housing or farming or Grass burned after harvest

2.11.1.10 Crop, Livestock, Cultivation

Table 2.5 Potential to cause global warming of greenhouse gas (Pisamai, 2005)

Greenhouse gas	Age in the atmosphere (year)	Potential to cause global warming (As carbon dioxide.)
Carbon dioxides	200-450	1
Methane	9-15	23
Nitrous oxides	120	296
CFC-12	100	10,600
Tetrafluoromethane	50,000	5,700
Sulfur hexafluoride	3,200	22,000

2.11.2 The Kyoto Protocol

According to the First Conference of the Parties to the UN Convention on climate change (COP-1) in year 1995, the meeting agreed to expedite the implementation of international obligations in the Annex 1 to achieve the ultimate goal of the Convention and decided to appoint the Ad Hoc Group on the Berlin Mandate (AGBM) in order for drafting a new agreement to force the implementation of obligations. The agreement has been drafted for two years and is presented in COP-3 in year 1997. Parties had approved the Kyoto Protocol to that meeting. (Pisamai, 2005)

2.11.3 The key principles of the Kyoto Protocol

2.11.3.1 The Kyoto Protocol had defined the legal binding in the implementation of the obligations. In section 3, it had defined obligation in the decrement of greenhouse gas emission of Parties in Annex 1 at least 5% of total emissions of the groups in 2000 within 2008-2012 by which the %emission differs in each country. For example, decrement of 8% carbon dioxide emission in 2000 for EU, decrement of 10% for Iceland, decrement of 6% for Japan, etc.

2.11.3.2 Section 3 had defined 6 types of greenhouse gas controlled in the Kyoto Protocol which are Carbon dioxides (CO_2), Methane (CH_4), Nitrous oxides (N_2O), Hydro-fluorocarbon (HFC), Per-fluorocarbon (PFC), and Sulfur hexafluoride (SF6) by defining decrement of these gases comparing as carbon dioxide equivalent.

2.11.3.3 Define additional obligations with the developed countries and no additional obligations with the developing countries.

2.11.3.4 Section 18 of protocol had defined procedures and mechanisms for judgment and punishment in case of Parties not implementing as obligated.

2.11.3.5 To solve climate change, the Kyoto Protocol had defined the following 3 flexibility mechanisms.

- Joint Implementation, JI as obligated in section 6 which had defined that the developed countries can implement the greenhouse gas emission reduction project within groups mentioned in Annex 1. The decrement amount is called Emission Reduction Units, ERUs.

- Clean Development Mechanism, CDM as obligated in section 12 which had defined that Parties in Appendix 1 can implement the greenhouse gas reduction project cooperating with the developing countries or Parties in Non-Annex I. The decrement amount must be certified and reasonably called Certified Emission Reduction, CERs.

- Emission Trading, ET as obligated in section 17 which had defined that Parties in Annex 1 who can't reduce greenhouse gas in his or her country as defined could purchase the emission right from Parties in Annex 1 whoever had emission right remaining (may remain from JI project and CDM project or from economic condition which cause lower emission than in 1990 and remain right for purchasing). Right of purchase is called Assigned Amount Units, AAUs. (Pisamai, 2005)

2.12 Assessment of greenhouse gas emission

Carbon Footprint (CF) is scientific notation which is calculated the amount of greenhouse gas emissions from products or activities to the atmosphere and expressed in carbon dioxide equivalent with both direct and indirect measurement. (Technical Committee on the carbon footprint of products, 2011)

2.12.1 Direct measurement

Direct measurement is the determination of greenhouse gas emission from activities itself such as fuel combustion, including energy consumption in household and vehicles.

2.12.2 Indirect measurement

Indirect measurement is the determination of greenhouse gas emission from goods or products consumption by calculating the whole production process since R/M receiving, cultivation, processing, transporting, application, product wreckage disposal , or thorough the product life cycle(LCA : Life Cycle Assessment)

2.13 Evaluation method for greenhouse gas emissions

The assessment of greenhouse gas emissions can be performed by one of the following method. (Technical Committee on the carbon footprint of products, 2011)

2.13.1 Cradle-to-Grave

Cradle-to-Grave (Business-to-Consumer: B2C) is assessment greenhouse gas emission thorough the product life cycle which begins from R/M receiving, production, transporting, distributing, applying and disposal

2.13.2 Cradle-to Gate

Cradle-to Gate (Business-to-Business : B2B) is assessment greenhouse gas emission from the R/M receiving step to the ready-delivery step, or to the R/M receiving step of the next producers as specified in PCRs of each product.

CHAPTER III
METHODOLOGY

3.1 The steps for purchasing used cooking oil

Consolidate data of origin and amount which are brought to produce biodiesel

3.1.1 Industrial factories

Used cooking oil from totally 3 industrial factories

3.1.1.1 Mongkol vegetable oil
3.1.1.2 E-ester (Bangkok)
3.1.1.3 Ngbaktai

3.1.2 Bangchak Gas Stations

Used cooking oil from totally 25 Bangchak Gas Stations

3.1.2.1 Khae Rai
3.1.2.2 Bang Bua Tong 3
3.1.2.3 Pibulsongkram
3.1.2.4 Chuanchuen
3.1.2.5 Kaset
3.1.2.6 Charansanitwong
3.1.2.7 Suwintawong
3.1.2.8 Bang Sue
3.1.2.9 Thepharak Km9
3.1.2.10 Pak Nam
3.1.2.11 Lasalle
3.1.2.12 Suksawat 1
3.1.2.13 Prachauthit
3.1.2.14 Ramindra Km14

3.1.2.15 Navamin
3.1.2.16 Permsin
3.1.2.17 Along the highway Ekamai-Ramindra
3.1.2.18 Phet Kaserm 57
3.1.2.19 Sukhumvit 99
3.1.2.20 Pinklao
3.1.2.21 Lemongreen
3.1.2.22 Chockchai 4
3.1.2.23 Watdansamrong
3.1.2.24 On Nut
3.1.2.25 Mahadthai

3.2 Transportation

Evaluate the consumed energy and carbon dioxides emission from purchasing sources.

3.2.1 Calculate the consumed energy

Calculate transportation by the assumed situation. Transporting distance unit is KM (for example, distance from Khae Rai Gas Station to Sukhumvit64 Gas Station equal to 10 Kilometers) and the rate of fuel and then multiplying with net calorific value of fuel.

Table 3.1 Net calorific value of diesel (Ministry of energy, 2011)

Type	Net calorific value
Diesel	36.42 MJ/Unit

3.2.2 Calculate carbon dioxide emissions

Calculate transportation by the assumed situation. Transporting distance unit is KM (for example, distance from Khae Rai Gas Station to Sukhumvit64 Gas Station equal to 10 Kilometers) considering round trip by empty loading for forward trip and fully used oil loading for backward trip and then multiplying with emission factor of that transporting truck.

$$CO_{2\ Emission,fuel} = \text{Fuel Consumption} * \text{Emission Factor}$$

Equation 3.1 CO_2 emission formula

When

$CO_{2\ Emission,fuel}$ = CO_2 emissions from fuel ($KgCO_2$)

Fuel Consumption = fuel usage (unit)

Emission Factor = The CO_2 emissions of each fuel type ($KgCO_2$/unit)

Table 3.2 Emission factor of truck (IPCC2007)

Type	Emission Factor
Ten-wheeled truck 0% Load	0.5851
Ten-wheeled truck 100% Load	0.0529
Pickup truck 0% Load	0.3105
Pickup truck 50% Load	0.2676

3.3 Biodiesel production process from used cooking oil

Biodiesel production process is divided into four main steps. Represented by the diagram below;

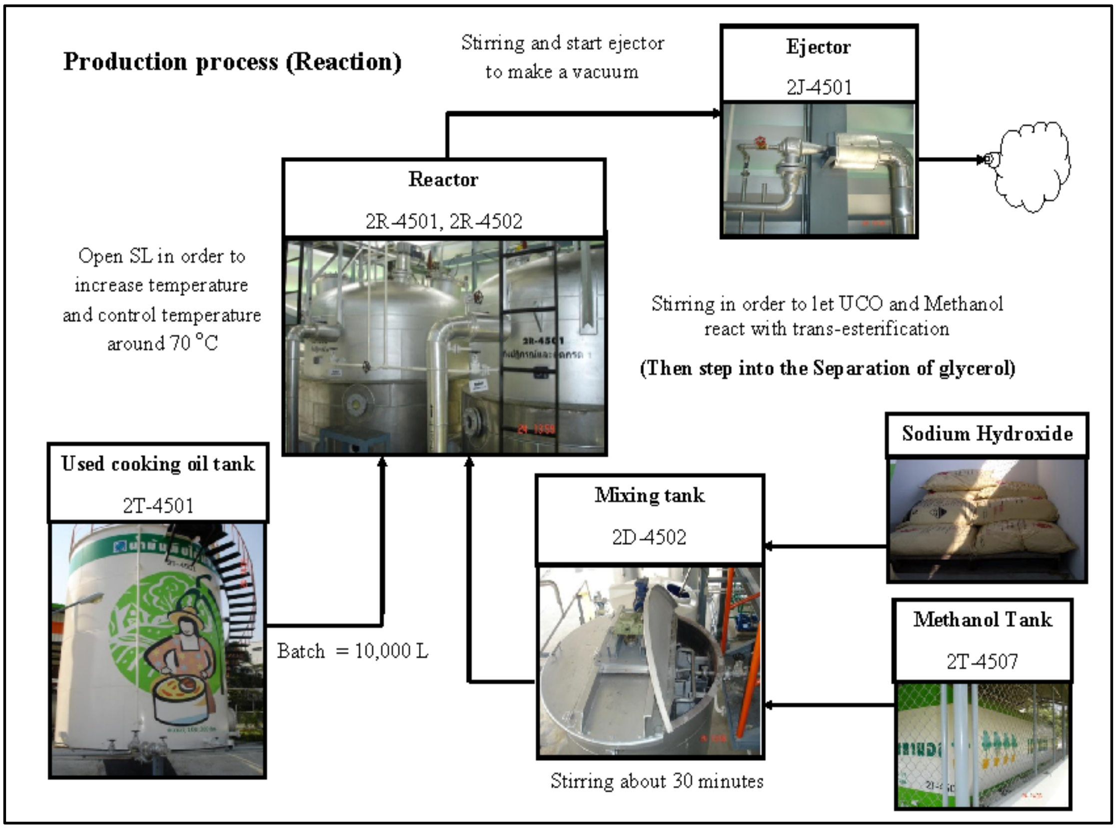

Figure 3.1 Production process (Reaction)

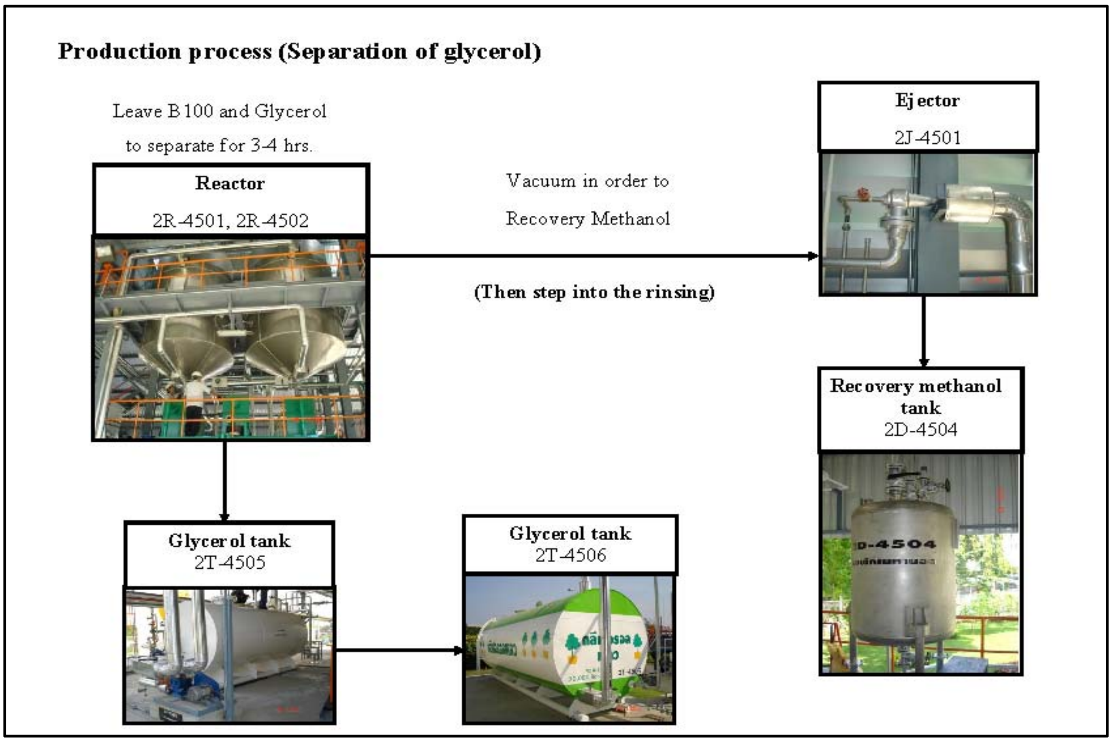

Figure 3.2 Production process (Separation of glycerol)

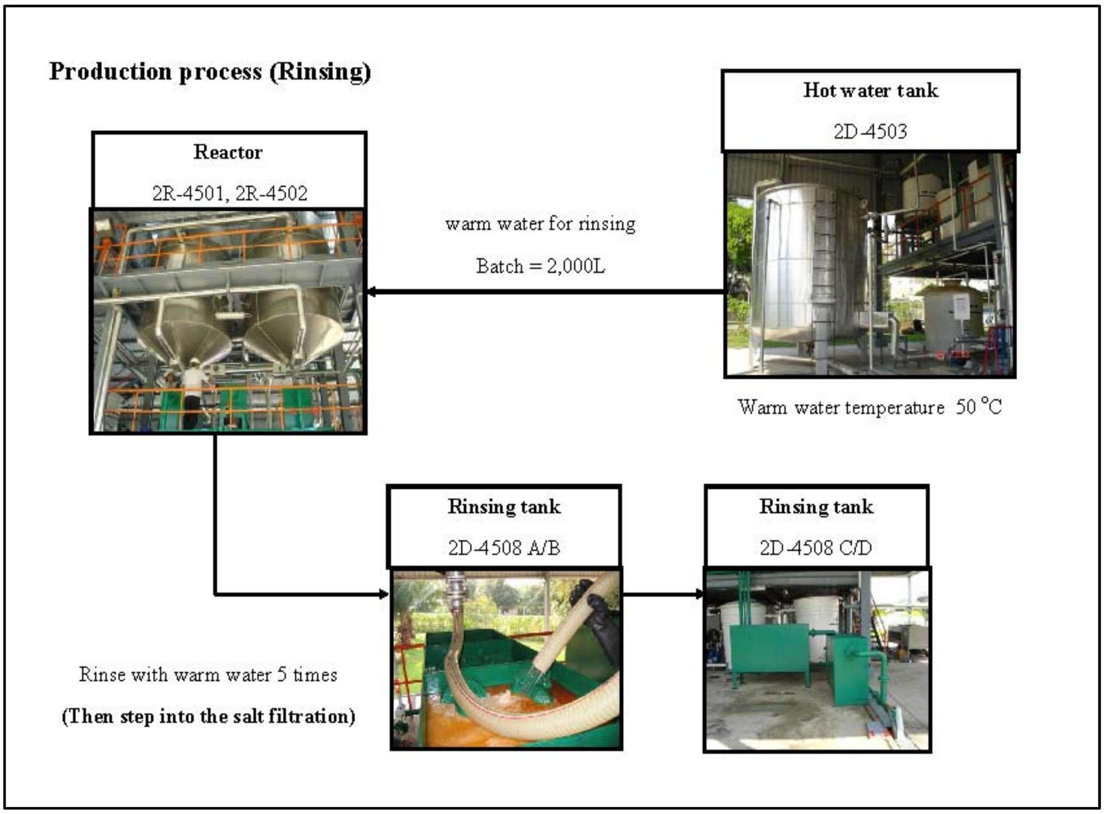

Figure 3.3 Production process (Rinsing)

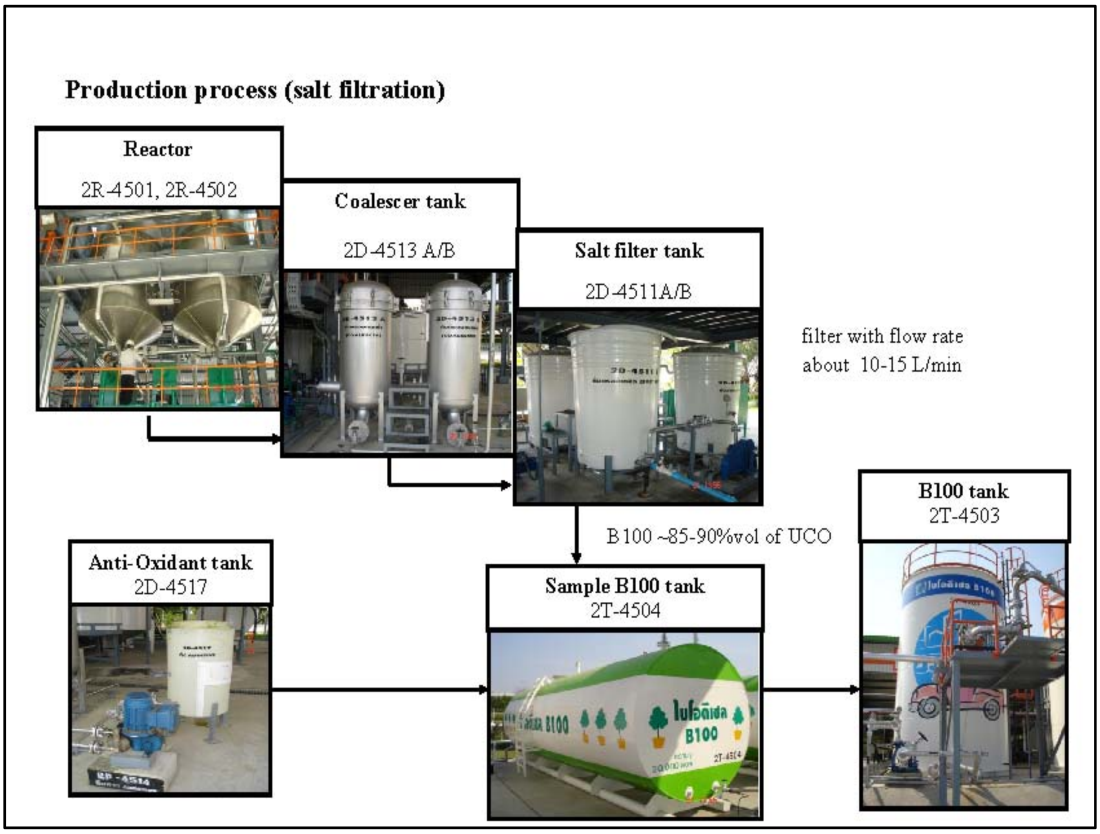

Figure 3.4 Production process (salt filtration)

Detail of biodiesel production process

3.3.1 Feeding used cooking oil from 2T-4501 10,000L into Reactor 2R-4501 or 2R-4502.

3.3.2 Setting SL pressure (Steam Low Pressure: 3.4 Barg, 185 C) in order to increase temperature in reactor and control temperature around 70 ^{o}C.

3.3.3 When temperature in reactor reach 70 ^{o}C, starting stirring (propellers in reactor) and start Ejector 2J-4501 to make a vacuum and eliminate moisture in oil by SL about 30 minutes.

3.3.4 Blending Methanol from 2T-4507 20%wt of UCO and Sodium Hydroxide 1%wt of UCO in Drum 2D-4502, and then stirring about 30 minutes.

3.3.5 Inject the blended Methanol and Sodium Hydroxide into reactor.

3.3.6 Start stirring in reactor about 30 minutes in order to let UCO and Methanol react with trans-esterification by controlling temperature in reactor around 65 ^{o}C

3.3.7 After stirring 30 minutes, stop stirring and leave B100 and Glycerol to separate for 3-4 hrs.

3.3.8 Transfer Glycerol from reactor to 2T-4505 to receive Glycerol about 2,500L and then transfer Glycerol in 2T-4505 to keep in 2T-4506.

3.3.9 Start Ejector 2J-4501 to make a vacuum by SL in order to remove the remaining Methanol from reaction. Methanol is recovered and kept in 2D-4504.

3.3.10 Make Up inlet water to 2D-4503 about 10,000L and increase temperature to 50 ^{o}C in order to warm the water for rinsing impurity in B100. When water temperature reach the setting point, feed warm water into reactor about 2,000L to rinse B100 the first times and leave B100 and water to separate for 30 minutes , and then drain water out of reactor to rinsing tank.

3.3.11 Feed warm water into reactor about 2,000 litres to rinse B100 the second time and leave it to separate about 30 minutes, and then drain water out of reactor to rinsing tank.

3.3.12 Proceed rinsing the third, fourth and fifth as 11.

3.3.13 Bring B100 in reactor to filter salt at Coalescer 2D-4513 and 2D-4510A/B with flow rate about 10-15 L/min .After filtering, transfer B100 to keep in 2T-4504.

3.3.14 Transfer B100 from filter unit to keep in 2T-4504, add anti-Oxidant to adjust the oxidation stability of B100 to be higher. When adding anti-Oxidant at required amount, circulate to mix anti-Oxidant and B100 thoroughly, and then take sample and dispatch to Lab. For testing, if quality meets the spec, keep B100 in 2T-4503.

3.4 Energy Consumption and CO_2 emission in biodiesel production process from used cooking oil

3.4.1 Calculate of electricity consumption

Calculate the energy consumption in production process of equipment used by the power and duration of the operation of the device, all in the process.

For example;

Equipment : Pump 2P-4501
Power : 2HP
Work time : 60 minute
Energy consumption : 1.492 kwh

3.4.2 Calculation energy consumption from steam

$$q = mc_p dT/t$$

Equation 3.2 Specific Heat formula

When
q = mean heat transfer rate (kW (kJ/s)
m = mass of the product (kg)
c_p = specific heat capacity of the product (kJ/kg.^{o}C)
dT = change in temperature of the fluid (^{o}C)
t = total time over which the heating process occurs (seconds)

3.4.3 Calculation CO_2 emission from electricity

$$CO_{2\ \text{Emission,Electricty}} = \text{Electricity Consumption} * \text{Emission Factor}$$

Equation 3.3 CO_2 emission formula

When
$CO_{2\ \text{Emission,Electricty}}$ = CO_2 emissions from electricity consumption ($KgCO_2$)
Electricity Consumption= electricity usage (kwh)
Emission Factor = The CO_2 emissions from electricity generation in Thailand ($KgCO_2$/kwh)

Table 3.3 Emission factor of Electricity (IPCC, 2007)

Type	Emission Factor
Electricity	0.5610

3.5 Diesel production process from crude oil

Collect data, document and research related in crude oil refining process by assessing energy used for producing and assess carbon dioxide emission.

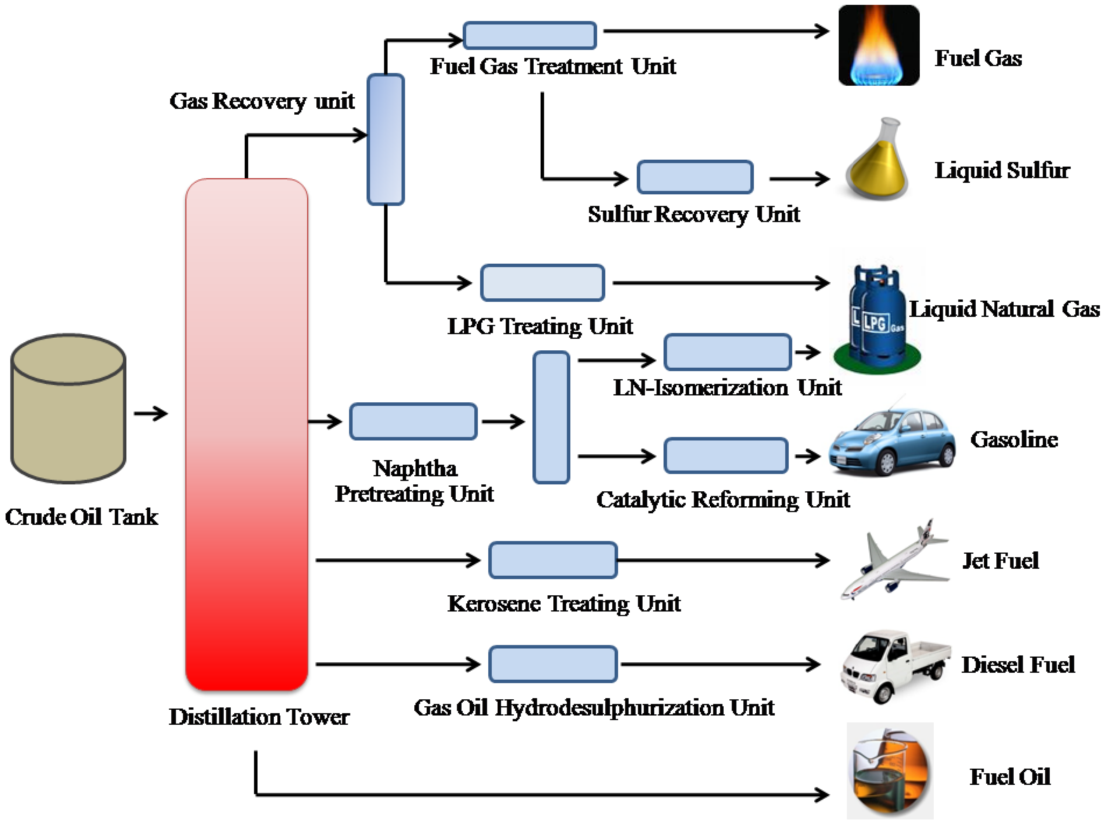

Figure 3.5 Diesel production process

CHAPTER IV
RESULTS

4.1 Transportation

Table 4.1 Distance used in transportation

Route	**Start**	**Destination**	**Distance(Km)**	
			Go	**Back**
1	Bankchak refinery (sukhumvit 64)	Mongkol vegetable oil	13.9	14.4
2	Bankchak refinery (sukhumvit 64)	E-ester (Bangkok)	53.4	56.9
3	Bankchak refinery (sukhumvit 64)	Ngbaktai	15.2	15.6
4	Bankchak refinery (sukhumvit 64)	Khae Rai	23.4	24.1
5	Bankchak refinery (sukhumvit 64)	Bang Bua Tong 3	43.2	47.1
6	Bankchak refinery (sukhumvit 64)	Pibulsongkram	31.7	34.0
7	Bankchak refinery (sukhumvit 64)	Chuanchuen	46.8	46.8
8	Bankchak refinery (sukhumvit 64)	Kaset	21.7	21.5
9	Bankchak refinery (sukhumvit 64)	Charansanitwong	22.8	27.8
10	Bankchak refinery (sukhumvit 64)	Suwintawong	47.6	47.8

Table 4.1 Distance used in transportation (cont.)

Route	**Start**	**Destination**	**Distance(Km)**	
			Go	**Back**
11	Bankchak refinery (sukhumvit 64)	Bang Sue	18.8	22.0
12	Bankchak refinery (sukhumvit 64)	Thepharak Km9	19.7	17.6
13	Bankchak refinery (sukhumvit 64)	Pak Nam	12.4	12.6
14	Bankchak refinery (sukhumvit 64)	Lasalle	8.0	6.2
15	Bankchak refinery (sukhumvit 64)	Suksawat 1	19.5	21.4
16	Bankchak refinery (sukhumvit 64)	Prachauthit	14.4	16.1
17	Bankchak refinery (sukhumvit 64)	Ramindra Km14	33.6	35.6
18	Bankchak refinery (sukhumvit 64)	Navamin	21.8	22.9
19	Bankchak refinery (sukhumvit 64)	Permsin	17.8	16.4
20	Bankchak refinery (sukhumvit 64)	Along the highway Ekamai-Ramindra	16.7	20.8
21	Bankchak refinery (sukhumvit 64)	Phet Kaserm 57	31.3	35.2
22	Bankchak refinery (sukhumvit 64)	Sukhumvit 99	3.8	2.2
23	Bankchak refinery (sukhumvit 64)	Pinklao	22.7	29.1
24	Bankchak refinery (sukhumvit 64)	Lemongreen	24.6	26.5

Table 4.1 Distance used in transportation (cont.)

Route	Start	Destination	Distance (Km)	
			Go	Back
25	Bankchak refinery (sukhumvit 64)	Chockchai 4	17.9	19.6
26	Bankchak refinery (sukhumvit 64)	Watdansamrong	8.1	8.5
27	Bankchak refinery (sukhumvit 64)	On Nut	11.7	12.0
28	Bankchak refinery (sukhumvit 64)	Mahadthai	15.3	15.8

Table 4.2 Data about transportation

Route	Volume of Used cooking oil (litres)	Frequency (Times per month)	Type of vehicle
1	16,000	3	Ten-wheeled truck
2	16,000	3	Ten-wheeled truck
3	16,000	3	Ten-wheeled truck
4	600	2	Pickup truck
5	600	2	Pickup truck
6	600	2	Pickup truck
7	600	2	Pickup truck
8	600	2	Pickup truck
9	600	2	Pickup truck
10	600	2	Pickup truck
11	600	2	Pickup truck
12	600	2	Pickup truck
13	600	2	Pickup truck
14	600	2	Pickup truck
15	600	2	Pickup truck

Table 4.2 Data about transportation (cont.)

Route	**Volume of Used cooking oil (litres)**	**Frequency (Times per month)**	**Type of vehicle**
16	600	2	Pickup truck
17	600	2	Pickup truck
18	600	2	Pickup truck
19	600	2	Pickup truck
20	600	2	Pickup truck
21	600	2	Pickup truck
22	600	2	Pickup truck
23	600	2	Pickup truck
24	600	2	Pickup truck
25	600	2	Pickup truck
26	600	2	Pickup truck
27	600	2	Pickup truck
28	600	2	Pickup truck

4.2 Energy Consumption and CO_2 emission in production process

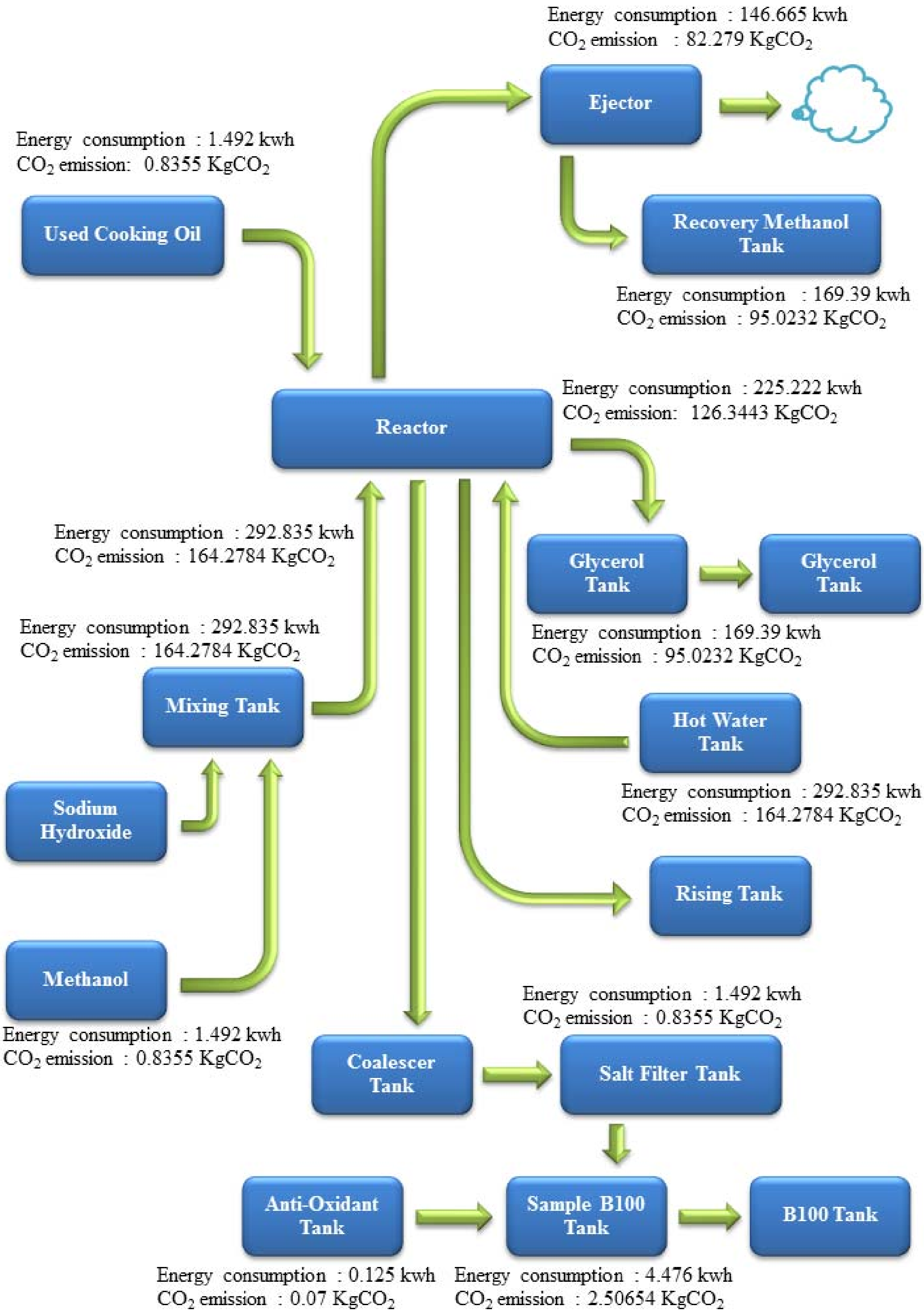

Figure 4.1 Production process

4.2.1 Energy consumption

4.2.1.1 Feeding used cooking oil from 2T-4501 10,000L into Reactor 2R-4501 or 2R-4502.

Equipment : Pump 2P-4501
Power : 2HP
Work time : 60 minute
Output : Used cooking oil
Energy consumption: 1.492 kwh

4.2.1.2 Setting SL pressure (Steam Low Pressure: 3.4 Barg, 185 C) in order to increase temperature in reactor and control temperature around 70 ^{o}C.

Equipment : Steam
Power : -
Work time : 30 minute
Output : Used cooking oil
Energy consumption : 220 kwh

4.2.1.3 When temperature in reactor reach 70 ^{o}C, starting stirring (propellers in reactor) and start Ejector 2J-4501 to make a vacuum and eliminate moisture in oil by SL about 30 minutes.

Equipment : Motor
Power : 5 HP
Work time : 30 minute
Output : Used cooking oil
Energy consumption : 1.865 kwh

Equipment : Steam
Power : -
Work time : 30 minute
Output : Used cooking oil
Energy consumption : 146.665 kwh

4.2.1.4 Blending Methanol from 2T-4507 20%wt of UCO and Sodium Hydroxide 1%wt of UCO in Drum 2D-4502, and then stirring about 30 minutes.

Equipment : Pump 2P-4509
Power : 2HP
Work time : 60 minute
Output : Methanol
Energy consumption : 1.492 kwh

Equipment : Motor
Power : 2 HP
Work time : 30 minute
Output : Mixture
(Methanol+ Sodium Hydroxide)
Energy consumption : 0.746 kwh

4.2.1.5 Inject the blended Methanol and Sodium Hydroxide into reactor.

Equipment : Pump 2P-4510
Power : 2HP
Work time : 60 minute
Output : Used cooking oil + Mixture
Energy consumption : 1.492 kwh

4.2.1.6 Start stirring in reactor about 30 minutes in order to let UCO and Methanol react with trans-esterification by controlling temperature in reactor around 65 ^{o}C

Equipment : Motor
Power : 5 HP
Work time : 30 minute
Output : B100 and Glycerol
Energy consumption : 1.865 kwh

4.2.1.7 After stirring 30 minutes, stop stirring and leave B100 and Glycerol to separate for 3-4 hrs.

4.2.1.8 Transfer glycerol from reactor to 2T-4505 to receive Glycerol about 2,500L and then transfer glycerol in 2T-4505 to keep in 2T-4506.

Equipment : Pump 2P-4504
Power : 2HP
Work time : 60 minute
Output : Glycerol
Energy consumption : 1.492 kwh

Equipment : Pump 2P-4518
Power : 2HP
Work time : 120 minute
Output : Glycerol
Energy consumption : 2.984 kwh

4.2.1.9 Start ejector 2J-4501 to make a vacuum by SL in order to remove the remaining Methanol from reaction. Methanol is recovered and kept in 2D-4504.

Equipment : Steam
Power : -
Work time : 30 minute
Output : Methanol
Energy consumption : 165.66 kwh

Equipment : Chiller
Power : 10 HP
Work time : 30 minute
Output : Methanol
Energy consumption : 3.73 kwh

4.2.1.10 Make up inlet water to 2D-4503 about 10,000L and increase temperature to 50 ^{o}C in order to warm the water for rinsing impurity in B100. When water temperature reach the setting point, feed warm water into reactor about 2,000L to rinse B100 the first times and leave B100 and water to separate for 30 minutes , and then drain water out of reactor to rinsing tank.

Equipment : Steam
Power : -
Work time : 30 minute
Output : Warm water
Energy consumption : 290.97 kwh

Equipment : Pump 2P-4520
Power : 2HP
Work time : 15 minute
Output : B 100
Energy consumption : 0.373 kwh

4.2.1.11 Feed warm water into reactor about 2,000 litres to rinse B100 the second time and leave it to separate about 30 minutes, and then drain water out of reactor to rinsing tank

Equipment : Pump 2P-4520
Power : 2HP
Work time : 15 minute
Output : B 100
Energy consumption : 0.373 kwh

4.3.2.12 Proceed rinsing the third, fourth and fifth as 4.3.1.11

Equipment : Pump 2P-4520
Power : 2HP
Work time : 15 minute
Output : B 100
Energy consumption : 0.373*3=1.119 kwh

4.2.1.13 Bring B100 in reactor to filter salt at Coalescer 2D-4513 and 2D-4510A/B with flow rate about 10-15 L/min .After filtering, transfer B100 to keep in 2T-4504.

Equipment : Pump 2P-4506
Power : 2HP
Work time : 60 minute
Output : B100

Energy consumption : 1.492 kwh

4.2.1.14 Transfer B100 from filter unit to keep in 2T-4504, add anti-Oxidant to adjust the oxidation stability of B100 to be higher. When adding anti-Oxidant at required amount, circulate to mix anti-Oxidant and B100 thoroughly, and then take sample and dispatch to Lab. For testing, if quality meets the spec, keep B100 in 2T-4503.

Equipment : Pump 2P-4514
Power : 250W
Work time : 30 minute
Output : B100
Energy consumption : 0.125 kwh

Equipment : Pump 2P-4508
Power : 2HP
Work time : 120 minute
Output : B100
Energy consumption: 2.984 kwh

Equipment : Pump 2P-4508
Power : 2HP
Work time : 60 minute
Output : B100
Energy consumption : 1.492 kwh

4.2.2 CO_2 emission

4.2.2.1 Feeding used cooking oil from 2T-4501 10,000L into Reactor 2R-4501 or 2R-4502.

Energy consumption : 1.492 kwh
CO_2 emission : 0.8355 KgCO_2

4.2.2.2 Setting SL pressure (Steam Low Pressure: 3.4 Barg, 185 C) in order to increase temperature in reactor and control temperature around 70 ^{o}C.

Energy consumption : 220 kwh

CO_2 emission : 123.42 $KgCO_2$

4.2.2.3 When temperature in reactor reach 70 °C, starting stirring (propellers in reactor) and start Ejector 2J-4501 to make a vacuum and eliminate moisture in oil by SL about 30 minutes.

Energy consumption : 1.865 + 146.665 = 148.53 kwh

CO_2 emission : 83.325 $KgCO_2$

4.2.2.4 Blending Methanol from 2T-4507 20%wt of UCO and Sodium Hydroxide 1%wt of UCO in Drum 2D-4502, and then stirring about 30 minutes.

Energy consumption : 1.492 + 0.746 = 2.238 kwh

CO_2 emission : 1.253 $KgCO_2$

4.2.2.5 Inject the blended Methanol and Sodium Hydroxide into reactor.

Energy consumption : 1.492 kwh

CO_2 emission : 0.835 $KgCO_2$

4.2.2.6 Start stirring in reactor about 30 minutes in order to let UCO and Methanol react with trans-esterification by controlling temperature in reactor around 65 °C

Energy consumption : 1.865 kwh

CO_2 emission : 1.044 $KgCO_2$

4.2.2.7 After stirring 30 minutes, stop stirring and and leave B100 and Glycerol to separate for 3-4 hrs.

4.2.2.8 Transfer Glycerol from reactor to 2T-4505 to receive Glycerol about 2,500L and then transfer Glycerol in 2T-4505 to keep in 2T-4506.

Energy consumption : 1.492 + 2.984 = 4.476 kwh

CO_2 emission : 2.5065 $KgCO_2$

4.2.2.9 Start Ejector 2J-4501 to make a vacuum by SL in order to remove the remaining Methanol from reaction. Methanol is recovered and kept in 2D-4504.

Energy consumption : 165.66 + 3.73 = 169.39 kwh

CO_2 emission : 95.0277 $KgCO_2$

4.2.2.10 Make Up inlet water to 2D-4503 about 10,000L and increase temperature to 50 ^{o}C in order to warm the water for rinsing impurity in B100. When water temperature reach the setting point, feed warm water into reactor about 2,000L to rinse B100 the first times and leave B100 and water to separate for 30 minutes , and then drain water out of reactor to rinsing tank.

Energy consumption : 0.373+290.970 = 291.343 kwh

CO_2 emission : 163.443 $KgCO_2$

4.2.2.11 Feed warm water into reactor about 2,000 litres to rinse B100 the second time and leave it to separate about 30 minutes, and then drain water out of reactor to rinsing tank

Energy consumption : 0.373 kwh

CO_2 emission : 0.2088 $KgCO_2$

4.2.2.12 Proceed rinsing the third, fourth and fifth as 4.1.11

Energy consumption : 0.373*3=1.119 kwh

CO_2 emission : 0.6266 $KgCO_2$

4.2.2.13 Bring B100 in reactor to filter salt at Coalescer 2D-4513 and 2D-4510A/B with flow rate about 10-15 L/min .After filtering, transfer B100 to keep in 2T-4504.

Energy consumption : 1.492 kwh

CO_2 emission : 0.8355 $KgCO_2$

4.2.2.14 Transfer B100 from filter unit to keep in 2T-4504, add anti-Oxidant to adjust the oxidation stability of B100 to be higher. When adding anti-Oxidant at required amount, circulate to mix anti-Oxidant and B100 thoroughly, and then take sample and dispatch to Lab. For testing, if quality meets the spec, keep B100 in 2T-4503.

Energy consumption : 0.125 + 2.984 + 1.492
= 4.601 kwh

CO_2 emission : 2.5765 $KgCO_2$

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Energy consumption of biodiesel from used cooking oil

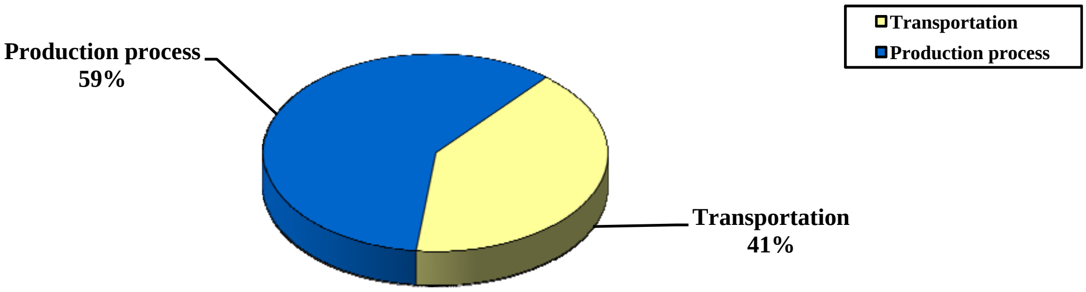

Figure 5.1 Energy consumption of biodiesel

5.1.1.1 Transportation = 0.2397 MJ/litres

Table 5.1 Description of energy consumption (Ten-wheeled truck)

Kind of truck	Ten-wheeled truck
The rate of fuel consumption	0% Load = 5.24 Km/litres. 50% Load = 3.87 Km/litres
Distance	*Go:* 53.4+13.9+15.2 = 82.5 Km. *Back:* 56.9+14.4+15.6 = 86.9 Km.
Volume of Used cooking oil (litres)	16,000*3 = 48,000 litres
Diesel fuel used	15.7442+22.4547 = 38.1989 litres.
Energy consumption	(38.1989L * 36.42MJ)/48,000L = 0.0289 MJ/litres.

Table 5.2 Description of energy consumption (Pickup truck)

Kind of truck	Pickup truck
The rate of fuel consumption	0% Load = 14 Km/litres. 50% Load = 12.5 Km/litres.
Distance	*Go:* 23.4+43.2+31.7+46.8+21.7+22.8+47.6+18.8 +19.7+12.4+8.0+19.5+14.4+33.6+21.8+17.8 + 16.7+31.3+3.8+22.7+24.6+17.9+8.1+11.7 +15.3 = 555.3 Km. *Back:* 24.1+47.1+34.0+46.8+21.5+27.8+47.8+22.0+17.6+12.6+6.2+21.4+16.1+35.6+22.9+16.4+20.8+35.2+2.2+29.1+26.5+19.6+8.5+12.0+15.8 = 589.6 Km.
Volume of Used cooking oil (litres)	600*25 = 15,000 litres
Diesel fuel used	39.6642+47.1680 = 86.8322 litres.
Energy consumption	(86.8322 * 36.42MJ)/15,000L = 0.2108 MJ/litres

5.1.1.2 Production process

Feeding used cooking oil from into Reactor = 1.492 kwh / Increase and control oil temperature = 220 kwh / Stirring = 1.865 kwh / Vacuum and eliminate moisture in oil = 146.665 kwh / Blending methanol = 1.492 kwh / Stirring mixture = 0.746 kwh / Inject the blended methanol and sodium hydroxide into reactor = 1.492 kwh / Stirring = 1.865 kwh / Transfer Glycerol = 4.476 kwh / Recovery methanol = 168.97 kwh / Make warm water = 290.97 kwh / Feed warm water into reactor = 1.865 kwh / Transfer B100 = 4.476 kwh / Add anti-Oxidant 0.125 kwh / Transfer B100 to storage 1.492 kwh

Energy consumption used to produce 8.75 m^3 of biodiesel produced is 848.411 kwh . So, energy consumption used to produce 1 litre of biodiesel produced is 0.0969 kwh or 0.3488 MJ/litres.

Energy consumption of biodiesel from used cooking oil is 0.5885 MJ/litres

5.1.2 CO_2 emission of biodiesel from used cooking oil

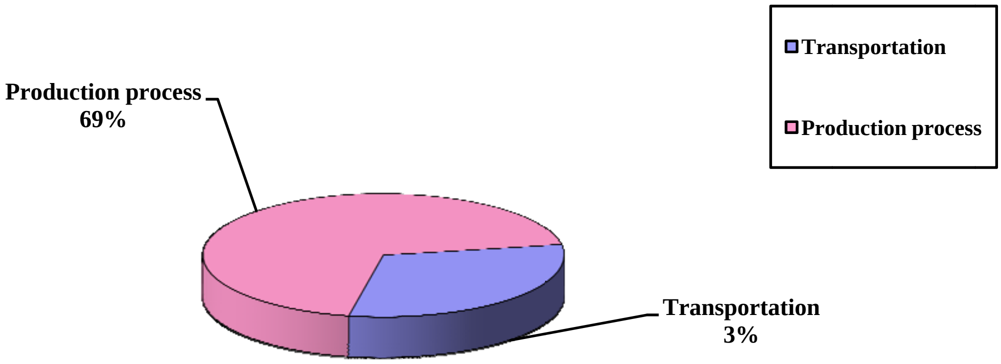

Figure 5.2 CO_2 emission of biodiesel

5.1.2.1 Transportation = 0.0248 $KgCO_2$

Table 5.3 Description of CO_2 emission (Ten-wheel truck)

Kind of truck	Ten-wheeled truck
Emission Factor of Ten-wheeled truck	0% Load = 0.5851 km 100% Load = 0.0529 tkm.
Distance	*Go:* 53.4+13.9+15.2 = 82.5 km. *Back:* 56.9+14.4+15.6 = 86.9 km.
Volume of Used cooking oil (litres)	16,000*3 = 48,000 litres.
Diesel fuel used	(Go) = 15.7442 litres. (Back) = 22.4547 litres.
Energy consumption	CO_2 emission = 0.0028 $KgCO_2$/litres

Table 5.4 Description of CO_2 emission (Pickup truck)

Kind of truck	Pickup truck
Emission Factor of pickup truck	0% Load = 0.3105 km 50% Load = 0.2676 tkm.
Distance	*Go:* 23.4+43.2+31.7+46.8+21.7+22.8+47.6+ 18.8+19.7+12.4+8.0+19.5+14.4+33.6+21.8+ 17.8+16.7+31.3+3.8+22.7+24.6+17.9+8.1+ 11.7+15.3=555.3 km. *Back:* 24.1+47.1+34.0+46.8+21.5+27.8+47.8+ 22.0+17.6+12.6+6.2+21.4+16.1+35.6+22.9+ 16.4+20.8+35.2+2.2+29.1+26.5+19.6+8.5+ 12.0+15.8 = 589.6 km.
Volume of Used cooking oil (litres)	600*25 = 15,000 litres.
Diesel fuel used	(Go) =39.6642 litres. (Back) =47.1680 litres.
Energy consumption	CO_2 emission = 0.022 $KgCO_2$/litres

5.1.2.2 Production process

Feeding used cooking oil from into Reactor = 0.8355 $KgCO_2$ / Increase and control oil temperature = 123.42 $KgCO_2$ / Stirring, vacuum and eliminate moisture in oil = 83.325 $KgCO_2$ / Blending methanol and stirring mixture = 1.253 $KgCO_2$ / Inject the blended methanol and sodium hydroxide into reactor = 0.8355 $KgCO_2$ Stirring = 1.044 $KgCO_2$ / Transfer glycerol 2.5065 $KgCO_2$ / Recovery methanol = 96.884 $KgCO_2$ / Make warm water = 163.2314 $KgCO_2$ / Feed warm water into reactor 0.2088 $KgCO_2$ / Transfer B100 and add anti-Oxidant 0.8355 +2.5765 $KgCO_2$

Production of biodiesel 8.75 m^3 volume of CO_2 emissions is equal to 487.1673 $KgCO_2$. So, CO_2 emission of biodiesel 1 litre is 0.0556 $KgCO_2$.

CO_2 emissions of 1 litres biodiesel from used cooking oil is 0.0804 $KgCO_2$.

5.1.3 Energy consumption CO_2 emission of diesel

From the LCA Case Studies research (Michael, Hanjie, and Johe, 2004), The energy consumption to produce 1 litres of diesel is 1.8255 MJ and energy consumption to produce 1 litres of biodiesel is 0.5885 MJ

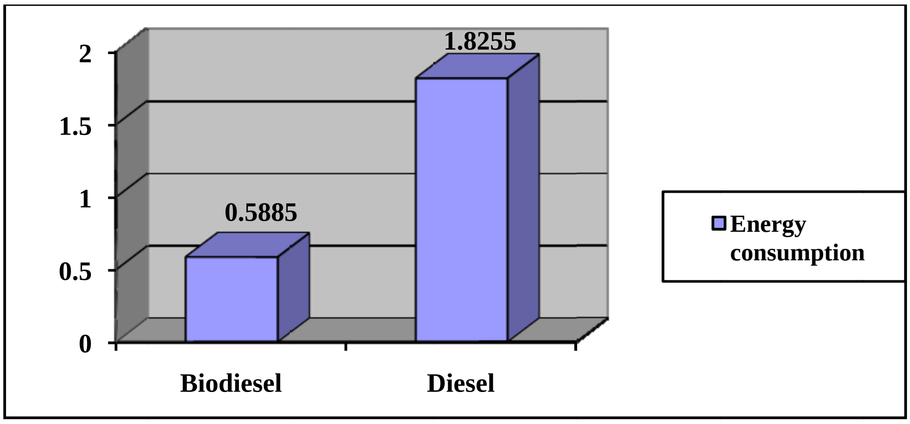

Figure 5.3 Energy consumption of biodiesel and diesel

The CO_2 emission of diesel is 0.2849 $KgCO_2$ and CO_2 emission of biodiesel is 0.0804 $KgCO_2$.

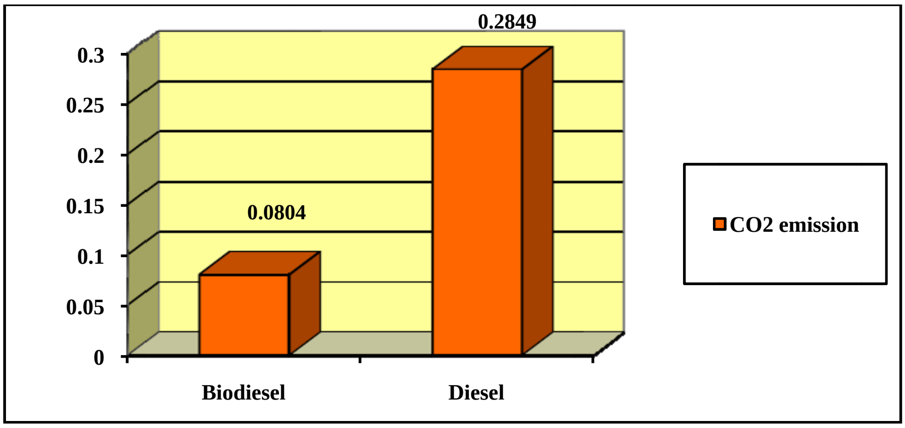

Figure 5.4 CO_2 emissions of biodiesel and diesel

Energy consumption and CO_2 emission of biodiesel from used cooking oil is less than energy consumption and CO_2 emission of diesel. Because in this research is not calculations from beginning to end. It calculates transportation and production process only, and does not calculate chemical in production. Therefore, the calculated value is less than diesel.

5.2 Limitation

Unfortunately, data from crude oil refining process is confidential in some parts as it is their competitive advantage, the assessment can’t go through all details of refining process.

5.3 Recommendations

5.3.1 Should collect data of the used oil amount purchased from Bangchak Gas Station in each area as for developing transportation routes. For example, if which ever branch purchased few amount of used oil that is not worth the carriage, that branch should not purchase used oil any longer.

5.3.2 In the step of glycerol transferring, there are two times transferring. It should save more energy if they arrange in one transferring.

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APPENDIX

EQUIPMENT ITEMS AND MAP TRANSPORT ROUTES

1.1Used cooking oil tank 2T-4501 capacity 100,000 liters.

1.2. Rector 2R-4501, 2R4502 capacity 10,000 liters.

1.3 Steam ejector 2J-4501

1.4 Methanol tank 2T-4507 capacity 20,000 liters.

1.5 Mixing tank 2D-4502 capacity 2,500 liters

1.6 Glycerol tank 2T-4505 capacity 10,000 liters

1.7 Glycerol tank 2T-4506 capacity 20,000 liters

1.8 Recovery methanol tank 2D-4504 capacity 500 liters

1.9 Hot water tank 2D-4503 capacity 10,000 liters

1.10 Rinsing tank 2D-4508 A/B/C/D capacity 1,000 liters

1.11 Coalescer 2D-4513

1.12 Salt filter tank 2D-4510A/B capacity 2,000 liters

1.13 Sample B100 tank 2T-4504 capacity 20,000 liters

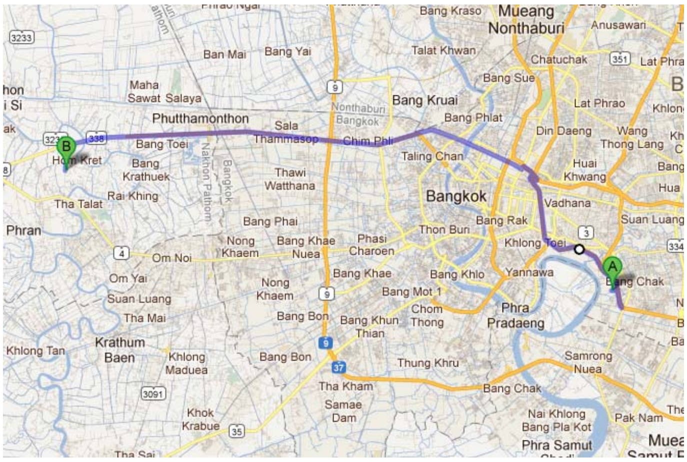
1.14 Anti-Oxidant tank 2D-4517 capacity 100 liters

1.15 Product B100 tank 2T-4503 capacity 50,000 liters

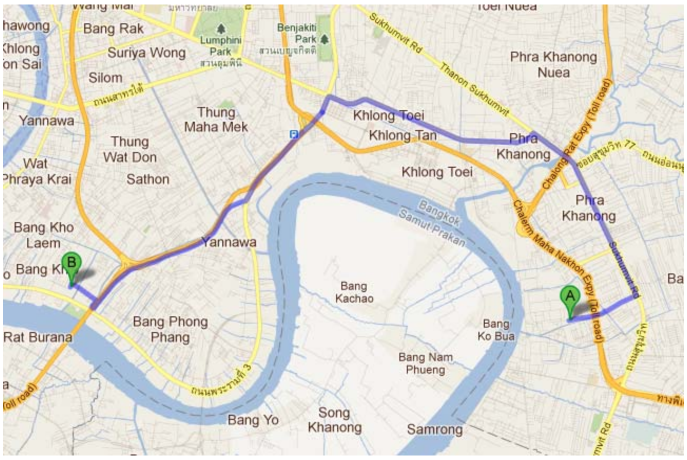
MAPS

2.1 Industrial factories

Mongkol vegetable oil

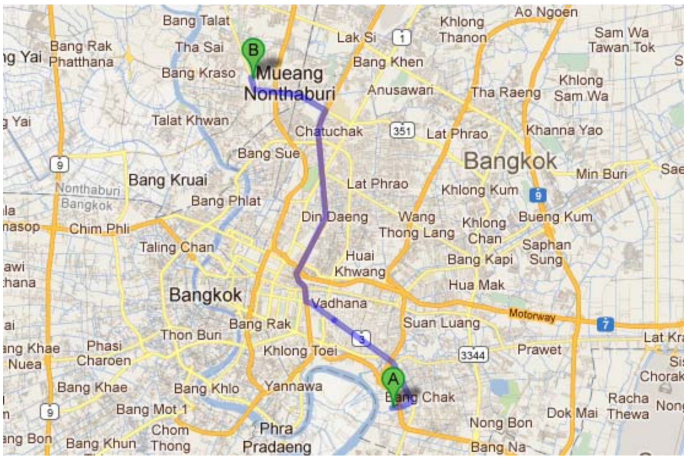


E-ester (Bangkok)



Ngbaktai

2 Bangchak Gas Stations



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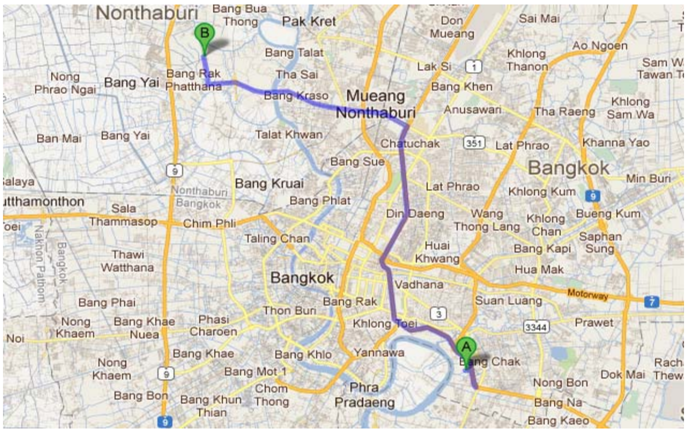

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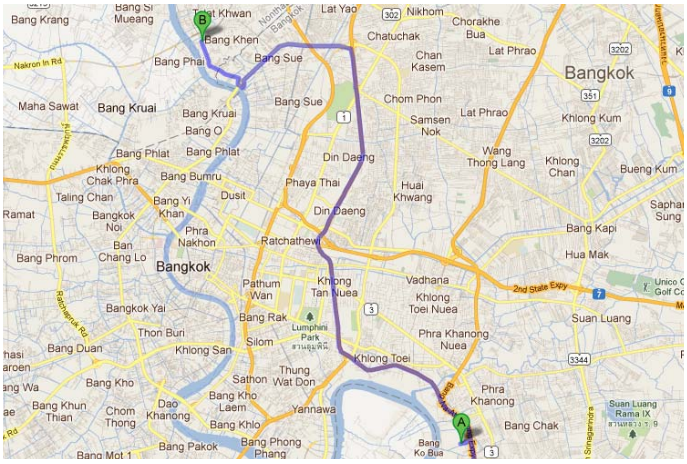

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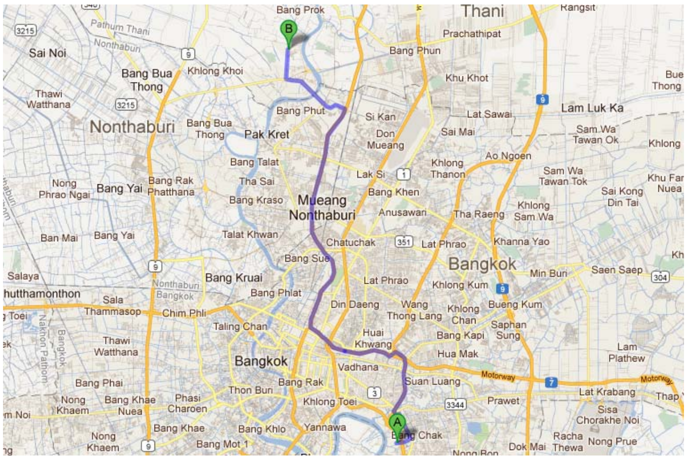

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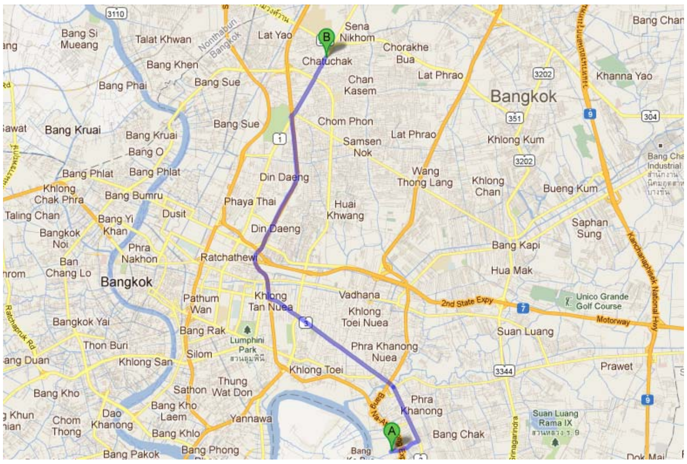

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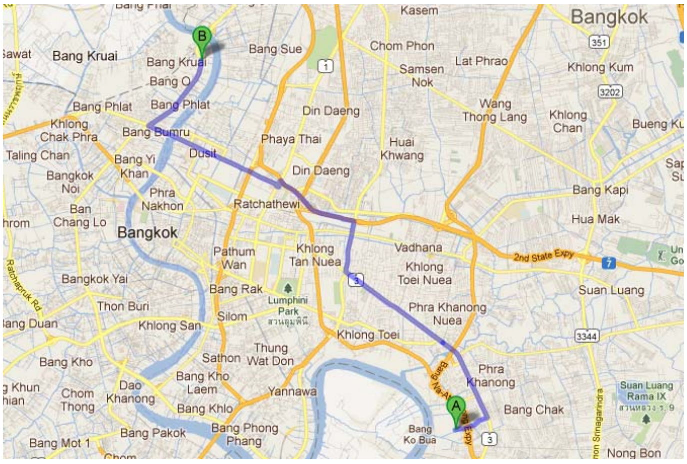

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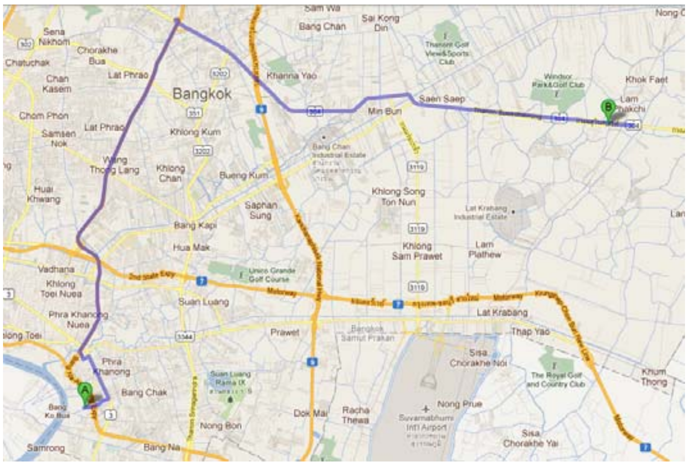

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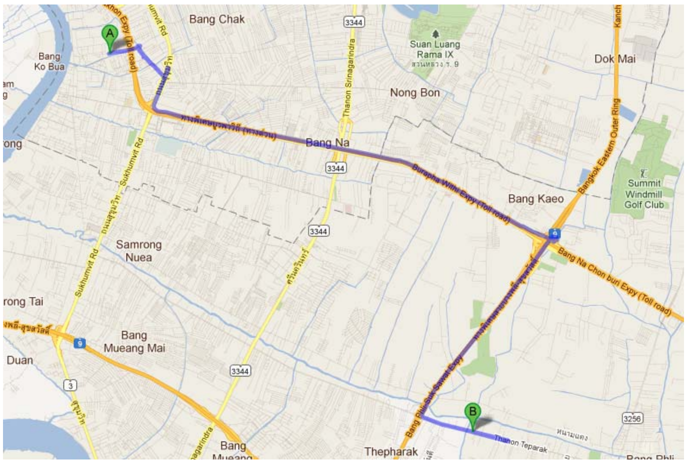
Bang Sue



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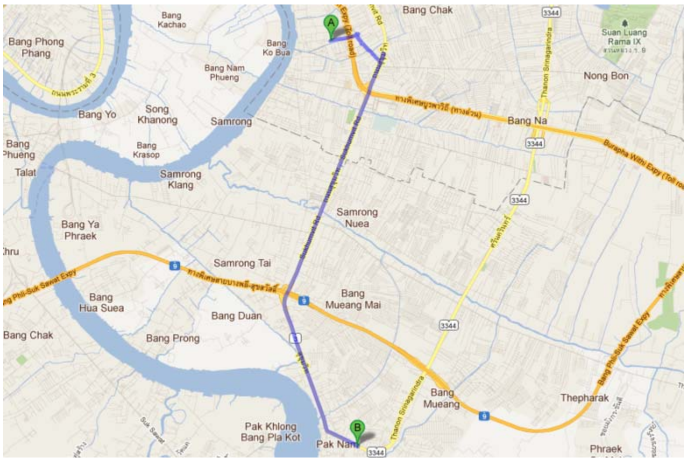

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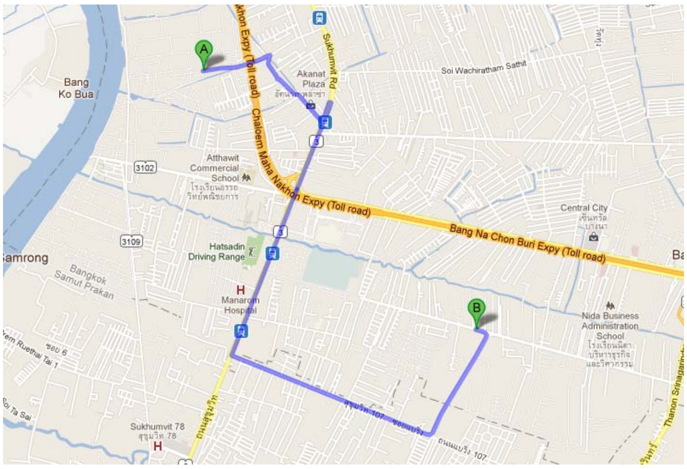

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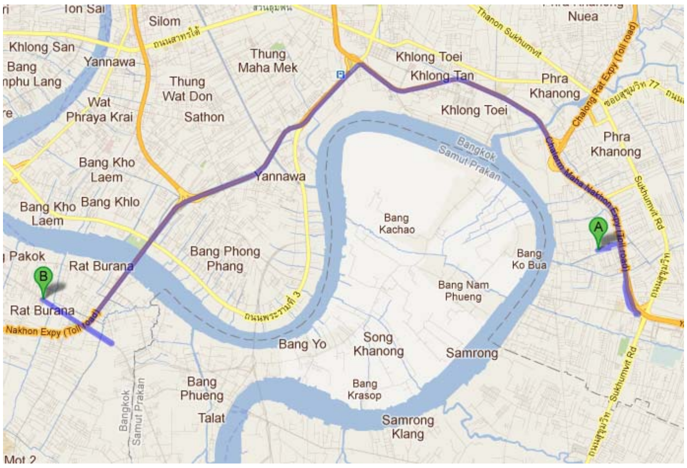

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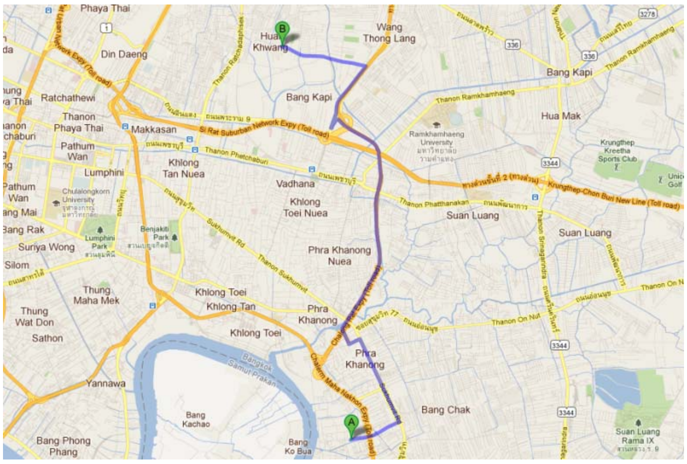

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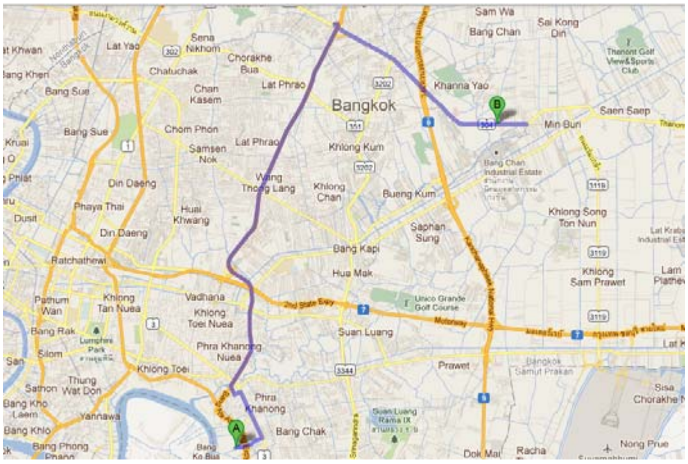

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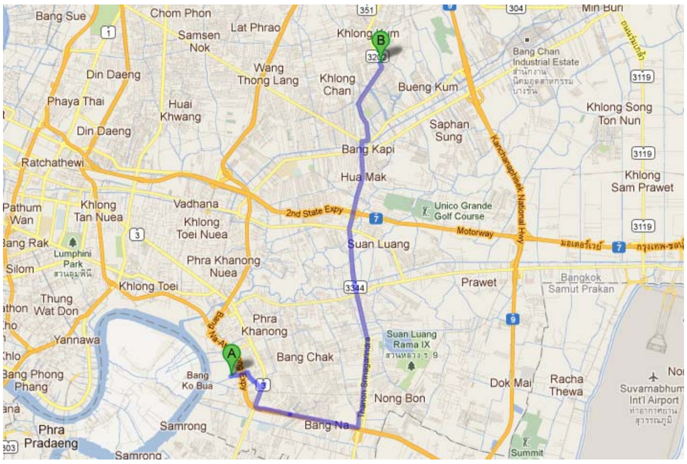

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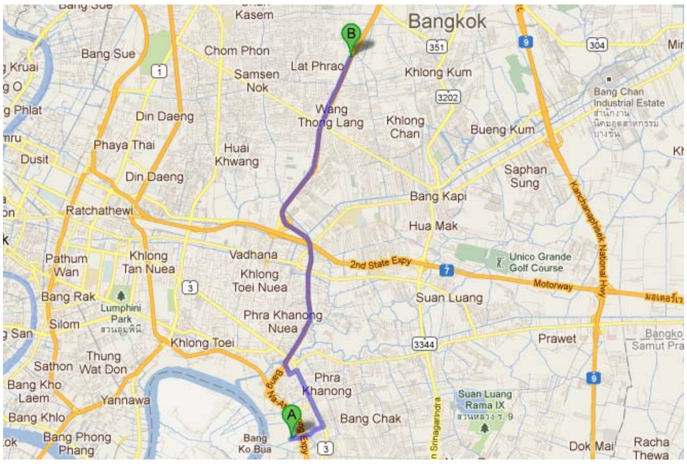

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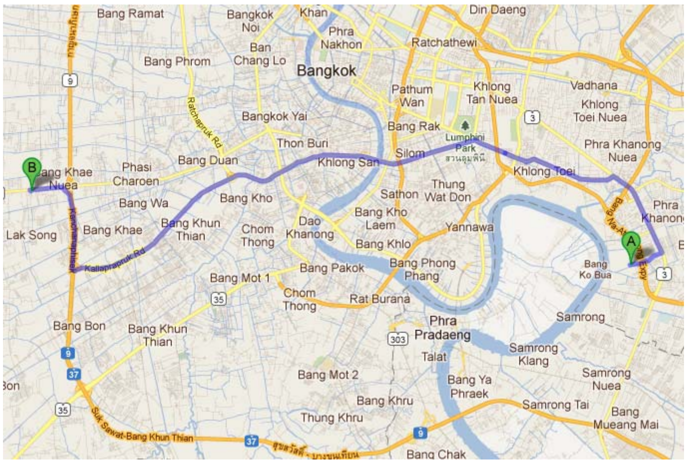

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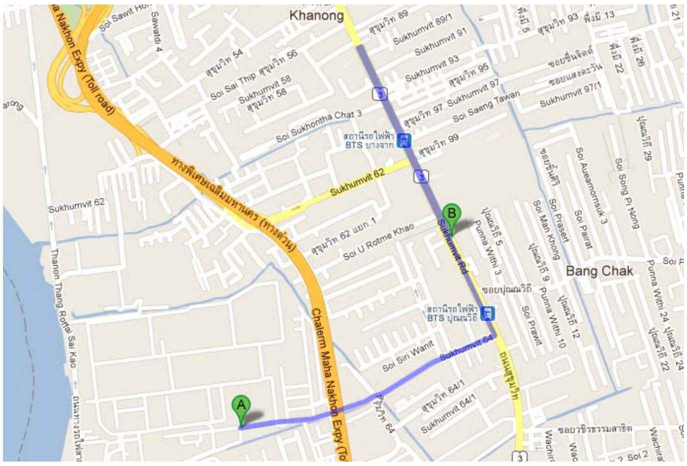

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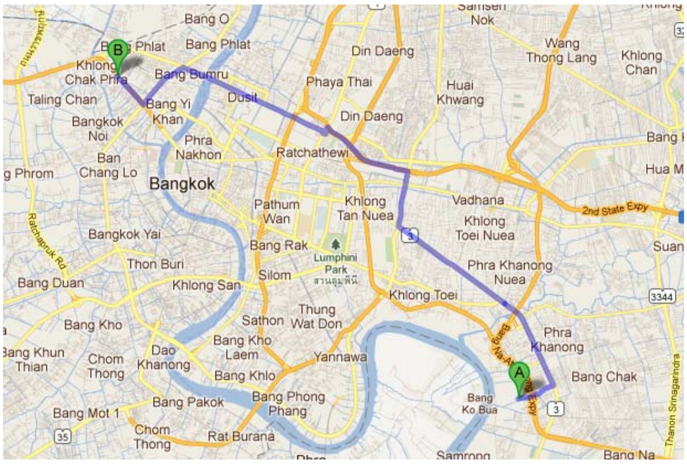

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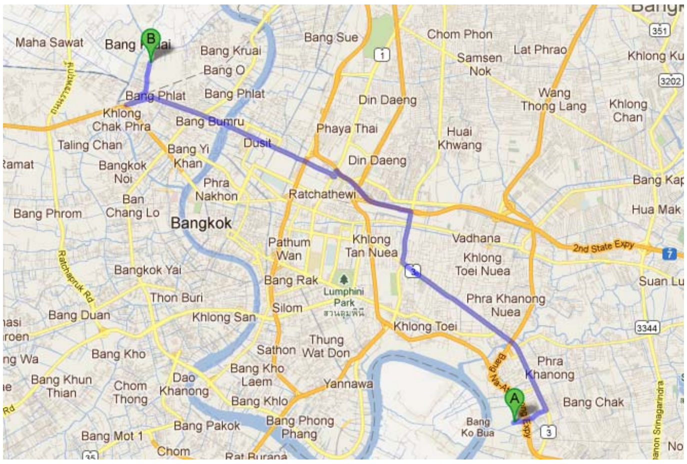

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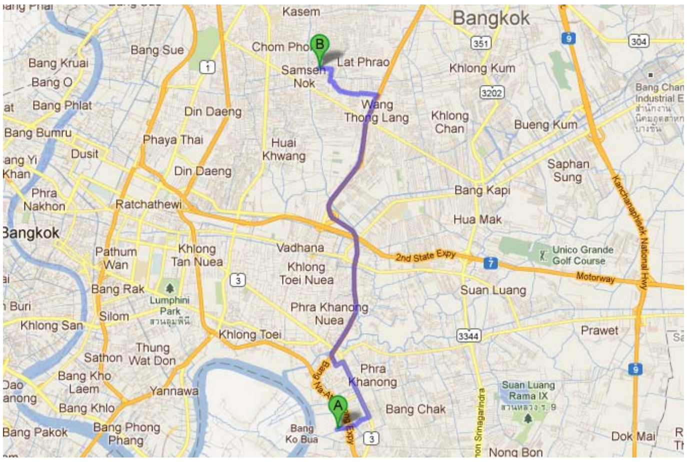

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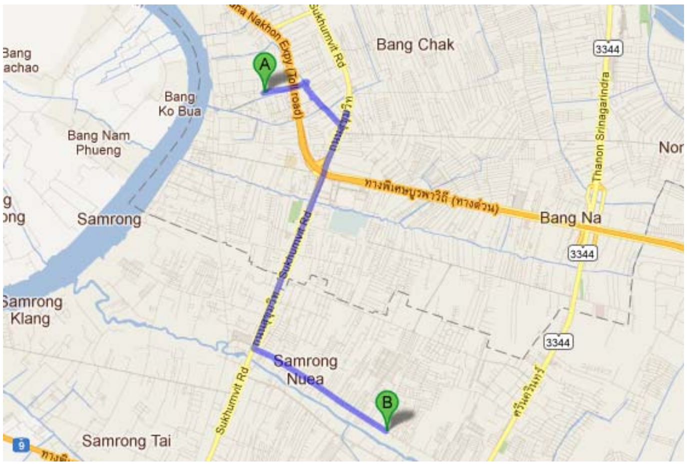

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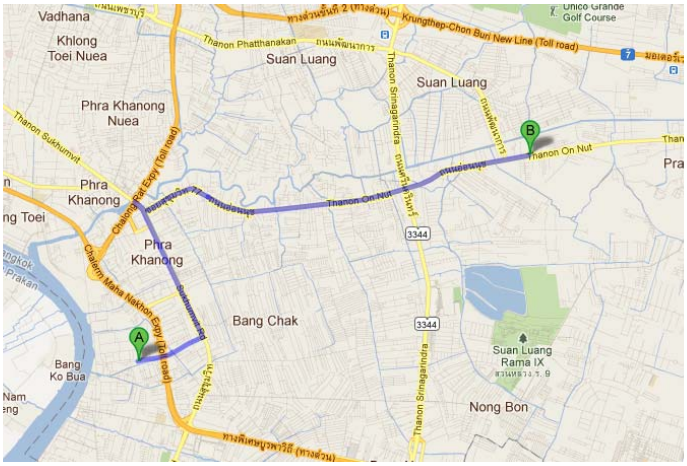

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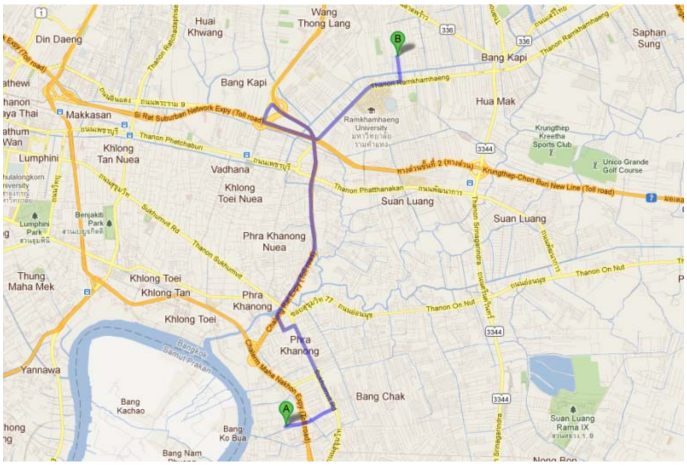

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