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# Biodiesel and electrical power production through vegetable oil extraction and byproducts gasification: Modeling of the system

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## HIGHLIGHTS

- The gasification and the biodiesel conversion processes where modeled.
- The feasibility of the method was demonstrated form a chemical point of view.
- The minimum farmed surface required for system sustainability was evaluated.
- An economical evaluation of the ROI was added to fulfill the discussion.

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ABSTRACT

Aim of this work is to introduce an alternative to the standard biodiesel production chain, presenting an innovative in situ system. It is based on the chemical conversion of vegetable oil from oleaginous crops in synergy with the gasification of the protein cake disposed by the seed press. The syngas from the gasifier is here used to produce electrical power while part of it is converted into methanol. The methanol is finally used to transform the vegetable oil into biodiesel. Through a coupled use of ASPEN PLUS™ and MATLAB™ codes, a rapeseed, soy and sunflower rotation, with a duration of three year, was simulated considering 15 ha of soil. This surface resulted sufficient to feed a 7 $kW_{el}$ power plant. Simulation outputs proven the system to be self-sustainable. In addition, economical NPV of the investment is presented. Finally the environmental, economical and social advantages related to this approach are discussed.


## 1. Introduction

The production and utilization of biofuels are a central topic for renewable energy for three reasons: the promise to mitigate the effect of climate change, cost savings and the wide distribution in many different location (Tao and Aden, 2009).

Biofuels also have a key role in industrial and agricultural business providing new sources of income, particularly when related to waste oil management (Talebian-Kiakalaieh et al., 2013; Torres et al., 2013). Biofuels and especially biodiesel obtained from dedicated cultures and rotations are indicated for transport and stationary power production (Koçar and Civaş, 2013; Atabani et al., 2012). The production chain from cultivating the seeds to selling the biodiesel on the market can be subdivided into two different macro areas: first the farmers cultivate the energy crops and sell the seeds on the market; then seed pressing and oil conversion plants buy the seeds and the methanol from the market and then produce and sell biodiesel (Gerpen et al., 2004; Thliveros et al., 2014).

This work is aimed at introducing a different way to produce biodiesel through a synergy of different technologies with two major purposes: maximizing the earnings of the farmers and increasing the sustainability of the conversion system through the centralization of all the stages in a single location. This study is based on a crop rotation composed of oleaginous crops only. In 2010 and 2011 Zegada-Lizarazu and Monti suggested two rotations suitable for Mediterranean zones: rapeseed-flax-sunflower and rapeseed-soy-sunflower (Zegada-Lizarazu and Monti, 2011; Zegada-Lizarazu and Monti, 2010). The second rotation mentioned is preferable due to the higher per hectare productivity of soy compared to flax. The simulations of the system were based on literature data concerning average oil production from these crops in Emilia Romagna, Italy.

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**Nomenclature**

| | |
|---|---|
| $\dot{m}$ | mass flow [kg/s] |
| $\dot{V}$ | volumetric flow [$Nm^3/s$] |
| $C$ | carbon |
| $d$ | diameter [m] or density [$kg/m^3$] |
| $ER$ | equivalence ratio [ad] |
| $F$ | mass fraction [%] |
| $H$ | hydrogen |
| $HHV$ | higher heating value [$MJ/Nm^3$ or MJ/kg] |
| $I$ | incoming [€] |
| $K$ | potassium |
| $l$ | length [m] |
| $N$ | nitrogen |
| $NPV$ | net present value |
| $O$ | oxygen |
| $p$ | pressure [atm] |
| $s$ | standard deviation |
| $t$ | time [s] |
| $n$ | moles of the product per mole of biomass [$mol/mol_{bio}$] |
| $v$ | net rate of reaction [mol $s^{-1}$] |
| $\alpha$ | hydrogen coefficient of the biomass |
| $\beta$ | oxygen coefficient of the biomass |

**Subscripts**

| | |
|---|---|
| $bio$ | biomass |
| $c$ | char |
| $m$ | moisture |
| $p$ | pyrolysis |
| $v$ | void |

In this region, rapeseed crops can easily produce 4.0 ton/ha of seeds with 9% of moisture, with peak production up to 4.9 ton/ha (Innocenti et al., 2008). About 46% of rapeseed seeds can be converted into PVO by mechanical processes (Innocenti et al., 2008). Sunflower crops can produce about 2.8 ton/ha of seeds (ISTAT, 2013). About 45% of sunflower seeds can be converted into PVO by mechanical processes (Online, 2013).

Oleaginous soy crop yields 3.7 ton/ha of beans, with peak production up to of 4.5 ton/ha (Maisadour, 2013; Uzun et al., 2006) and about 20% of soy beans can be converted into oil by mechanical processes (Uzun et al., 2006).

The system layout is depicted in Fig. 1. The approach of single culture cultivation is as follows: every year a different crop is cultivated on the whole surface and the seeds are converted into PVO by a mechanical process. The protein cake obtained as a byproduct of the oil extraction is gasified in a downdraft stratified reactor connected to an IC engine-electrical generator of 10 kW peak power. The choice of a stratified reactor allows us to gasify difficult feedstocks in respect to single or double throat downdraft reactors which prefer wood chips with an ash content lower than 3% wt (Reed and Das, 1988; Martnez et al., 2012; Allesina et al., 2013). Seed pellets have a high ash content (from 3 to 7% wt) and a low consistency compared to wood chips and the stratified reactor is able to convert a biomass with these properties into syngas (Reed and Das, 1988). A small part of the syngas is converted into methanol. The methanol is then used in the transesterification of the PVO to produce biodiesel.

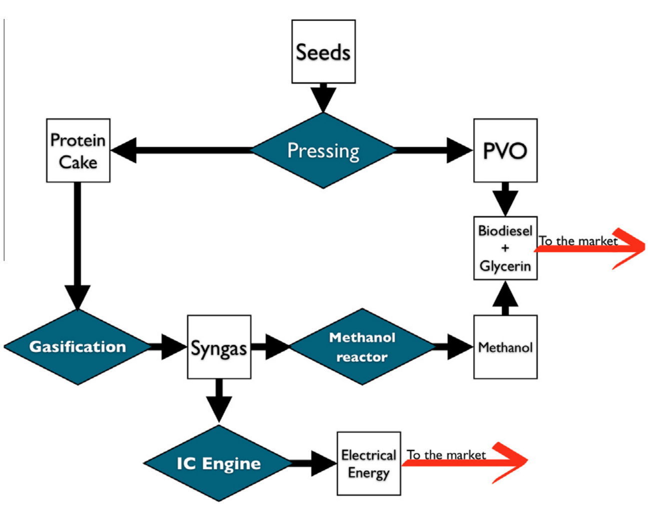


**Fig. 1.** System layout.

The gasifier model is based on the following parameters: the composition of the protein cake, the dimensions and physical properties of the protein cake and the geometrical parameters of the gasifier. Other studies on protein cake gasification are reported in literature (Christodoulou et al., 2014; Prasad et al., 2014; Duman et al., 2014). The biodiesel production process is divided into two stages: the syngas is converted into methanol and the conversion reaction is simulated with an equilibrium-based approach; then PVO and methanol are mixed in a second reactor with a catalyzing agent and the reaction is modeled by a stoichiometric approach.

The whole model allows us to calculate the mass of biodiesel oil and glycerin obtained every year along with the electrical energy produced by the generator connected to the gasifier. In addition, an economical analysis is made to evaluate the return of investment.

## 2. Methods

### 2.1. Experimental analysis

The input data used in the gasifier model can be obtained from the ECN biomass database (Phyllis, Online Database for biomass and waste), but for a more specific comprehension of the gasification of the protein cake, different experiments have been carried out on a sample of sunflower cake pellet to evaluate geometrical and physical properties. These data were used for the description of each pellet considered in this work.

The gasifier model requires the true density and the void fraction of the fuel. The true density has been obtained with a gas pycnometer which uses helium as working gas. The average value obtained with this measurement is 1790 $kg/m^3$ (s = 5 $kg/m^3$). The void fraction was obtained from the apparent density of the sample equal to 930 $kg/m^3$ (s = 51 $kg/m^3$) measured using hydro-static weighting.

The geometrical properties of the protein cake pellets were obtained with a series of 50 measurements using a caliper. The average diameter is 8.5 mm (s = 2.8 mm), the average length is 8.8 mm (s = 0.2 mm) and the average particle volume is 490 $mm^3$ (s = 15.6 $mm^3$). Further analyses were made on the sample for the evaluation of the moisture content, ash content and the composition. Table 1 summarized the geometrical and physical properties of the protein cakes.