CHEMICAL ENGINEERING TRANSACTIONS

VOL. 65, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Eliseo Ranzi, Mario Costa

ISBN 978-88-95608-62-4; **ISSN** 2283-9216

DOI: 10.3303/CET1865085

Parametric Algorithm for the Study of Technical and Economic Feasibility of Biodiesel Production Plants at Small and Medium Scale in Colombia

Bibiana Galeano Amaya[a], Jair Alexander Ladino[b], Dionisio Malagón-Romero[a]*

[a] Universidad Santo Tomás, GEAMEC Research Group, Bogota, Colombia
[b] Universidad del Valle, School of Mechanical Engineering, Cali, Colombia
dionisiomalagon@usantotomas.edu.co

Production of biodiesel in Colombia employs as raw material palm oil. However, production costs can be reduced by using wasted cooking oil (WCO). The objective of this paper is the development of a parametric algorithm for the technical and economic analysis of the implementation of a new biodiesel production plant by ,alkali transesterification process using waste cooking oil (WCO) for small and medium scale facility. The computational tool determines the internal rate of return (IRR) and net present value (NPV) as economic indicators and the specification of the equipment, plant capacity and energy consumption as technical results for the feasibility analysis as function of the quantity of WCO to storage per month and WCO price. The methodology to estimate the costs involving the biodiesel plant was supported on the technical and economic studies presented in the literature in order to determine the percentage each factor such over the total capital investment cost. Factors such as maintenance, operation costs, acquisition and total equipment cost. The methodology determines the dimension of the equipment for each plant capacity: Storage tanks, flow rate of the centrifuges and dimension of column distillation for the purification of the co-product glycerol. The obtained results show IRR in a range of 9.81% to 35.89 % for plant capacity of processing 1 million to 3 million of WCO liters collected in Bogotá D.C (Colombia), respectively in a project period of 15 years. The NPV obtained was in the range US$ 5.71 million - US$ 89.68 million. The feasibility of this project is possible when WCO prices would be lower than US$ 0.2/liter and the volume of WCO collected upper to 720,000 liters/month.

1. Introduction

Biodiesel, as a renewable fuel, is produced from virgin vegetable oils, animal fats and waste oils. Also, this is one of the most used renewable fuels and a potential substitute of petroleum–diesel, which usually is mixed with them (Zhang et al., 2003). The main industrial facilities producing biodiesel, are based on virgin vegetable oils such as soybean oil or palm oil, constituting the first generation of biodiesel (Rincón et al., 2014). However, and due to the drop of petroleum prices in cycles of 6 years, starting from 2008 and again in 2014, new generation of biodiesel, based on recyclable raw materials (animal fats, waste cooking oil WCO, microalgae),(Alarcón, Malagón-Romero and Ladino, 2017), (Rodríguez et al., 2017) have been gaining more attention in order to respond to the drop of petroleum prices and preserve the biodiesel production economically viable at industrial scale. The last is true when, in fact, almost 70%-90% of the biodiesel production cost come from the raw materials prices (Skarlis et al., 2012; Apostolakou et al., 2009).
For biodiesel production, there is a global trend to focus on recycled raw materials such as waste cooking oil in substitution of virgin oils. The last with the aim to do not affect the size of production for human feedstock and reduce the rise in prices of virgin oils used to produce Biodiesel in detriment of human consumption (Khan et al., 2014). Under the aforementioned scenario, new generation of biodiesel production, represents an opportunity to analyze if and implementation of a biodiesel production plant based on recyclable raw materials, is technical and economically feasible. The last considering that the oil represents the greatest percentage in the breakdown cost analysis for biodiesel production (Skarli et al., 2012).

Please cite this article as: Galeano B., Ladino A., Malagon-Romero D., 2018, Parametric algorithm for the study of technical and economic feasibility of biodiesel production plants at small and medium scale in colombia, Chemical Engineering Transactions, 65, 505-510
DOI: 10.3303/CET1865085

However, the production of biodiesel from recycled materials such as WCO and animal fats, has several technical challenges about the kind of transterification process (alcaki or acid) and also the need of pretreatment of recycled oils such as moisture reduction, solid particle filtering and reduction of Free Fatty Acids (FFA) via esterification, which impacts directly in the class and yield of the whole process (Talebian-kiakalaieh et al., 2013; Zhang et al., 2003). The first one (alkali) is the most common and economical transterification technique implemented in industrial facilities, while the latter (acid) is more expensive and mainly used when the amount of FFA is high (about 5% or more) (Khan et al., 2014; Talebian-kiakalaieh et al., 2013). Finally, there exist a logistic problem to solve which involve the collecting, classifying and properties standardization or recycled raw material (Araujo et al., 2010).

On the other hand, in the Colombian context, the current biodiesel standard in local consumption is 10% Biodiesel and 90% petro diesel (B10) in 2017. These legislation generates about 99% of production capacity for local consumption (Naylor and Higgins, 2017), which is up to 0.6 billion liters per year. Also, it is estimated that Colombia will move to B20 in 2020. So, in order to satisfy the new requirements, there will be two ways: To increase the palm oil areas to be cultivated or explore and implement other production alternatives based on other raw materials. For the latter, WCO could play an important role for this purpose.

Therefore, the aim of this work is to make a technical and economic study involving the most relevant aspects and variables associated with the biodiesel production from WCO in Bogotá, Colombia, by the development and application of an algorithm for technical and economical evaluation in order to determine the feasibility of the implementation of a biodiesel plant at small or medium scale.

2. Methodology.

2.1 Technical process

The technical process for biodiesel production was considered from waste cooking oil in different unit operations, which includes: pre-treatment of the waste cooking oil with acid catalyst (esterification), transterification reaction and separation employing decantation and distillation according to Skarlis et. al (2012) and Apostolakou et. al (2009). Plant capacity considered in this study is in the range of 10,000 to 50,000 tons of biodiesel per year which corresponds to a small-medium scale installation.

The first step is filtration of solid particles and subsequent reduction of FFA via esterification. These characteristics are commonly presented in WCO. For the case of filtration, according to Alptekin et. al (2014), filtration process eliminates solid particles greater than 2mm. For esterification reaction, WCO reacts with methanol in presence of 1% of acid catalyst (sulfuric acid) over the total mass of WCO, in a storage tank at 60°C for 20 minutes with resulting two phases: the upper phase is water and free fatty acids, and the lower phase is the treated waste cooking oil. For phases separation, centrifugal equipment is employed.

Once WCO is filtered and neutralized, transterification stage takes place in order to obtain the methyl esters (Biodiesel) and the corresponding by product glycerol. In this work, an alkali trasterification is considered with preprocessed WCO, methanol as alcohol and catalyst potassium hydroxide (KOH)(López et al., 2015). The reaction condition was molar ratio of 6:1 (methanol:oil) at temperature 60°C with a reaction time of 1 hour achieving a yield of 88%. These parameters are consistent with data given in literature (López et al., 2015);(Rodríguez et al., 2017);(Alarcón et al., 2017).

When the reaction finish, separation process result in two well defined phases: a top layer which is crude biodiesel (880 kg/m^3) and the bottom layer of glycerol (1050 kg/m^3). For an efficient separation process, it is highly recommended to use centrifugal equipment. Also, for the overall process, there is a general rule of thumb that from one ton of virgin vegetable oil, it is possible to obtain one ton of biodiesel and 0.11 tons of glycerol(Apostolakou et al., 2009). However, and considering the yield for biodiesel production under the conditions mentioned above, from one ton of WCO, it is possible to obtain 0.88 ton of biodiesel (Atadashi et al., 2010).

Neutralization of crude biodiesel, soap removing and water washing treatment at 60°C complements biodiesel purification before drying. The wet process consists in washing the crude biodiesel in order to eliminate impurities and adjust the pH to a neutral grade. The washing process consumes two tons of water per one ton of biodiesel in a mixer tank.

After washing stage, next stage is the drying which uses flash drum units (Stojković *et al.*, 2014) and is performed in order to dry the excess of water in the resultant biodiesel. Also, some impurities are extracted from crude biodiesel using a potential drying unit. The last process is commonly used when virgin oil is the raw and pH adjustment is no required (Stojković et al., 2014). Later, evaporated water is recycled in the water tank for next use.

Finally, the last stage which is to recover the remaining methanol and separate the residual biodiesel, is by distillation of glycerol layer. For this process, a distillation column of 23 stages is recommended Apostolakou et. al (2009). Also, Treybal (1980) defines some considerations for the design of distillation columns, suggesting that for an optimal distillation behavior, the flow rate must be 0.015 m^3/s per one meter of diameter of the plates. This relation is important in order to select the diameter of the column depending of the flow rate of the process.

2.2 Economical aspects

In order to determine the equipment cost, it is necessary to determine the dimension of each equipment for the biodiesel production. Table 1 shows the most relevant cost functions for the capacity and cost of equipment for biodiesel production plant with alkali transterification. The bare module (BM) in Table 1 refers to direct and indirect costs for equipment such as valves and piping connections.

Table 1: Bare module for equipment

Equipment	Bare module	Cost expression
Transesterification Reactors	2.8	$C_R^0 = 15000V^{0.55}$
Centrifuges	1.3	$C_{FF}^0 = 28100Q^{0.574}$
Mixing Tanks	2.8	$C_V^0 = 12080V^{0.525}$
Flash Drum	2.8	$C_D^0 = 6500V^{0.62}$
Distillation Columns	-	$C_T^0 = 4555H_C^{0.81}D_C^{1.05}$ D_c = Column diameter [m] $D_C = \sqrt{\frac{4A}{0.88\pi}}$ A is the net column area *[m^2]*. H_c is the column height [m] determined by the equation 9. $H_c = 1.2(TS)(N-1)$ Where, TS is the Tray Spacing *[m]* N the number of real trays.
Storage tanks	1.2	$C_{ST}^0 = 250000 + 94.2V$ *(Storage tank cost for volume between 2.000 m^3 to 50.000 m^3)* $C_{ST}^0 = 65000 + 158.7V$ *(Storage tank for volume lower than 2.000 m^3)*
Total Installed equipment cost	1.2	$T.I = \sum Cost\ of\ Equipment$
Total Equipment Cost	2	$T.E.C = 2\,(T.I)$

Source:(Apostolakou et al., 2009)

In order to use the expressions for equipment costs, the next step project them to present values according to Peters and Timmerhaus 1991 (All prices and cost are referred to 2017):

$$Present\ Cost = Original\ Cost\left(\frac{Index\ value\ at\ present\ time}{Index\ value\ at\ time\ original\ cost\ was\ obtained}\right)$$

The index value is taken from the CEPCI (Chemical Engineering Plant Cost Index) which varies each year and it is presented in Table 2 for plants according from 2007 and projected to 2017.

Table 2: Index value according to CEPCI for the 2007 and 2017

Item	2007 (Apostolakou *et al.*, 2009)	Present February 2017
Equipment	602.8	672.0
Heat exchangers and tanks	556.9	587.3
Process machinery	586.1	671.1
Pipe, valves and fittings	724.9	852.0

3. Parametric algorithm

The algorithm developed starts with defining the amount of WCO that potentially can be gathered. Costs employed for this study corresponding to values for Colombia. The evaluated range was from 500,000 liters/month to 3,000,000 liters/month of WCO. The price for water is US$ 1.115/m^3, and the price for electricity is US$ 0.1549/kWh. For natural gas the prices is US$ 0.0249/kWh. The WCO cost considered is in the range of US$ 0.1-0.2/liter. The plant cost is calculated as 1.8 times the overall cost of the installed equipment (Apostolakou et al., 2009). The internal rate of return (IRR) and net present value (NPV) are calculated as economic indicators for estimate the economic feasibility in period of evaluation of 15 years. The interest for NPV calculation was assumed in 4% annual.

The assumptions made in this study are: 1. Quantities of WCO, catalyst, alcohol and glycerol involved in the biodiesel production process are based on the standardized process mentioned in 2.1, proved at GEAMEC research group and supported by (López et al., 2015);(Rodríguez et al., 2017);(Alarcón et al., 2017). 2. The study is conceived for a Biodiesel plant near Bogotá D.C, Colombia (population, 10mill people, GDP COP $37 billion), which is the main supplier of WCO. 3. The facility is at the outside of Bogotá D.C. 4. Derived from 3, the transportation cost is included in the range of WCO price studied. 5. All prices and cost are for year 2017.

The algorithm developed has the following overall steps:

1. Define a range of liters per month of WCO that can potentially be gathered. These values must be in accordance to small and medium size biodiesel plant (Apostolakou et al., 2009). For this study, the range was from 500,000 liters/month to 3,000,000 liters/month of WCO potentially collected in Bogotá D.C (Colombia) and neighbors.
2. Define actual cost of raw materials and commodities. For Colombia case study: Water US$ 1.115/m^3, electricity US$ 0.1549/kWh, natural gas US$ 0.0249/kWh, range cost of gathering and purchasing WCO US$ 0.1-0.2/liter.
3. Estimate plant cost and projected equipment. Plant cost is calculated as 1.8 times the overall cost of the installed equipment according to Table 1. Estimation of the internal rate of return (IRR) and net present value (NPV). IRR and NPV are used as economic indicators for feasibility. The considered period of evaluation (amortization) was 15 years (Marchetti, Miguel and Errazu, 2008). The interest for NPV calculation was assumed in 4% annual.
4. Definition of values for feasibility. According to Marchetti et al. (2008) a good IRR must be in a range of 16% to 24% at 15 years for biodiesel production plants as an economic criteria for feasibility.
5. Combinatory loop. Loop over the combination between the range of liters per month and cost of gathering-purchasing recycled WCO, including their corresponding cost increment for process a particular amount of liters per month of WCO.

4. Results and Analysis

The Figure 1 shows results of IRR and NPV. According to feasibility criteria, if the cost of WCO is greater than US$ 0.2/liter, the IRR will be lower to 13%. Therefore, the cost of WCO is the most important variable for the feasibility of the biodiesel production. On the other hand, increasing production volume of biodiesel from WCO, IRR also increases. The potential of WCO just in Bogotá D.C (Colombia) is 720,000 liters/month (Castro Camargo Jorge Weimar, Vanessa, Castro, & Piracoca, 2015 -data not published-) . So, the only possibility for installing a plant for biodiesel production is with a cost of WCO less than US$ 0.2 per liter. This result is similar to obtained by Marchetti et al. (2008) who affirms that raw material cost (oil) is the most important contribution to the unit production cost. The values employed for WCO collected in Bogotá are similar to data reported in the literature for Argentina´s scenario (Marchetti et al., 2008): Near to US$ 0.2 per liter, according to local collectors. In Colombia scenario, the cost of virgin palm oil US$0.7/liter.

The NPV is a financial measurement of the value of money as a function of time (Marchetti et al., 2008). In the Figure 1, NPV is showed for conditions evaluated. When the cost of WCO decreases and the volume of WCO increases, the NPV increases. In the conditions near to Bogotá with a collecting potential of 720,000 liters per month, the NPV is US$ 30.56 millions and US$ 19.82 millions for WCO cost US$ 0.1 per liter and US$ 0.2 per liter, respectively. The value obtained is lower than other studies (Marchetti et al., 2008),(Apostolakou et al., 2009) but the annual production capacity is also lower (7.1 kton/year). In the case of virgin oils as raw materials, if the capacity is lower than 15 kton/year, this is considered a project with high level of risk(Apostolakou et al., 2009), so the installation of biodiesel plant falls in this category. Therefore, a good alternative for using WCO is not as 100% raw material but as a partial substitute of virgin oil in a mixed process (Rodríguez et al., 2017),(Alarcón et al., 2017).

On the other hand, total equipment cost after tax is US$ 2.35 millions and the total capital investment is US$ 4.52 millions. The equipment cost is higher than reported (Apostolakou et al., 2009) due to installation in

Colombia requires import of equipment and the consequent taxes and fees, but the cost is similar to reported for installing a production plant in Greece (Skarlis et al., 2012). In addition, the small scale increases the costs of the equipment compared with high scale (Skarlis et al., 2012). Also, this project considers esterification and transesterification in the plant operation, so the cost is higher than transterification plant. One parameter for economic analysis is the Specific Investment Cost (SIC) (Skarlis et al., 2012) defined as the cost of production per ton of biodiesel produced; for this project this parameter is 636.7 €/ton is higher than reported by Skarlis et al.(2012) which is in the range 370-610 €/ton. According to this value, the production cost is higher than other projects due to plant capacity, so it is necessary to install a plant with capacity greater than 15 kton/year. However, this capacity it is not possible due to limitation in the production of WCO in Bogotá D.C.
One important factor for the profitability of this project depends of the biodiesel selling price which is higher to other studies about US$ 0.79-0.86 (Marchetti, 2011). The price used in this study was the value reported in Colombia by Fedebiocombustibles (Association of biofuels producers) for biodiesel from palm oil (Fedebiocombustibles, 2017). In this project the value of biodiesel selling prices is 1,415.4 €/ton compared with 850 €/ton(Skarlis et al., 2012), so this parameter is higher than reported but it is supported in the real prices offered in the Colombian market.

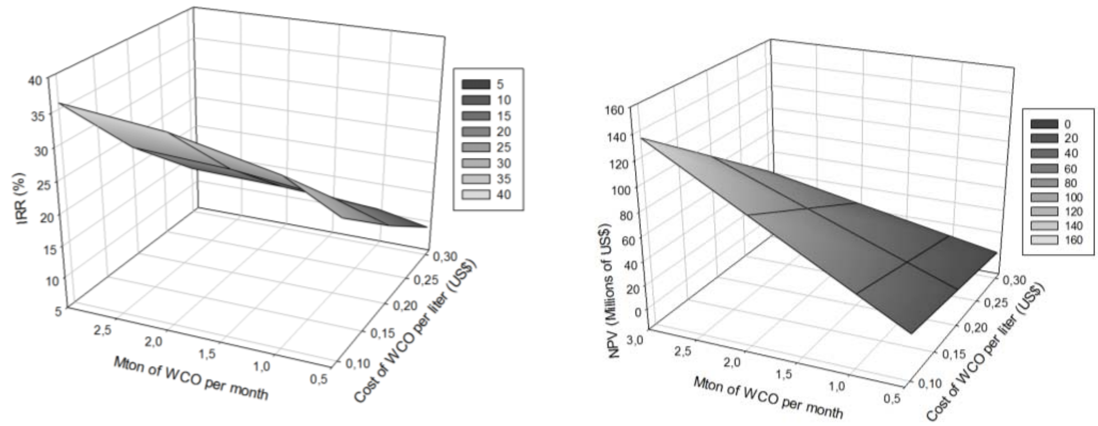

Figure 1. Internal Rate of return IRR (left) and Net Present Value NPV (right) as function of cost of WCO per liter and WCO produced per month

Other factor that increases the production costs is the esterification step, but this one is necessary for reducing the FFA content. This result is similar to obtained by Zhang et al. (2003). So, the possibility of installation of a small plant in Bogotá is when the WCO price would be lower than US$ 0.2/liter and/or the capability of collected WCO would be 720,000 liters/month.

5. Conclusions

This work implements a parametric algorithm for technical-economic analysis for feasibility of biodiesel facility. The algorithm is used to perform a feasibility study for a small biodiesel plant in the context of a Latin-American city such as Bogotá D.C Colombia. Results for the particular case shows the influence of the price of WCO, size and scalability of the plant as the most influent factors and illustrates some particular issues such as the increment in price due to additional equipment for pretreatment of WCO and also the effect of the prices of WCO. In fact, for facility scenario in Bogotá, estimations show that a plant with 720.000 tons of WCO is not feasible due to scalability and WCO cost. In this results are in reasonable agreement with similar cases exposed in literature in Latin-American and some European countries. Finally, this work suggests that a profitable scenario for this order WCO quantities that should be explored is the biodiesel production using virgin – waste oil mixings at low ratios.

Acknowledgments

Authors would like acknowledgments to Universidad Santo Tomás for their financial support by FODEIN grant and Universidad del Valle for their research support.

Reference

Alarcón, R., Malagón-Romero, D. and Ladino, A. (2017) 'Biodiesel production from waste frying oil and palm oil mixtures', *Chemical Engineering Transactions*, 57, pp. 571–576. doi: 10.3303/CET1757096.

Alptekin, E., Canakci, M. and Sanli, H. (2014) 'Biodiesel production from vegetable oil and waste animal fats in a pilot plant', *Waste Management*. Elsevier Ltd, 34(11), pp. 2146–2154. doi: 10.1016/j.wasman.2014.07.019.

Apostolakou, A. A. *et al.* (2009) 'Techno-economic analysis of a biodiesel production process from vegetable oils', *Fuel Processing Technology*. Elsevier B.V., 90(7–8), pp. 1023–1031. doi: 10.1016/j.fuproc.2009.04.017.

Araujo, V. K. W. S., Hamacher, S. and Scavarda, L. F. (2010) 'Economic assessment of biodiesel production from waste frying oils', *Bioresource Technology*. Elsevier Ltd, 101(12), pp. 4415–4422. doi: 10.1016/j.biortech.2010.01.101.

Atadashi, I. M., Aroua, M. K. and Aziz, A. A. (2010) 'High quality biodiesel and its diesel engine application: A review', *Renewable and Sustainable Energy Reviews*, 14(7), pp. 1999–2008. doi: 10.1016/j.rser.2010.03.020.

Castro Camargo Jorge Weimar *et al.* (2015) *Estudio De Prefactibilidad Técnico Económica Para La Instalación De Una Planta Procesadora De Aceite Usado De Cocina Obtenido De Las Localidades De Usaquén Y Chapinero En Bogotá*. Universidad Santo Tomás. Available at: http://repository.usta.edu.co/handle/11634/2762.

Fedebiocombustibles (2017) *Distribution of mixture biodiesel and diesel in Colombia*, *Statistics of production of biofuels in Colombia*.

Khan, T. M. Y. *et al.* (2014) 'Recent scenario and technologies to utilize non-edible oils for biodiesel production', *Renewable and Sustainable Energy Reviews*, 37, pp. 840–851. doi: 10.1016/j.rser.2014.05.064.

López, L., Bocanegra, J. and Malagón-romero, D. (2015) 'Production of biodiesel from waste cooking oil by transesterification', *Ingeniería y Universidad*, 19(1), pp. 155–172. doi: 10.11144/Javeriana.iyu19-1.sprq.

Marchetti, J. M. (2011) 'The effect of economic variables over a biodiesel production plant', *Energy Conversion and Management*. Elsevier Ltd, 52(10), pp. 3227–3233. doi: 10.1016/j.enconman.2011.05.008.

Marchetti, J. M., Miguel, V. U. and Errazu, A. F. (2008) 'Techno-economic study of different alternatives for biodiesel production', *Fuel Processing Technology*, 89, pp. 740–748. doi: 10.1016/j.fuproc.2008.01.007.

Naylor, R. L. and Higgins, M. M. (2017) 'The political economy of biodiesel in an era of low oil prices', *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, 77(February), pp. 695–705. doi: 10.1016/j.rser.2017.04.026.

Peters, M. S. and Timmerhaus, K. D. (1991) *Plant Design and Economics for Chemical Engineers*. 4 edition. Edited by J. Carberry et al. Singapore: McGraw-Hill.

Rincón, L. E., Jaramillo, J. J. and Cardona, C. A. (2014) 'Comparison of feedstocks and technologies for biodiesel production: An environmental and techno-economic evaluation', *Renewable Energy*, 69, pp. 479–487. doi: 10.1016/j.renene.2014.03.058.

Rodríguez, D., Riesco, J. and Malagon-Romero, D. (2017) 'Production of Biodiesel from Waste Cooking Oil and Castor Oil Blends', *Chemical Engineering Transactions*, 57, pp. 679–684. doi: 10.3303/CET1757114.

Skarlis, S., Kondili, E. and Kaldellis, J. K. (2012) 'Small-scale biodiesel production economics: a case study focus on Crete Island', *Journal of Cleaner Production*. Elsevier Ltd, 20(1), pp. 20–26. doi: 10.1016/j.jclepro.2011.08.011.

Skarlis, S., Kondili, E. and Kaldellis, J. K. (no date) 'Design and Feasibility Analysis of a new Biodiesel Plant in Greece', pp. 1–11.

Stojković, I. J. *et al.* (2014) 'Purification technologies for crude biodiesel obtained by alkali-catalyzed transesterification', *Renewable and Sustainable Energy Reviews*, 32, pp. 1–15. doi: 10.1016/j.rser.2014.01.005.

Talebian-kiakalaieh, A. *et al.* (2013) 'A review on novel processes of biodiesel production from waste cooking oil', *Applied Energy*, 104, pp. 683–710. doi: 10.1016/j.apenergy.2012.11.061.

Treybal, R. (1980) *Mass transfer Operations*. 3 Ed. Edited by J. J. Carberry et al. Singapore: MacGraw-Hill.

Zhang, Y., Dubé, M. a., *et al.* (2003) 'Biodiesel production from waste cooking oil: 1. Process design and technological assessment', *Bioresource Technology*, 89, pp. 1–16. doi: 10.1016/S0960-8524(03)00040-3.

Zhang, Y., Dubé, M. A., *et al.* (2003) 'Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity analysis', *Bioresource Technology*, 90(3), pp. 229–240. doi: 10.1016/S0960-8524(03)00150-0.