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Techno-Economic Investigations on the Small-Scale Production of Ethanol from Egyptian Rice Straw

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Ligno-cellulosic biomass represents a major source of pollution worldwide as it is utilized as a source of fuel in rural stoves which are of very low efficiency or disposed of by direct/open burning. Efforts are being conducted worldwide to utilize ligno-cellulosic biomass for the production of ethanol, bio-oil or other sources of fuel that could replace the depleting fossil fuels. Most of the studies and early stage applications are directed towards the production of ethanol in large scale facilities of capacities around 15 - 100 Mm^3/y. Taking into consideration the high transport costs especially in rural communities where ligno-cellulosic biomass is generated, it seems appropriate to investigate the techno-economics of production of ethanol on a relatively small-scale (about 2,800-4,000 t/y). Such units could be established close to the source of generation of ligno-cellulosic biomass without the need of transport to a centralized facility. In this work, techno-economic studies for the production of ethanol from rice straw for the proposed scale have been conducted. Technology aspects are first presented for the 40 ton/day rice straw process comprising the various processing stages. These include shredding to appropriate particle size, alkaline pretreatment stage followed by washing with water and acid to neutralization, enzymatic hydrolysis (saccharification) simultaneous with fermentation (SSF) using *Saccharomyces Cerevisiae* .The produced ethanol is then concentrated to over 99 % through azeotropic distillation. Preliminary design of the wastewater treatment plant is also provided.
ASPEN PLUS from ASPENTECH for simulation has been used for conducting the material & energy balance and preliminary design of the processing units. Techno-economic studies have been conducted taking into consideration the conditions prevailing in our area. Capital investments, annual production costs and financial analysis has been conducted using ASPEN ICARUS. The capital costs have been estimated to be about LE 6-10 million for various proposed scenarios. The corresponding annual operating costs ranged between LE 1-1.5 million respectively. The Internal Rate of Return (IRR), has been estimated for several anticipated selling price for the produced ethanol ranging from 0.4 to 0.6 cents/l. It has been concluded that the proposed process could be feasible when the selling price is about 0.5 cents/L.

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1. Introduction

Egypt depends currently to a great extent on fossil fuel, oil and natural gas, to meet the increasing demand on primary energy, where fossil fuel satisfied about 94 % of primary demand in 2004/2005 including 50.4 % as oil share and 43.6 % as natural gas (NG) share. The rest is mainly met through hydropower and coal. The energy sector is still playing a vital role in Egypt's economy. However, the Egyptian government currently faces a real challenge to make a strategic choice between satisfying the ever increasing national primary energy demand (depending by more than 94 % on oil and gas) that is being offered to end-users with subsidized prices, and maintaining a certain level of hard currency revenues from oil and gas exports at world prices, even with a growing risk of accelerated depletion rates of national proven reserves. Different scenarios expect that if current practices in the energy sector will continue as it is, Egypt will become a net oil importer during the near future. This tendency, if continues, should certainly lead to a non sustainable energy future that government and citizens should work hand in hand from now to avoid its occurrence (Georgy 2007).Thus efforts to develop New and Renewable Energy sources are being undertaken by the governmental authorities and the R&D community.

On the other hand, enormous quantities of agriculture waste are generated annually. In Egypt, as of 2008, the estimated quantities of agricultural residues exceed 30 million t/y. These essentially comprise rice straw, cotton stalks, maize and sorghum stalks and sugarcane residues. Although these residues are partially used as a source of energy in rural stoves of low efficiency or animal fodder, most of these wastes are disposed of by open burning causing severe health hazards.

The production of liquid fuels from ligno-cellulosic materials, with emphasis on ethanol, is being extensively investigated in both developed and developing countries. The National Renewable Energy Laboratory of the US has published comprehensive reports covering technical, scientific and economic aspects for production of ethanol from ligno-cellulosic materials and recommendations for its utilization (NREL). Results of R&D undertaken worldwide have been published (Kurian 2008, Hamelinck 2005). The production of ethanol from rice straw has been discussed by several authors (Yoswathana 2010). Also, there has been extensive progress in the establishment of demonstration plants in most of the developed countries.

This article addresses the techno-economic aspects of a small-scale production facility of ethanol from rice straw. The adopted approach and methodology are first presented. The proposed process is then summarized. Engineering and cost indicators are outlined

2. Proposed process for ethanol production from rice straw

The proposed method for production of ethanol from ligno-cellulosic materials essentially comprises the following:

Shredding of Rice Straw

The rice straw has to be shredded to 1-2 mm, washed and dried to obtain clean ligno-cellulosic materials for further treatment

Pretreatment
This phase is needed to liberate the cellulose from the lignin seal and its crystalline structure so as to render it accessible for a subsequent hydrolysis using physical or chemical means. In this work, alkaline hydrolysis has been the method of choice.
Hydrolysis or Saccharification Process
The cellulose molecules are composed of long chains of sugar molecules of various chemicals. In the hydrolysis process, these chains are broken down to free the sugar, before it is fermented for alcohol production. Cellulose hydrolysis can be performed either by chemical or enzymatic.The enzymatic approach has been the method of choice in this work *Microbial Fermentation*
Traditionally baker's yeast, has long been used to produce ethanol from hexoses (6 carbon sugar). However, recently, genetic engineering and technologies based on natural breeding & evaluation were able to generate yeasts strains with improved ability to grow on xylose. The rate of improve in growth rate has been exponential.. In this work, it is assumed that bakers yeast is the base case. However, the effect of using micro-organisms that would partially ferment the xylose has been financially appraised.
Concentration of Ethanol Solution
Distillation followed by azeotropic distillation is the proposed method.
Wastewater Treatment
The treatment of liquid effluents resulting from the processing stages has been taken into consideration

3. Proposed Small-Scale Capacity

The proposed small-scale capacity that has been assumed in this work is 40 to t/d rice straw which is equivalent to about 12000 t/y. Rice straw has a typical composition of about 36 % cellulose, 25 % hemicellulose, 12 % lignin and 27 % ashes and others. Based on this composition and realistic conversion factors and yield, the annual quantity of ethanol obtained is as follows:
Scenario I: 4000 t/y ethanol on using strains that would ferment the C6 and C5 Sugars
Scenario II: 2800 t/y ethanol on using strains that could ferment C6 and partially C5

4. Simulation of Ethanol Production from Rice Straw

The appropriate type and size of the main equipment has been selected as depicted in Figures 2-4.

4.1 Cost Estimation

The capital costs have been estimated using ASPEN ICARUS for available equipment and local prices for other equipment as of 2008. Due to the possible variations in estimates five levels of the investment costs have been estimated in the range of about $5.3 millions for the Base Case up to about $8.3 millions. Operating costs have been estimated according to prevailing prices of raw materials, utilities and labour. Maintenance cost has been assumed to be 2% of the capital investment for the various cases. The revenues have been estimated based on a price of ethanol in the range of about $ 0.39 to $ 0.53 /kg ethanol. It is worth mentioning that there has been fluctuations in the price of ethanol over the last five years from as high as $0.62 to as low as $0.27/kg ethanol.

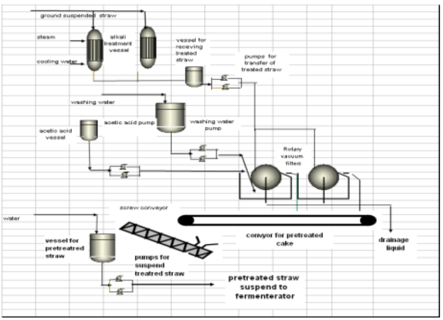

Figure 1: Rice Straw preparation and pre-treatment

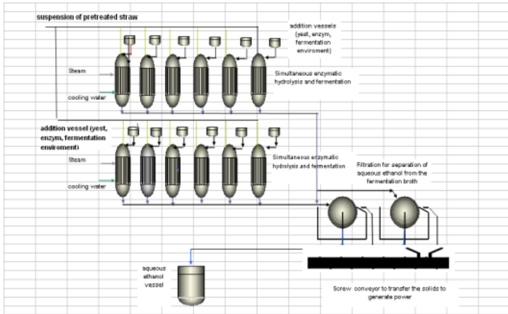

Figure 2: Simultaneous saccharification and fermentation

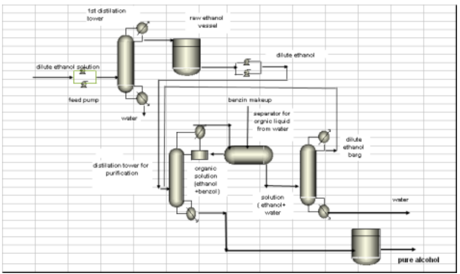

Figure 3: Azeotropic Distillation for concentration

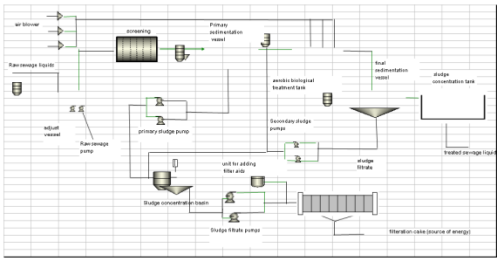

Figure 4: Wastewater treatment system

4.2 Economic Indicators

Based on the fore-mentioned estimates and using ASPEN ICARUS for financial analysis, economic indicators have been obtained. Results are depicted in the following:
Figures 5 and 6 include the economic indicators for the assumed cases of investment costs for the production of Scenario I: 4000 t/y and Scenario II: 2800 t/y ethanol. These include: Capital Costs, Annual Production Costs, Internal Rate of Return (IRR) % at the prevailing discount factor of 10 % and the Net present Value (NPV).

The IRR% is about 14 % for the pessimistic assumption of the capital cost and reaches about 19.1 % for the optimistic assumption of capital costs for Scenario I. The prices of ethanol that provides 10 % IRR ranges between $ 0.37 to 0.48/kg ethanol for the various assumptions of the capital costs. As for Scenario II, it is indicated that, at selling price 0.53 $/kg, the IRR % is below the prevailing discount factor. Hence the NPV is negative for the assumed capital costs. The situation is different for the assumed sales price of ethanol 0.71 $/kg. IRR exceeds 22 % for optimistic capital cost estimates. The prices of ethanol that provides 10 % IRR ranges between $ 0.37 to 0.68/kg ethanol for the three lower assumptions of the capital costs (Cases I-III).

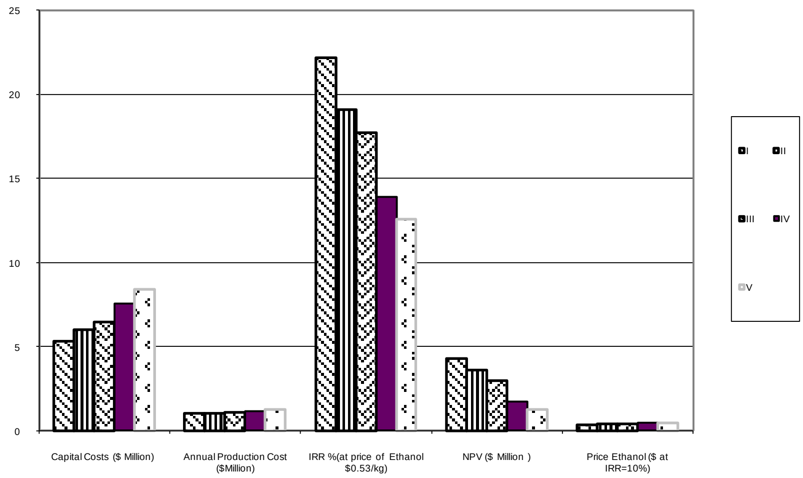

Figure 5: Economic Indicators for Production of 4000 n Ethanol/y

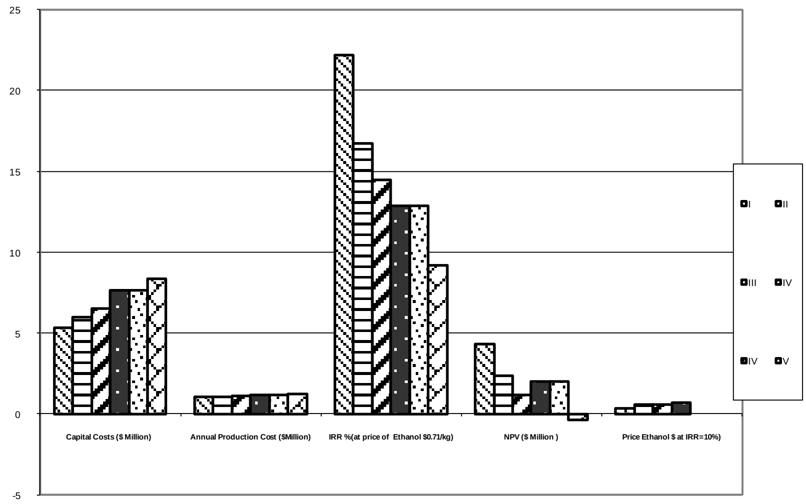

Figure 6: Economic Indicators for Production of 2800 t Ethanol/y

5. Conclusions

Small-scale ethanol production units from rice straw, as a typical ligno-cellulosic material that is currently an environmental nuisance, is technically and economically viable.

Acknowledgement

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