Energy Conversion and Management 75 (2013) 658–663

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Influence of economical variables on a supercritical biodiesel production process

J.M. Marchetti *

Department of Mathematical Science and Technology, Norwegian University of Life Sciences, Drøbakveien 31, 1432 Ås, Norway

ARTICLE INFO

Article history:
Received 6 June 2013
Accepted 20 July 2013

Keywords:
Biodiesel production
Supercritical technology
Economic study

ABSTRACT

Biodiesel has becoming more and more relevant in today's society and economy due to its environmental advantages such as biodegradability, lower CO and CO_2 emissions as well as less particulate pollutants.

In this work the study of market and economic variables is presented and their effects compared when biodiesel is being produced using a supercritical technology. The production process is based on a supercritical technology with no catalyst and no co-solvent. Price for the raw materials, such as price for the alcohol as well as the oil has been studied. Also, selling price for biodiesel as well as glycerin has been analyzed and compared with prices from other biodiesel production technologies. Economic decisions such as percentage of failure in the production process, investment in research and development, and advertisement have been evaluated; also it has been considered the influence of the tax incentives on the global economy of the production process.

Small variations on some of the major market variables would produce significant effects over the global economy of the plant, making it non profitable in some cases.

1. Introduction

Due to today's energy market is growing, and to the need of new renewable alternatives, is that several substitute for petroleum fuels are been tested and investigated. Biodiesel appears as the natural and logical alternative to substitute diesel fuels. It is defined as the mono alkyl esters of long chain fatty acids derived from a renewable lipid feedstock such as vegetable oil or animal fat. Among the mayor benefits, it can be found that is biodegradable, it has a better combustion into CO_2, producing almost none CO, it produces no sulfur contaminants and no particulate pollutants [1–3].

Biodiesel is generally produced using a base catalyst, such as sodium or potassium hydroxide in the presence of alcohol [2,4–7]. The industrial choice of alcohol is methanol due to its properties; however, in order to have a more renewable fuel, ethanol is gaining more and more relevance in biodiesel research [2,7].

Despite the fact that high conversion is achieved when using conventional technology; the raw material employed must be a refine oil, meaning that the amount of impurities must be considerable reduced before it can be used. Even more, refine oils are use for food purposes and its transformation into fuel is a debatable decision. Therefore, new technologies capable of using waste oil, has been generally studied: such as homogeneous acid catalyst [8–10], heterogeneous catalyst [11–14], enzymatic approaches [15–18], supercritical technologies [19–21], as well as membrane reactors and monolithic alternatives [22,23].

The main reaction taking place in the biodiesel process, despite the catalyst employed, is the transesterification reaction. In this reaction, a triglyceride interacts with an alcohol to produce fatty acids alkyl esters and glycerin, which is normally call fatty acid methyl ester (FAME) due to the used of methanol. The main reaction could be summarized as follows:

$$\begin{array}{ccccccc} CH_2\text{-}OOC\text{-}R_1 & & & & R_1\text{-}COO\text{-}R' & & CH_2\text{-}OH \\ | & & & \text{Catalyst} & & & | \\ CH\text{-}OOC\text{-}R_2 & + & 3R'OH & \leftrightarrow & R_2\text{-}COO\text{-}R' & + & CH\text{-}OH \\ | & & & & & & | \\ CH_2\text{-}OOC\text{-}R_3 & & & & R_3\text{-}COO\text{-}R' & & CH_2\text{-}OH \\ \textit{Triglycerides} & & \textit{Alcohol} & & \textit{Esters} & & \textit{Glycerin} \end{array} \quad (1)$$

It is important to notice that this is a series of reactions, in which from triglycerides diglycerides are produced. Then, the diglycerides are transformed into monoglycerides and finally, the latest is modified into glycerin. In every single step biodiesel is produced. Because this is an equilibrium reaction, higher amounts of alcohol are used in order to swift the reaction towards the desire product.

Besides technical aspects and viability, economic feasibility is as relevant, making a process to be profitable or not. Different authors have also done economic analyses of several biodiesel production scenarios [24–30]. Marchetti et al. [27] studied a supercritical process where waste oil, as defined by Marchetti [31], with 5 wt% of

* Tel.: +47 64966397.
E-mail address: jorge.mario.marchetti@umb.no

0196-8904/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enconman.2013.07.039

FFA undergoes a two reactor process with intermediate separation. The authors found that the process was not profitable as it was presented due to the high cost on operation, which was more than 50% of the total cost of the process. Contrarily, Van Kasteren and Niswore [32] found that their proposed process was rentable when studied. The differences are based on the reaction system, the amount of equipment as well as the post purification. The latest have used the biodiesel selling price as comparison variable.

However, to my knowledge, there has not yet been a study where the economic variables over a supercritical biodiesel plant were analyzed and compared in order to examine the influence of the economic variables over the process.

In this work, the influence of several market dependant variables (price of raw material, selling price of biodiesel, etc.), over the economy of a biodiesel plant, has been studied. This analysis was done over a biodiesel production plants that employees a supercritical technology with no catalyst neither co-solvent. This technology has been selected due to its versatility for raw materials with high amount of impurities.

2. Study case

For this study, a supercritical biodiesel was design as follow: methanol and the impure oil are fed into the first supercritical reactor. After the reaction, a distillation column is used to separate the methanol phase from the oil and glycerin phase. The methanol is then recycled and the oil phase is separated into glycerin and biodiesel/unreactant components. The latest is fed into a second supercritical reactor with methanol in order to achieve a higher conversion, yield and selectivity. After the second supercritical reactor, the methanol is separated and recycled by a distillation column and the oil/glycerin phase is passed through a decanter to produce high pure biodiesel and glycerin of high concentration. Fig. 1 shows the flow sheet of the process.

For this purpose, it was used a commercial software, Super Pro Design [33]. Data from the literature was employed as a source for the cost and prices of equipment and materials. The technical aspects (operational conditions for the process), cost of equipment as well as other assumptions used in this work, plus the mayor economic variables were set as previously done in Marchetti et al. [27].

Table 1 show the major economic parameters used in this work such as investment, total capital cost and plant capacity. The major economic assumptions have been done according to information from the literature [27]. In this work it has been compared the internal return rate (IRR) and the payback time. Net present value (NPV) has not been used since the tendencies obtained for IRR and NPV will not suffer major modifications if one or the other are presented. This work is to show tendencies and comparison more than absolute numbers.

As mentioned, the production biodiesel has several physical–chemical variables involved, such as: reaction temperature, molar ratio between reactants, types of catalyst, amount of catalyst, and many others. It also has economic parameters which require

Table 1
Technical and economical aspects.

Technical aspects	
Plant capacity (kg/year)	39,910,500
Project life time (year)	15
Feed streams (kg/h)	
Oil	4550
Methanol	8700
Out coming streams (kg/h)	
Biodiesel (purity over 98%)	4556
Glycerin	424
Economic aspects	
Total capital investment ($)	$ 12,464,138
Equipment purchase cost ($)	$ 2,613,366
Direct fixed capital (DFC) ($)	$ 8,744,177
Working capital ($)	$ 3,132,752
Start up and validation cost ($)	$ 437,209
Total operating cost ($/yr)	$ 42,086,302
Labor dependant ($/yr)	$ 273,240
Utilities ($/yr)	$ 1,556,634
Laboratory ($/yr)	$ 40,986
Biodiesel unitary cost (US$/kg)	$ 1.1789

specification. Some of these economic variables have been studied to evaluate their influence on the global process. Their effect over the internal return rate, which is a key variable in order to see if a process is profitable or not, and over the payback time, which gives idea of the time needed to recover the investment, were analyzed.

It was carried on a research to identify how each of the following variables separately affects the global economic of a biodiesel process.

1. Oil price (associated to its purity).
2. Biodiesel selling price.
3. Glycerol selling price.
4. Alcohol price.
5. Advertisement and selling expenses.
6. Tax incentives.
7. Investment in research and development.
8. Product failure.

These variables are market related and their values are ruled by the market as well as other companies and political decisions.

Each of these variables has a study range in order to evaluate the influence over the IRR and the payback time. Table 2 shows these ranges for all the studied variables. In the same table it is also included the standard value for each of them.

3. Results and discussion

3.1. Changes on the selling price of biodiesel

Biodiesel selling price is a key variable of the process, it is a fundamental variable that will allow the process to be economically

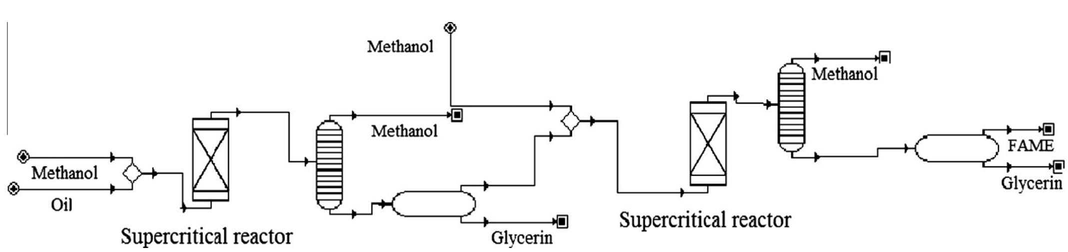

Fig. 1. Flow diagram of the process under studied.

attractive or not. Now a day, biodiesel price is not fixed in the market, it depends on tax incentives, price of petroleum oil, subsidies for transportation, etc. Taking all this into account, the range used for this study was from 0.63 to 0.7 US$/l. These values are an average among different prices found in the literature [34–36].

Fig. 2 shows the variations of the payback time and the IRR when the biodiesel price suffers modifications.

It can be seen that as the biodiesel price increases, the IRR increases as well following a straight tendency; however, the payback time decreases but not in the same proportion as the increments of IRR. From Fig. 2 it can be seen that a small modification of 20 US$ on the price of biodiesel (from 650 to 630 USD/l) makes the process to require 80% more time to recover the investment, as well as a reduction of 85% on the IRR. This result shows the influence and relevance of the selling price of biodiesel. This price is normally attached to market supply and demand requirements, international and national agreements, etc. The cut off price is hard to predict since this is a very dynamic scenario and the representation here is not, making it just a good estimation.

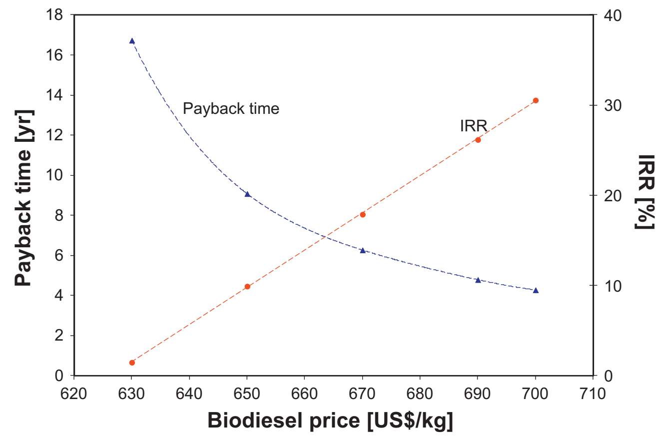

Fig. 2. Variation of the payback time as well as the IRR when the biodiesel price varies. (▲) Payback time and (●) IRR.

3.2. Changes on the oil price

The supercritical process is an expensive alternative due to the high demands on operational pressure and temperatures. Contrarily to the homogeneous alternative, the amount of FFA can be as high as desired, eliminating the restriction of lower amounts of FFA (below 0.5 wt% [2–5] for refine oil in order to avoid soap formation). The price range for the oil has been selected between 325 and 415 U$S/tonne. This scale is an average among the prices for edible oils (478–650 U$S per tonne [34]) and waste cooking oil (110–220 U$S per tonne [25,26,35]).

In Fig. 3 it could be seen the variations of the payback time as well as those of the IRR due to modifications in the oil price. As the oil price gets smaller, which could be associated with higher amounts of impurity, the IRR values gets higher following a straight tendency. Payback time, on the other hand, increases exponentially with more pure raw materials. This tendency shows that even if the oil is for free, there is a payback time associated with the minimum time required to recover the investment, and therefore the exponential tendency.

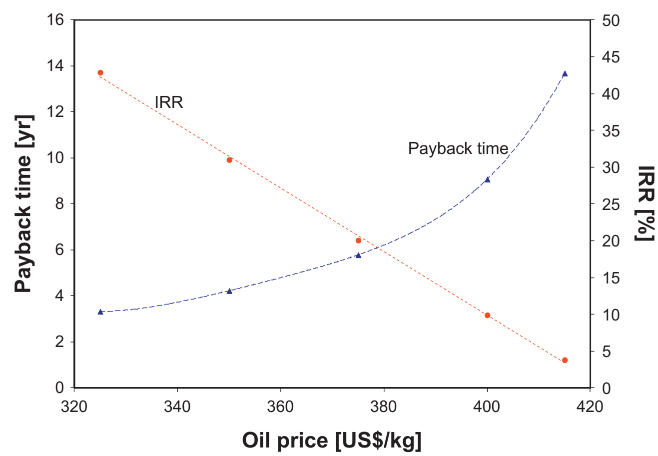

Fig. 3. Variation of the payback time as well as the IRR when an oil price varies. (▲) Payback time and (●) IRR.

3.3. Changes on the glycerol price

Market price for glycerol is very variable and very attach to its purity and availability. Pharmaceutical grade glycerol (purity above 98%) could be sold at a price around 1.322 US$/kg [36], while industry grade glycerol has a much cheaper price since it is produced in greater amounts due to the biodiesel industry. The amount of glycerol produced is ca. 10% of the total biodiesel generated. Therefore, its price does have an important influence over the economics of the process. The glycerol produced using the conventional homogenous technology has a purity around 75–80%, and consequently a lower price.

In this section, the influence of the glycerol selling price was studied. The range for the glycerol price was selected based on the concept that the purity of the glycerol from this technology is superior to the purity of the glycerol from conventional technology but not as good as pharmaceutical grade glycerol. Therefore, the range selected was in the range from 450 to 710 US$.

The influence of the glycerol price can be seen in Fig. 4. As the price gets smaller, the IRR decreases as expected. It can be seen that the lower price of glycerol under consideration will provided a value of IRR of around 7%. However, the payback time is higher than 10 years, which in some cases it could be considered as the upper life limit for the production process. Payback time gets reduce to 7 years when the price is close to 700 US$/kg of glycerol. It is important to see that the required time is still quite big (7 years). Therefore, if the process could produce a more pure glycerol, the payback time will be considerable reduce by the increase selling price of the by-product.

Table 2
Variables and their limits.

Variable	Minimum	Standard	Maximum
Biodiesel price (US$/kg)	0.63	0.65	0.7
Glycerol price (US$/kg)	0.475	0.55	0.7
Alcohol price (US$/kg)	0.1	0.25	0.5
Advertisement and selling (US$/yr)	0	100.000	500.000
Tax (%)	12	15	21
Failure (%)	0.01	0.1	1
R&D* (US$/kg of biodiesel)	0.12	0.15	0.16
Oil price (US$/kg)	325	400	415

* R&D: research and development.

3.4. Changes on the alcohol price

The influences of the raw materials price are crucial for any economic study. The price of methanol and how it could affect the economy of a biodiesel production plant has been studied. For this research, it has been considered a range from 0.1 to 0.4 US$/kg with a middle operation value matches those from Ref. [36].

Fig. 5 shows that the influence of the methanol price over the IRR is relevant as it was the effect of the oil price. When the price increases from 0.1 to 0.4 US$/kg, the IRR suffers a reduction of 82%, showing its great influence on the global process. This widely variations have the possibility to make the process not profitable. It can be seen, as it was the case for the oil price, which both raw materials have a very high effect over the economy of the process, as expected. A small modifications on any of them could have a very relevant impact on the profitability of the plant.

3.5. Variations on the advertisement and selling expenses

One of the most relevant market variables is selling and advertisement expenses. This variable is unpredictable, it is based on each particularly company and their interest in this matter. For our case it has been assumed very different scenarios, from no advertisement (cost = 0 US$/yr) to an investment of 500.000 US$/yr.

Fig. 6 shows the variations of the IRR and the payback time when different amount are entitled for advertisement as well as selling expenses. It can be seen that as expected, when no budget for advertisement is allocated, the IRR (11%) reaches its higher value while the payback time reaches its lower time of 8.5 years. An increase in the budget for advertisement and selling expenses produce a net decrease in the IRR, when 500.000 US$/yr are use, the IRR is reduced to less than half of its previous value, showing the high effect and strong influence in the profitability of the process.

3.6. Variations on percentage of product failure ratio

As in any production process, failure, or product out of specification, can occur. The frequency of how often this happens could eventually turn the process into a non economic alternative. Therefore, it has been studied the effect of increasing the percentage of failure in the production technology with the aim of finding its influence. The failure range was from 0.01% to 1%.

In Fig. 7 it can be seen the effect of percentage of product fail and its effect in the IRR and payback time. Despite the fact that the effect it is not considerable significant, the IRR could decrease in 20% due to an increase in the failure of the product.

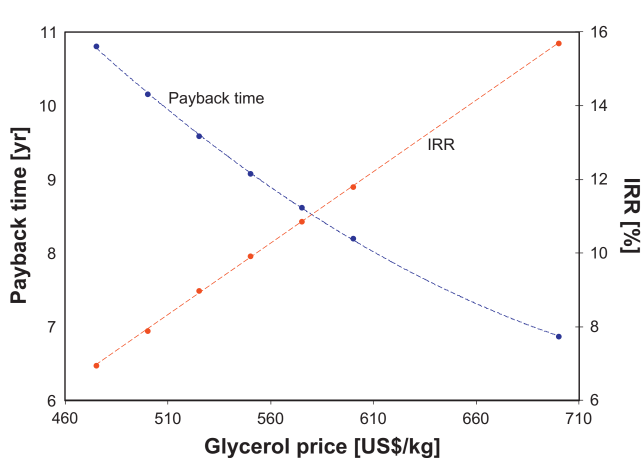

Fig. 4. Variation of the payback time as well as the IRR when the glycerol price varies. (▲) Payback time and (●) IRR.

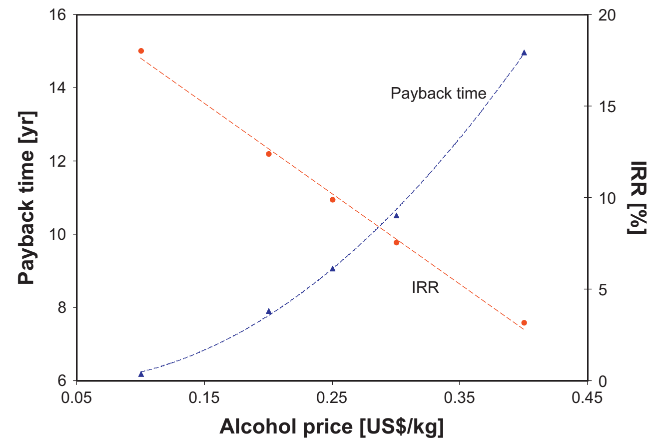

Fig. 5. Variation of the payback time as well as the IRR when the alcohol price varies. (▲) Payback time and (●) IRR.

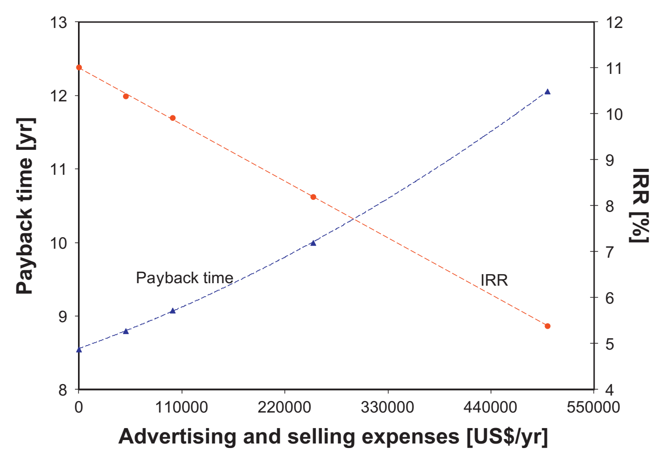

Fig. 6. Variation of the payback time as well as the IRR when analyzing the advertisement and selling expenses. (▲) Payback time and (●) IRR.

3.7. Variations over tax

Different countries have different taxes for their products; even more, some countries have different tax levels for the products that are imported based on the necessity level of such products. Based on the fact that tax incentives have been a good help for biodiesel plant development, a study over the effect of this variable is relevant to show weather this should be maintain over time or not. It is important to point out that tax incentives are available for all types of production technologies in a very diverse possibility of economic scenarios. In this conceptual work it will only be applied to a particular process in a particular economic scenario. Therefore, it is important to comprehend the tendency but not the absolute numbers.

Tax range varies from 12% to 21% in order to cover the tax range of many countries in the world.

In Fig. 8 it can be seen the effects over the IRR and the payback time. As it is presented, when the taxes increase the revenues decreases considerably. The IRR decreases but far from making it a non-profitable alternative. However, the payback time it is still quite high for all the studied taxes values, making a non attractive approach to produce biodiesel due to the minimum of 8 years to recover the investment.

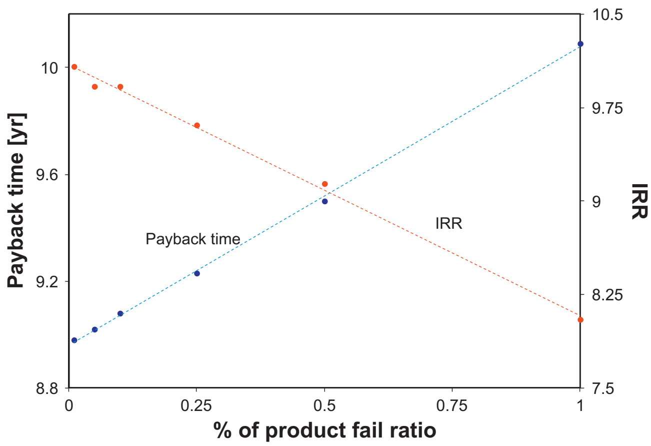

Fig. 7. Variation of the payback time as well as the IRR when the percentage of product fail varies. (▲) Payback time and (●) IRR.

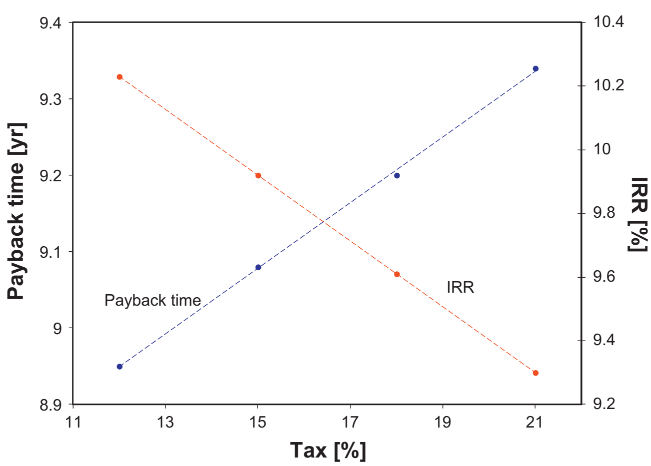

Fig. 8. Variation of the payback time as well as the IRR when the tax percentage varies. (▲) Payback time and (●) IRR.

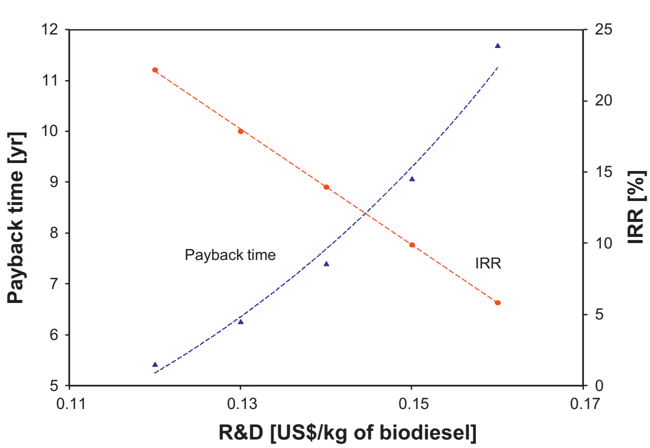

Fig. 9. Variation of the payback time as well as the IRR when the amount of US$ destiny to research and development changes. (▲) Payback time and (●) IRR.

3.8. Variations on the US$ used for research and development

The influence of the US$ per kilo of biodiesel produced designated for research and development was studied. Several companies invest money from their revenues for research and development in order to improve their production processes. In this section, it was studied how this variable might influenced the IRR and the payback time of a biodiesel plant. It was studied the range between 0.12 and 0.16 US$/kg of biodiesel produced.

Fig. 9 shows that the IRR decreases in 75% when the increase on the amount invested for research and development increases only 33%. The payback time decreases in a 53% as a consequence of the same variations on the amount given for R&D.

4. Conclusions

An economic study over a biodiesel process that involves a supercritical technology to produce biodiesel, and how each market variable affects the internal return rate and the payback time, was analyzed.

It has been found that the entire incomes variables (selling price of glycerol as well as biodiesel) have a positive effect over the internal return rate making a reduction on the payback. Contrarily, the outcomes variables have the opposite effect, making the process less profitable. It is important to notice that not all of the outcomes variables have the same effect over the process and not all of them might produce a non profitable scenario for the variable ranges studied.

All the studies included in this work show that the payback time never tends to zero. This result is in accordance to a net investment in equipment that at least should be recovered.

These results are of high interested since they shows tendencies of how several relevant variables modifications can affect the IRR of a biodiesel plant. Even more, the fact that an idea of the evolution of the economic indicator as a function of several variables is showed, allows decision to be taken ahead, preventing economic crisis to strike.

Disclaimer

The authors and UMB do not accept responsibility for any decision taken based on these model results. The model used on this work is for research purpose only. For specific applications please contact the authors, as well as for recommendations regarding the limitations and scope of the model.

Acknowledgements

J.M.M. would like to thanks to UMB for its financial support. J.M.M. would also like to PLAPIQUI, UNS and CONICET for its support. He would also like to thanks to Professor Errazu for its fruitful suggestions.

References

[1] Kulkarni MG, Dalai AK. Waste cooking oil – an economical Source for biodiesel: a review. Ind Eng Chem Res 2006;45:2901–13.
[2] Marchetti JM. Biodiesel production technologies. New York, New York, USA: Novapublishers; 2010.
[3] Knothe G, Van Gerpen J, Krahl J, editors. The biodiesel handbook. Champaign, Illinois, USA: AOCS Press; 2005.
[4] Tomasevic AV, Siler-Marinkovic SS. Methanolysis of used frying oil. Fuel Proces Technol 2003;81:1–6.
[5] Darnoko D, Cheryan M. Kinetics of palm oil transesterification in a batch reactor. JAOCS 2000;77(12):1263–7.
[6] Mittelbach M, Trathnigg B. Kinetics of alkaline catalyzed methanolisis of sunflower oil. Fat Sci Technol 1990;92(4):145–8.
[7] Marchetti JM, Miguel VU, Errazu AF. Possible methods for biodiesel production. Renew Sust Energy Rev 2007;11:1300–11.
[8] Canakci M, Van Gerpen J. Biodiesel production from oils and fats with high free fatty acids. Trans ASAE 2001;44(6):1429–36.
[9] Zheng S, Kates M, Dubé MA, McLean DD. Acid-catalyzed production of biodiesel form waste frying oil. Biomass Bioenergy 2006;30(3):267–72.

[10] Schuchardt U, Sercheli R, Vargas RM. Transesterification of vegetable oils: a review. J Braz Chem Soc 1998;9(1):199–210.
[11] Marchetti JM, Miguel VU, Errazu AF. Heterogeneous esterification of oil with high amount of free fatty acids. Fuel 2007;86:906–10.
[12] Peterson GR, Scarra WP. Rapeseed oil transesterification by heterogeneous catalysis. JAOCS 1984;61(10):1593–7.
[13] Di Serio M, Cozzolino M, Giordao M, Tesser R, Patrono P, Santacesaria E. From homogeneous to heterogeneous catalysts in biodiesel production. Ind Eng Chem Res 2007;46(20):6379–84.
[14] Gryglewicz S. Rapeseed oil methyl esters preparation using heterogeneous catalysts. Biores Technol 1999;70(3):249–53.
[15] Kaieda M, Samukawa T, Matsumoto T, Ban K, Kondo A, Shimada Y, et al. Biodiesel fuel production from plant oil catalyzed by Rhizopus oryzae lipase in a water-containing system without an organic solvent. J Biosci Bioeng 1999;88(6):627–31.
[16] Nelson LA, Foglia TA, Marmer WN. Lipase-catalyzed production of biodiesel. JAOCS 1996;73(8):1191–5.
[17] Watanabe Y, Shimada Y, Sugihara A, Noda H, Fukuda H, Tominaga Y. Continuous production of biodiesel fuel from vegetable oil using immobilized Candida antarctica lipase. JAOCS 2000;77(4):355–60.
[18] Sanchez F, Vasudevan PT. Enzyme catalyzed production of biodiesel from olive oil. Appl Biochem Biotechnol 2006;135(1):1–14.
[19] Lim S, Lee KT. Optimization of supercritical methanol reactive extraction by Response Surface Methodology and product characterization from Jatropha curcas L. seeds. Biores Technol 2013;142:121–30.
[20] Pérez MA, Aracil I, Fullana A. Biodiesel production by transesterification of sludge in supercritical conditions. Fuel 2013;109:427–31.
[21] Saka S, Kusdiana D. Biodiesel fuel from rapeseed oil as prepared in supercritical methanol. Fuel 2001;80:225–31.
[22] Dubé MA, Tremblay AY, Liu J. Biodiesel production using a membrane reactor. Biores Technol 2007;98(3):639–47.
[23] Tonetto GM, Marchetti JM. Transesterification of soybean oil over Me/Al_2O_3 (Me= Na, Ba, Ca and K) catalyst and monolith K/Al_2O_3-corderita. Top Catal 2010;53:755–62.
[24] Bender M. Economic feasibility review for community-scale farmer cooperatives for biodiesel. Biores Technol 1999;70:81–7.
[25] Zhang Y, Dubé MA, McLean DD, Kates M. Biodiesel production from waste cooking oil: 2 Economic assessment and sensitivity analysis. Biores Technol 2003;90:229–40.
[26] Haas MJ, McAloon AJ, Yee WC, Foglia TA. A process model to estimate biodiesel production costs. Biores Technol 2006;97(4):671–8.
[27] Marchetti JM, Miguel VU, Errazu AF. Techno-economic study of different alternatives for biodiesel production. Fuel Process Technol 2008;89(8):740–8.
[28] Marchetti JM, Errazu AF. Technoeconomic study of supercritical biodiesel production plant. Energy Convers Manage 2008;49(8):2160–4.
[29] West AH, Posarac D, Ellis N. Assessment of four biodiesel production processes using HYSYS plant. Biores Technol 2008;99(14):6587–601.
[30] You YD, Shie JL, Chang CY, Huang SH, Pai CY, Yu YH, et al. Economic cost analysis of biodiesel production: case in soybean oil. Energy Fuels 2008;22:182–9.
[31] Marchetti JM. A summary of the available technologies for biodiesel production based on a comparison of different feedstocks properties. Proc Saf Environ Protec 2012;90(3):157–63.
[32] Van Kasteren JMN, Nisworo AP. A process model to estimate the cost of industrial scale biodiesel production from waste cooking oil by supercritical transesterification. Resour Conser Recyc 2007;50(4):442–58.
[33] SuperPro Designer v. 8.5 software Intelligen Inc.; 2007.
[34] Gui MM, Lee KT, Bhatia S. Feasibility of edible oils vs. non-edible oils vs. waste edible oil as biodiesel feedstock. Energy 2008;33:1646–53.
[35] Haas MJ. Improving the economics de Biodiesel production through the use de low value lipids as feedstocks: vegetable oil soapstocks. Fuel Process Technol 2005;86:1087–96.
[36] Lee S, Posarac D, Ellis N. Process simulation and economic analysis of biodiesel production processes using fresh and waste vegetable oil and supercritical methanol. Chem Eng Res Des 2011;89:2626–42.