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Studies Concerning the Integrated use of Sweet Sorghum for Bioethanol Production in Romania

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Biomass can be considered as a strategic resource because it is not only renewable, but also available everywhere. It can provide products of vital interest to sectors of strong external dependence (i.e. transportation fuel, electricity, chemicals etc.), and also may raise benefits for the environment and for socio-economic development, particularly in rural areas.

Fuels derived from biomass are renewable and are sufficiently similar to fossil fuels to provide direct replacement. The primary ways of converting biomass into biofuels/energy are combustion, gasification, liquefaction, and biochemical processes. Biochemical processes convert biomass to liquid fuel (bioethanol, biodiesel) through a fermentation process.

One of the most tempting energy crops is the sweet sorghum, which can be grown in different climatic conditions, has been identified as the first promising crop having the potential to provide a wide spectrum of energy and industrial commodities that can match local market situations.
Sweet sorghum produces a very high yield in terms of grains, sugar, lignocellulosic biomass (on average a total of 30 dry t/ha per year) in low-quality soils, with much lower inputs of fertilizers and irrigation water than other crops (200 t water/dry t of crop, representing half of the water amount required by sugar beet and a third of the requirement for sugar cane or corn). The total yield of bioethanol can reach 5 m^3/ha per year. Plantations need less seed than for other crops: 15 kg/ha compared with 40 kg/ha for corn or 150 kg/ha for wheat.

It is expected that bioethanol from sweet sorghum can be co-produced in the EU (central and south-east regions) at a marginal cost of about 250 USD/m^3. The selling value of bioethanol produced in integrated complexes with sweet-sorghum plantations will depend the market value of the other co-products (heat, electricity, etc.) and possible support from investments that are sometimes available (e.g. structural funds, etc.) to create permanent jobs.

The paper presents a study of the technical and economic feasibility of an integrated plant using sweet sorghum as feedstock in Romania.

The integrated concept aims at producing bioethanol from sweet sorghum crops, green biomass (sweet sorghum), carbon dioxide, fertilizers, and power (heat and electricity), by combining agricultural activities, with biochemical and power generation activities.

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1. Introduction

During last decades, the increasing debate on climate issues, and the raise in the price of the oil barrel made the world to turn its attention to research on alternative/renewable energy resources, particularly on biofuels, derived from biomass/renewable resources.

Biomass is a strategic resource because it is not only renewable, but also available everywhere. It can provide products of vital interest to sectors of strong external dependence (i.e. transportation fuel, electricity, chemicals etc.), and also may raise benefits for the environment and for socio-economic development, particularly in rural areas.

Fuels derived from biomass, biofuels, are renewable and sufficiently similar to fossil fuels to provide their direct replacement. They offer potential for long-term, relatively cheap, secure energy supplies, and can contribute significantly less to greenhouse gas emissions in their production and use than fossil fuels.

Among biofuels, bioethanol, produced by fermentation from crops, is considered as carbon neutral, reducing net carbon emissions that would contribute to climate change.

2. Results and discussions

2.1 Romanian National Policy concerning Renewable Energy Sources (RES)

The Romanian National Policy concerning RES is set by several documents, as: the National Renewable Energy Action Plan, 2010; the Energy Roadmap for Romania, approved by the Government Decision (GD) 890/2003; the Strategy for Using Renewable Energy Sources, approved by GD 1535/2003; the National Development Plan 2007-2013 (NDP); GD 1844/2005 supplemented by GD 456/2007, stating the promotion of use of biofuels and other renewable fuels for transport; the Energy Strategy in Romania for the period 2007-2020, approved by GD 1069/2007 - by the end of 2020, the percentage of use of biofuels shall be of minimum 10%, provided that the new generations of biofuels are used; the National Strategy for sustainable development – Horizons 2013-2020-2030, approved by GD 1460/2008; the National Program for Rural Development 2007-2013 (NPRD) - Romania has the potential to produce approximately 2,000,000 t of bioethanol and 400,000 t of biodiesel by 2012, and has the potential to supply raw material both for biodiesel and for bioethanol so as the set targets to be achieved.

2.2 Sweet sorghum as raw material for bioethanol

The energy crops should meet some requirements, such as: perennial character, high biomass yield, high growth rate, with reduced input requirements, to be fully adapted to the geographic regions where will be planted, easy to manipulate via genetic improvement, non-invasive, tolerant to stress and with a good carbon sequestration rate (Jessup, 2009).

Nowadays, energy crops are mainly represented by perennial grasses as switchgrass (*Panicum virgatum L*.), energy cane (*Saccharum spp*), sweet and forage sorghum (*Sorghum bicolor*), miscanthus (*Miscanthus spp*.) as well as other short-rotation forest resources (willow –*Salix spp*- and poplar – *Populus spp*) (Jessup, 2009; McCutchen et al., 2008).

A promising crop for fuel is sorghum (*Sorghum bicolor (L.) Moench*) (Reddy et al., 2005; Zhang et al., 2010).

This is a high efficient photosynthetic crop that reached a worldwide production 56,000,000 t of grain in 2009 (FAOSTAT, 2011). About 30% of this production is harvested in North America, being used for feed.

Sorghum is a C4 plant, highly resistant to biotic and abiotic factors as insects, drought, salinity, and soil alkalinity. It has one of the best rates of carbon assimilation (50 g/m^2/d) which allows a fast growth and a better rate of net CO_2 use. Sorghum requires one third of the water required by sugar cane and 80 - 90% needed by corn (Almodares and Hadi, 2009; Wu et al., 2010), being considered as one of the most drought resistant crops. Furthermore, sorghum requires approximately one third of the fertilizer required by sugar cane (Kim & Day, 2011) and its growth cycle is between 3 to 5 months, allowing two or three crops per year instead of one commonly obtained with sugar cane.

Besides environmental advantages, sorghum is one of the more acquiescent plants to genetic modification because it is highly variable in terms of genetic resources and germplasm. This facilitates plant breeding and development of new cultivars adapted to different regions around the globe (Zhang et al., 2010).

The main product obtained from sweet sorghums is a sugar rich juice that is produced and accumulated in the stalks in a similar fashion as sugar cane, and is fermentable. The extracted sweet juice is mainly composed of sucrose, glucose, and fructose, and thus can be directly fermented into ethanol with efficiencies of more than 90% (Wu et al., 2010). Sorghum yields a better energy output/input ratio compared to other feedstock such as sugar cane, sugar beet, corn and wheat (Almodares and Hadi ,2009).

The mature stems of sweet sorghum contain about 73% moisture and 27% solids, consisting mainly in carbohydrates. About 13% of solids consist in sucrose, glucose and fructose. Sugars in sweet sorghum are very sensitive to microbial contamination especially after crushing stalks for juice production.
It is expected that bioethanol from sweet sorghum can be co-produced in the EU (central and south-east regions, including Romania) at a marginal cost of about \$250/m^3.

The selling value of bioethanol produced in integrated complexes with sweet-sorghum plantations will depend on the market value of the other co-products (heat, electricity, etc.) and possible support from investments that are sometimes available (e.g. from structural funds) to create permanent jobs.
Sweet sorghum hybrid used in our project is Fundulea F 135 – ST (INCDA Fundulea, Romania).

2.3 Sweet sorghum to energy through an integrated concept

Sweet sorghum is a perspective raw material for bioethanol. A juice with a high content of sucrose can be extracted from Sorghum stalks, while a high amount of starch can be obtained from its grains and an important source of lignocellulosic biomass is represented by sorghum bagasse (Cardona, 2007).
The main steps of the technology for ethanol production from sweet sorghum juice are the extraction of juice from sorghum stalks, fermentation of juice, and purification of the obtained bioethanol by distillation/dehydration

The production of ethanol from sorghum grain involves supplementary steps before fermentation, in order to isolate and hydrolyze the starch from grains, while the use of sorghum bagasse for ethanol production implies a pre-treatment acid hydrolysis step, in order to separate the cellulose (Almodares et al., 2009, Serna-Saldivar, 2010).

The concept for ethanol production from sweet sorghum in Romania consists in integrated obtaining of bioethanol, Dried Distillers Grains with Soluble (DDGS) (proteins), electrical power and thermal energy. The flowchart of this integrated concept is presented in Figure 1.

Table 1 shows the raw materials and energy consumption needed for obtaining 1 t of bioethanol.

Table 1: Materials and utilities specific consumption

INPUT	Unit	Quantity	OUTPUT	Unit	Quantity
Green biomass	t	28.5	Bioethanol	t	1
Stalks and leaves	t	20	CO_2	t	0.7
Juice (14-22 brix)	t	10	Fertilizer (liquid)	t	11.365
Syrup (50 brix)	t	4.015	Additional power	kWh	416.65
Process water	t	21	Hot water	t	0.7575
Power	kWh	447.5			
Steam	t	11.515			

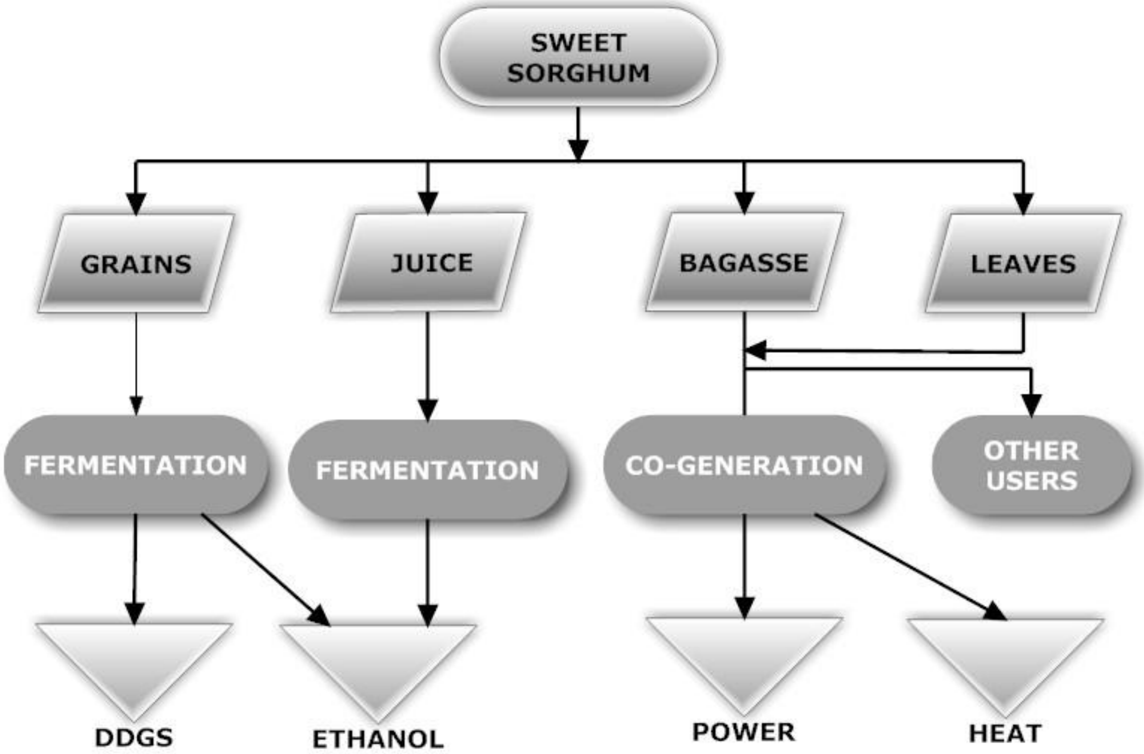

Figure 1: Flowchart of integrated ethanol production from sweet sorghum in Romania

Technology for ethanol production from sweet sorghum involves harvesting, transportation and storage of sorghum stems. Harvesting can be done mechanically or manually. The maximum recommended period for stem storage should be of two days.

The sorghum stems are then crushed and the juice is extracted, and concentrated by evaporation of water.

The concentrated juice produced as syrup is diluted, using effluent recycle from the distillation column and process water. The syrup is then subjected to a continuous fermentation process. The fermented mass is distilled and dehydrated on molecular sieves to obtain pure bioethanol (>99%).

The bagasse and the residual leaves are used in a co-generation process, in order to produce the electrical power and thermal energy needed to auto-maintain the process of integrated production of bioethanol from sweet sorghum and to raise its economic efficiency.

3. Conclusions

The feasibility of the use of sweet sorghum as a feedstock for integrated bioethanol production seems to be possible and advisable for countries like Romania, in order to help reducing the overall energy consumption and costs, while promoting rural development.

Because of sweet sorghum ability to sequester important amounts of CO_2, environmental advantages are also achievable. The crop residues (bagasse, leaves) can be used for thermal and electrical energy production, but also a feedstock for future lignocellulose ethanol production.

Integrated Sweet Sorghum ethanol production can lead to the achievement of important goals, such as production of renewable energy at competitive cost, both in the transport market (bio-ethanol from Sweet Sorghum sugar juice and grains), as well as in the power industry and heat market (from Sweet Sorghum bagasse); achievement of the EU Kyoto goals for greenhouse gas emission reduction; decrease the dependency of fossil energy resources; raising the competitiveness of agricultural and industrial SMEs; significant co-production of vegetal proteins (DDGS); creation of new permanent jobs in agriculture, as well as in industry; development and innovation of advanced and emerging technologies for integrated production of ethanol from sweet sorghum.

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