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Energy production balance for biogas generation from cactus prickly in a staged biorefinery

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Abstract

Bioenergy production in remote areas is only profitable when the energy generation plant is close to abundant biomass sources. Cactus prickly (Opuntia spp) is widespread in the centre-north region of Mexico, where it produces large quantities of biomass (11.29% dry matter) despite growing in a harsh environment with low and ill-distributed rainfall, large temperatures variations, poor soils and lacking skilled crop management. Nevertheless, it is utilized mostly as human food and animal fodder, as raw matter to medical, fragrance and cosmetic industries, and nowadays it emerges as a potential biogas provider by wisely using its lignocellulosic biomass. By applying, essential technical and methodological principles originated for descentral energy generation to benefit marginal communities, the biorefinery philosophy is proposed to achieve an integral use of cactus prickly biomass, either directly as fresh mass or through its new derived conversion components, in a scheme of staged biorefinery from by-products to raw material to obtain food, fodder, fertilizer, medical and cosmetology products, and biogas. This work presents an analysis where research is being undertaken to promote an integral and sustainable program through a biorefinery scheme, for supplying small farmers with unsophisticated equipment, improved techniques for harvesting and industrializing and making an integral use of cactus prickly biomass and animal wastes for biogas production. Cactus biomass constitutes mainly from cladodes (thorned pads), flowers, ripe and immature fruit, and yield ranges from 20 to 100 tonne per hectare per year. At this point, constraint affect efficient utilization of cactus prickly as raw matter for biorefinery; quality of cactus biomass as large amount of cladodes are discarded because of its unavailability as livestock fresh fodder and those still attached to the plant get mature and eventually get old. It was appreciated basic requirements in order to make an efficient process and to reduce energy consumption: a) short distance transportation of raw matter and b) undertake a basic process – low investments and supplying small quantities of energy. Transportation costs of a bioenergetic of low enthalpy is reduced by utilizing a portable container-biodigester, where biomass is fermented in a thermofilic process and adequate quality biogas is produced with low investments, and suitable for rural population needs. Cactus prickly biomass competes with other agricultural crops (maize silage) and agroindustrial wastes (sugarcane and agave bagasse) on biogas generation, and shows on average one of the highest methane production to biomass ratio (57.12%).

Keywords: biorefinery, biogas, cactus prickly, waste management, biomass
1. Introduction

A series of challenges for world society in years to come will be to fully satisfy the increasing expectations of a constant growing population, amongst many priorities it can be distinguish; food on sufficient quantity and quality and an affordable and non-stop energy supply. Nevertheless, both issues are interrelated since to produce more food means more energy has to be provided and from a sustainable thinking both should get here from one of the scarcest of all factors: available fertile farmland. In order to cross the threshold we need sustainable increases in productivity from non-food crops and investigating other potential biomass providers.

Nowadays, a feasible alternative for small farmers in the semiarid regions of Mexico to additionally raise their income is through planting, harvesting and processing of non-traditional plants. However, in order to achieve this goal sustainable, they require of adequate tools, reliable techniques and sustainable processes according to inputs, yield and quality demands (Mendez-Gallegos et al., 2000). At present, cactus prickly looks like the most promising plant; it has a high ecological adaptation, straightforward field establishment and ease of reproduction, highly adaptable to many soil qualities and low availability of water.

It could be considered as one of the vegetable resources more important in arid and semi-arid zones of Mexico, because it is mainly used as animal fodder, fresh green vegetable, its fruits are freshly consumed and fruit and young cladodes are processed in value added by-products (Figure 1). Around 30 small cottage industries manufacture food products from cactus prickly and because of its nutritional, medical and cosmetic qualities just a few plants compete with cactus prickly. Despite to its diverse potential applications; peasants still use solely cactus prickly biomass as a supplement and emergency food for their backyard animals, while farmers cultivate cactus prickly for fruit production.

### Figure 1. Sizing by pruning cactus prickly plants in a fruit production orchard.

Recently, cactus prickly biomass is being trialed to generate biogas to be used directly by farmer’s families (Rössel & Ortiz-Laurel, 2012). Energy production from rural biomass only makes economic sense if crops are harvested within an area just a few...
kilometers radius from the energy production facility. In addition, marginal communities have limited energy inputs such as: human power, biological energy and accessible technical chemistry through agrochemicals, water, and energy required for mechanization (Rössel et al., 2004).

This feasible technology has to be adopted and adapted to specific needs and conditions prevailing on these remote rural areas (Figure 2). This work presents an analysis where research is being undertaken to promote an integral and sustainable program for using cactus prickly biomass through a biorefinery scheme, through training farmers with unsophisticated equipment, improved techniques for harvesting and industrializing for making an integral use of cactus prickly biomass and animal wastes for biogas production. The joint planning, organization and implementation of training, research and technical realization on the field of descentral sustainable energy production is an additional goal of this project.

**Energy balance**

*technological flow*

Reduction of energetic inputs such as: human power, biological energy and technical chemistry (agrochemicals, water, energy required for mechanization, etc.)

Agricultural production (for example, cactus prickly)

Production of biogas and its storage

Separation of mass not viable for conversion to biogas but useful to obtain byproducts

advantages: reduction of energy for: a) transportation, b) the process itself - reduction of investment and energy to undertake the process technique

Increase the efficiency for the biogas process, through: selection of material useful to produce biogas (without byproducts in this first separation), reduction of transportation with low entalphy (portable bio-container), thermophilic process (low investment and high quality biogas), integration of some other renewable energies, use of sub-products to reduce the quantity of energetic feedstocks (compost, manure), biological treatment of raw materials (cactus prickly) added to the biodigester, usage of biogas (without cleaning - no energy) in agricultural processes.

*Figure 2: Processes involved in a scheme for a more efficient energy balance from biomass to generate biofuels.*
2. Materials and methods

The production of energy from biomass, indirectly using the solar energy stored up by photosynthesis in plants is a promising area of research. Developing countries are the largest consumers; however, their use of biomass is still inefficient. While biomass produced from cactus prickly (Opuntia spp) yields 20 to 100 tonne per hectare per year.

The crucial constraint to utilize cactus prickly as food and bioenergy provider is to program a sustainable exploitation during harvest period (Ortiz-Laurel & Rössel, 2009). Primarily, large quantities of biomass (pads) is discarded because of its unavailability to be used as livestock fresh fodder and those still attached to the plant get mature and eventually lose their nutritious and digestible value (Figure 3).

Through the basic constituents of cactus prickly on their own or through some of its derivatives allow to obtain products with higher added value and useful for specialty industries with a scheme similar to oil refining (Figure 2). Basic raw materials are available for cosmetics, pharmaceuticals, food products for human (mainly related to dietary and functional food) and animal feedstock.

On the other hand, solar dehydration of biomass cactus prickly has been experimented in rural manufactured facilities, as drying does not alter its nutritious value, therefore industrial and livestock managers will have feedstock through unproductive season and during unavailability of other raw materials. The technology will also promote to increase cactus prickly biomass production, harvest mechanization, ease of handling, transportation and safe distribution.
Different methodology for handling cactus prickly has to take effect for bioenergy purposes. To start with, separation of mass not viable for immediate conversion to biogas but useful as food or to be processed to obtain other byproducts and once they have reached their waste stage (compost, manure), they can be used as a substrate for the biodigestion (Rössel et al., 2001).

This basic procedure increases the efficiency for the biogas process, through: reduction of energy for; a) transportation, b) the process itself – reduction of investment and energy to facilitate the process technique. It also reduces low enthalphy biomass transportation by concentrating raw matter storage and employing a portable biodigestion container, where a thermophilic process is achieved with low investment and getting high quality biogas. It is viable to improve the energy balance by integrating some other renewable energies in order to aid the course of the process, thus having an almost self-sufficient energetic process. When necessary, raw mass receives a biological treatment (cactus prickly) and then poured into the biodigester and raw biogas can also be used directly, thus no additional energy is supplied.

3. Results and Discussion

Table 1 contains fundamental identifiers for some trialed organic material used in this work. Since digestibility value is a key parameter that influences quantity of biogas production, it can be said that sugarcane bagasse has the lowest figure and cactus prickly and agave have identical and reasonable high value, while maize silage has the largest figure, indicating it is ideal for obtaining quite significant quantities of biogas. The above statement is confirming and illustrated in Table 2, where also it is observed that methane ratio for cactus prickly was highest.

Table 1: Data from a bromatologic analysis for sugarcane bagasse, agave bagasse, cactus prickly and maize silage.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Sugarcane bagasse</th>
<th>Agave bagasse</th>
<th>Cactus prickly</th>
<th>Maize silage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%D</td>
<td>%</td>
<td>%D</td>
</tr>
<tr>
<td>Dry matter</td>
<td>96.05</td>
<td>-</td>
<td>90.8</td>
<td>-</td>
</tr>
<tr>
<td>Protein</td>
<td>1.55</td>
<td>67.8</td>
<td>2.1</td>
<td>67.8</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>6.21</td>
<td>82</td>
<td>49.3</td>
<td>82</td>
</tr>
<tr>
<td>Fiber</td>
<td>0.56</td>
<td>19.9</td>
<td>2.6</td>
<td>23.8</td>
</tr>
<tr>
<td>Fats</td>
<td>74.73</td>
<td>70</td>
<td>29.8</td>
<td>72.9</td>
</tr>
<tr>
<td>Ashes</td>
<td>3.95</td>
<td>-</td>
<td>8.2</td>
<td>-</td>
</tr>
<tr>
<td>Gross organic dry matter</td>
<td>96.5</td>
<td>-</td>
<td>91.8</td>
<td>-</td>
</tr>
</tbody>
</table>

%D= % digestibility

Regarding an analysis of the pretreatment procedure for the lignocellulosic materials, it was found a diverse range of records for the final product and dissimilar speed of decomposition, which depends much on the inner constituents of the original material.
Results from chemical analysis carried out on cactus prickly showed differences because plant development is influenced either through biotic factors as specie, breed, age, etc, as well as abiotic factors as sampling date, edaphic and climatic and others. It can be concluded that cactus prickly can play an important role to provide bio-energy to the most of the time forgotten isolated rural communities.

### Table 2: Biogas and methane production from some agricultural crops and agroindustrial wastes.

<table>
<thead>
<tr>
<th></th>
<th>Biogas yield (l/kg of dry matter)</th>
<th>Methane yield (l/kg of dry matter)</th>
<th>Methane ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane bagasse</td>
<td>155.83</td>
<td>84.08</td>
<td>53.95</td>
</tr>
<tr>
<td>Agave bagasse</td>
<td>352.10</td>
<td>190.84</td>
<td>54.20</td>
</tr>
<tr>
<td>Cactus prickly</td>
<td>356.46</td>
<td>203.62</td>
<td>57.12</td>
</tr>
<tr>
<td>Maize silage</td>
<td>557.15</td>
<td>306.86</td>
<td>55.08</td>
</tr>
</tbody>
</table>

Results obtained from feeding animals with green cactus prickly have showed that milk and meat production is much less, although also cost per unit of production is also less. There is little information about using dry cactus prickly as fodder conditions are changed because nutrition value is higher that fresh cactus prickly.

### 4. Conclusions

Cactus prickly is used on food, textile, pharmaceutical and cosmetology industries and nowadays is a viable alternative to provide a renewable biofuel within a decentral production scheme, offering an inexpensive and continuous bioenergy for communities located in rural, isolated and poorest regions. Superior biomass and great cellulose content makes cactus prickly a viable feedstock either directly or through some of its derived by-products which should receive mechanical and biological treatments with the aim of getting greatest quantity and highest purity of biogas.

### 5. References


