sweethanol

SUSTAINABLE ETHANOL FOR EU

## Diffusion of a sustainable EU model to produce 1st generation ethanol from sweet sorghum in decentralised plants

# Technical Manual

Supported by INTELLIGENT ENERGY EUROPE

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# Technical Manual

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## 2. FOREWORD

The bioethanol produced from sweet sorghum is sustainable in terms of environmental remarks and economic viability: the attributed GHGs emissions saving meets the European target to 2018 (i.e. higher than 60%) and the exploitation of by-products guarantees the economic viability also for decentralised small-medium plants (max 15,000 t/y).

In the current situation the EU bioethanol market is controlled by big industrial groups and large agricultural cooperatives of the sugar and alcohol industries and mainly cereals are processed in big plants (100,000-200,000 t/y). This situation is due to some relevant barriers: economic, logistical, ecological, environmental, social and dissemination barriers.

The SWEETHANOL project, supported by the Intelligent Energy program of the European Commission, is aimed to change the current situation concerning the raw material diversification, decentralisation and development of energy chain using sweet sorghum, which can be grown in the southern regions of the EU.

The absence of know-how about the potentialities of sweet sorghum as energy crop to produce sustainable bioethanol and other energy commodities in decentralised plants has been overcome through a widespread discussion of the main technical and non-technical aspects with the market players. Furthermore, this pathway is going to be completed through the training of stakeholders.

This technical manual follows the "*Sweethanol – Early manual*", where the background about the processing of sweet sorghum was implemented with the experiences of the visits in India, Spain and Peru.

The specific objective of this manual is to provide the stakeholders with the technical details, which are basic to implement feasibility studies and then to start up new entrepreneurships in the bioenergy sector using sweet sorghum.

At this aim the "*Sweethanol - Technical manual*" has been planned in order to highlight some general guidelines to use sweet sorghum as energy crop and to explain two chain models for supplying a decentralised plant with some case studies, contextualised in the different countries that are participating in the project (i.e. Italy, Greece, Spain).

The English version can be available for the not-participant countries where sweet sorghum can be grown (e.g. Romania, Bulgaria, France, Portugal, Croatia, Hungary) in order to increase the transferability of the project's outcomes in southern EU regions.

The text of the "Sweethanol – Technical manual" was produced by Michela Pin, Denis Picco and Alessia Vecchiet (CETA – Centre for theoretical and applied ecology, Italy), Oscar León, Paloma Gonzàlez, Roberto Marcos and Anabel Elisa Ruiz (Foundation Cartif – Technological centre, Spain), Kostas Konstantinou, Iakovos Sarigiannis, Irene Tsakiridou, Nikos Remvos (REACM – Regional energy agency of Central Macedonia – Anatoliki S.A., Greece), Luca D'Apote and Luisa Daidone (INIPA – Coldiretti, Italy), Marina Sanz Gallego, Maria Hernando Sanz and

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## 3. LIST OF ACRONYMS AND ABBREVIATIONS

**AEBIOM** European association of biomass

**Bio-ETBE** ethyl-ter-butyl-ether obtained from bioethanol

**CAICYT** advisory committee on scientific and technical research (Spain)

**$CH_4$** methane

**CHP** combined heat and power production

**CO** carbon monoxide

**$CO_2$** carbon dioxide

**COD** chemical oxygen demand

**CRA-CIN** council for the research and experimentation in agriculture – research centre for the industrial crops (Italy)

**CRA-ING** council for the research and experimentation in agriculture – research unit for the agricultural engineering (Italy)

**CRA-RPS** council for the research and experimentation in agriculture – research centre for the study of the relationship between plant and soil (Italy)

**Crpa S.p.A.** research centre for animal production (Italy)

**db** dry basis

**DDG** distillers dried grains

**DDGS** distillers dried grains with solubles

**DPI** integrated production specifications

**E100** bioethanol 100 %

**EC** European commission

**E85** bioethanol 85% blend

**ENEA** national agency for the new technologies, energy and sustainable economic development (Italy)

**FYROM** Former Yugoslav Republic of Macedonia

**FIT** feed in tariff

**FP** framework programme

**FFV** flexible fuel vehicles

**GHGs** green house gases

**$H_2S$** hydrogen sulphide

**HHST** higher-heat shorter time

**HRT** hydraulic retention time

**HTST** high temperature short time pasteurisation

**IEE** intelligent energy europe programme

**INIA** research and technology national agriculture and food (Spain)

**IRR** internal rate of return

**LCA** life cycle assessment

**LHV** low heating value

**LUC** land use change

**MIPAAF** Italian Ministry of agriculture and forestry

**MON** motor octane number

**MSE** Italian Ministry for economic development

**MSW** municipal solid wastes

**MTBE** methyl-ter-butyl-ether

**$N_2$** molecular nitrogen

**$NO_x$** nitrogen oxides

**$O_2$** molecular oxygen

**ORC** organic Rankine cycle

**O&M** operative and maintenance

**R&D** research and development

**RED** renewable energy directive, 2009/28/EC

**RES** renewable energy sources

**rpm** revolutions per minute

**RON** research octane number

**RUE** radiation use efficiency

**SMEs** small medium enterprises

**toe** tons of oil equivalent

**TRPF** toothed roller pressure feeder

**UP** ultra pasteurisation

**US** United States

**VOC** volatile organic compounds

**v/v** volume/volume

**wb** wet basis

**w/w** weight/weight

**WUE** water use efficiency

# 4. SWEETHANOL PROJECT

SWEETHANOL is a project financed and supported by the European Commission in the ambit of the program IEE-II 2009 (Intelligent Energy Europe), action "ALTENER" – New and Renewable Energies sources.

It is a project related to the diffusion of a sustainable EU model to produce bioethanol and other energy commodities from sweet sorghum in decentralised plants. The project is organised in the following actions:
- know-how refining about the bioethanol production from sweet sorghum. The more interesting data (e.g. investment costs, energy consumption, production costs, bioethanol yield, by-products exploitation) are collected visiting the agricultural research institutes, the plant construction companies and the existing plants;
- sustainable model discussion of the EU model with representatives of each chain player. The chain players (i.e. farmers, agricultural associations, fuel processors, SMEs, seeds and agricultural companies, investors, policy makers and public authorities representatives, energy agencies) are engaged in an EU model discussion through sectorial and intersectorial workshops at national and international level;
- chain actors training through tailor-made courses per categories of chain actor;
- creation and management of the online community (i.e. "*Esse community*", link: http://esse-community.eu/), a virtual place where all the chain actors may create the network in order to share and gather information about the sweet sorghum bioethanol chain: articles, info about events, blog, forum, social network, teleconferences and reputation management are performed.

The project covers the following priority activities:
- encouraging market players in the bioethanol supply chain to increase the economic competitiveness and environmental sustainability of the biofuel itself;
- supporting and promoting the application of sustainability criteria for bioethanol;
- addressing the issues under discussion in the current debates on land use and sustainability;
- facilitating and promoting the well-informed debate and the balanced attitude among decision makers and the general public.

The main objectives of the project are:

- *know-how diffusion about the sustainable EU model*
The sustainable EU model is shared among the chain actors which accept it through the discussion of the technical, logistic, economic, financial, energetic, environmental and administrative aspects and it will be widely spread by each target group. Consequently, as market players, they are encouraged to start up new entrepreneurships to increase the economic competitiveness and at the same time the environmental sustainability of bioethanol. The changes in the bioethanol market are the enhanced raw material diversification, decentralisation of the production and sustainability of bioethanol (mainly as GHGs saving). The proposed wide discussion about the production of bioethanol using sweet sorghum contributes to address the current debates on land use and sustainability

and to facilitate and promote a well-informed discussion and a balanced attitude amongst decision makers and the general public

- *daily updating through the network building and the supply chain co-ordination*
Through the "*Esse Community*" the market players are able to count on daily updating of the legislative, administrative and technical aspects related to the bioethanol production and market (in general, and specifically using sweet sorghum). The daily offered updated service simplifies the market analysis necessary for the start up of new entrepreneurship; consequently the diversification of the bioethanol market is stimulated and the market centralisation among few numbers of chain actors is contrasted. Moreover, the network building contributes to address the issues under discussion in the current debates on land use and sustainability and to facilitate and promote a well-informed debate and a balanced attitude amongst decision makers and the general public.

## 5. SWEETHANOL PARTNERSHIP

***CETA – Centre for theoretical and applied ecology - Italy***

CETA was created in 1987 in Gorizia (Italy) and is a non-profit association which carries out research, applied experimentation and innovative technology development in four areas: environment such as sustainable management of environmental and natural resources (water, soil, landscape) and environmental balances and models of environmental accounting; energy such as promotion and diffusion of renewable energy technologies (biomass, biogas, biofuels, solar energy – photovoltaic, geothermal, hydroelectric), energy efficiency, energy planning, analysis and models of territory management, costs-benefits and multi-criteria analyses; territory such as strategic planning and programming, government of the territory (large area and local level), studies of environmental impact and strategic environmental assessment, and knowledge such as experimentation of production and innovation models for fuel biomasses and biofuels of 2$^{nd}$ and 3$^{rd}$ generation, research and development of energy crops with low environmental impact for energy production. CETA carries out its own multidisciplinary activities employing high-degree professionals such as engineers, agronomists, biologists, naturalists, economists, architects.

***Foundation CARTIF – Technological centre - Spain***

CARTIF was created in 1994 as the Automation, Robotics, Information and Manufacturing Technology Centre, a non-profit association focused on applied research and based in Boecillo Technology Park, Valladolid (Spain). From October 2005, CARTIF is legally established as a Foundation keeping its main goals: identifying technology needs and developing R&D-based knowledge, supporting technological innovation in Industry mainly among SMEs and disseminating R&D and innovation results.

***REACM– Regional energy agency of Central Macedonia – Anatoliki S.A. - Greece***

Region of Central Macedonia and Local Development Agency - Anatoliki S.A. established REACM in 1997, through the European Union's SAVE programme. The main activities include: data acquisition for energy production and consumption in the region, support to the region's local authorities in energy policy planning, dissemination activities for RES and RUE technologies, training and education, mobility management on municipal level, promotion of biofuels, support to local industry, SMEs & commercial, pilot application of EMAS in heavy industries in Thessaloniki, training of personnel in industrial sector in ECO-Energy audits, promotion of RES technologies to the agricultural sector, definition of REP, collaboration with neighbouring countries in energy savings, participation in regional planning for development and management of geothermal fields.

***INIPA- Coldiretti - Italy***

INIPA is the research, training and development National Department for agri-food, environmental and services sectors of Coldiretti (The National Confederation of Farmers - Italy), and it is a legally recognized non-profit organization. It is a unitary structure distributed throughout the country, with associated institutes at regional level and territorial divisions. INIPA promotes, organizes and participates (in partnership with leading agencies at both National and European Community level) in research, scientific information and training for farmers, organizations and territories pointing out the results in favour of the continuous innovation of the agri-food system.

### *ADABE – Association for the diffusion of biomass - Spain*

ADABE is a national association, no-profit, founded in 1986 according to the Directorate General of Domestic Policy of the Ministry of Interior. It is a founding member of AEBIOM based in Brussels, founded in 1990. It brings together individuals and entities involved in research, technology and/or dissemination of the use of biomass in Spain.

### *Agricultural co-operative of Halastra - Greece*

The major activities of the agricultural co-operative of Halastra include: services related to agricultural products (e.g. rice, corn, cotton, wheat, cereals), collection, drying and storage of agricultural products, sale of agricultural supplies, sale of agricultural products on behalf of the members of the association, retail of agricultural goods, rice packaging and trade.

# 6. SWEET SORGHUM AS ENERGY CROP

## 6.1 Why sweet sorghum?[1,2,3,4,5,6,7]

The common name of "Sorghum" is applied to a wide range of genotypes, mainly from *Sorghum bicolor* (L.) Moench species, within the gramineous family (*Poaceae)*. Under this name, five groups of varieties are recognized:

A. grain sorghums. Usually dwarf varieties – 50-80 cm high –, which are grown for grain. Grain sorghum is the 4th most important cereal crop in the world after wheat, rice and maize;
B. forage (or fodder) sorghums. Varieties used primarily as silage for livestock due to their high protein and fiber content;
C. fiber sorghums. Tall, fine stemmed and rich in cellulose and hemicellulose varieties;
D. broom sorghums. Varieties that exhibit inflorescences with long and elastic branches, mainly used for brooms;
E. sweet sorghums. Varieties with thick and long stalks and high content of sugars in the stem, mainly sucrose, which are easily fermentable into ethanol.

All these sorghums share to a certain extent some physiologic characteristics as high photosynthetic rate or sensibility to photoperiod and temperature, and some morphologic characteristics as the common size of big grasses of the tropical origin. However, sweet sorghum, as commented, stands out because of a physiologic characteristic: its high capacity to accumulate sugars (non structural carbohydrates) in the stem. Therefore, in order to avoid any confusion, it is advisable to use the name sweet sorghum and not only sorghum for those varieties that accumulate sugars easily fermentable in the stems and consequently which are interesting for the production of bioethanol like other sucrose-containing feedstock (e.g. sugarcane, sugar beet).

Sweet sorghum is a $C_4$ pathway crop. Among other particularities, $C_4$ plants have a characteristic leaf anatomy, called "Kranz anatomy", which gives special separation between the photosynthetic $CO_2$ fixation and the synthesis of assimilates - compounds produced by plants as a result of the photosynthesis and responsible for plant growth. This compartmentalization allows a higher solar radiation use and high photosynthetic efficiency of sorghum comparing to $C_3$ crops, more common in temperate regions of the world. Photosynthetic assimilation rate is especially remarkable in conditions of high solar radiation and water availability. Studies on the RUE of sweet sorghum conducted in South Europe have shown high values of RUE, explaining the high productivity of this crop when is grown in favourable conditions (temperature, solar radiation and water supply). Values between 3.10 in France and 4.96 in Spain have been reported.

Biomass yield of sweet sorghum ranges 40–110 tons of fresh matter per hectare per year. Dry matter content is 19-30% depending on the variety, crop conditions and harvesting date. At the end of the cycle stalks usually represent more than 75% of the final weight of the harvested biomass (on dry weight), although these values can be variable depending on the variety and can reach the 90%.

The sugars accumulated in the stalks of sweet sorghum are water soluble sugars easily fermentable, mainly sucrose and a certain amount of glucose and fructose. Juice concentration in the stems is 65–80%. Sugar content in the juice of the stems is 9–15%. Sugar content in the fresh stem is 7.9–12.0%. At the harvesting date, sugar concentration in the stalks (on dry weight) may range between 20–45% (mostly is sucrose) depending on the cycle length.

Biomass yields of sweet sorghum, grown in non-limiting water conditions in mild Mediterranean climates, are included between 25–35 t db/ha. Assuming 75-85% wb stalk proportion, 40% sugar content and 0.591 litres of ethanol/kg sugar as conversion factor, the bioethanol production using sweet sorghum could reach 4,400–7,000 l/ha.

Sweet sorghum can be grown in a very wide range of soils and climates (tropical, sub-tropical and temperate regions). Although best yields are obtained from fertile, deep and well drained soils, it could be cultivated in worse soil conditions, shallowness or in soils with low organic matter content. pH range of soils where sorghum can grow well is also wide (5.0–8.5). Sweet sorghum is drought resistant (it has good water stress resistance) if compared to other tropical crops, it is water-lodging tolerant and shows a good adaptability to saline and alkaline soils. This wide adaptability allows sweet sorghum to be grown where other crops could not be cultivated.

As regards to the water requirements, under Mediterranean conditions, sweet sorghum needs to be irrigated, but its water use efficiency is very high. Values between 3.7 and 5.4 g aerial biomass (db) per litre of water were reported for Spain. Sweet sorghum shows a higher drought resistance than maize or sugarcane (low evapotranspiration and the ability to stop transpiration if water is limited) and thus it requires less water per unit of ethanol produced. The quantity of water needed by sweet sorghum is only 1/3 of that required by sugarcane and almost 2/3 of sugar beet needs. Furthermore, sweet sorghum has relatively lower nitrogen needs than other crops.

Sweet sorghum is easily grown from seeds (3.0–6.0 kg seeds/ha), which allow an easy mechanization. This is an advantage if compared to sugarcane, which is propagated from stem cuttings (i.e. ratoons, in the range of 4,500–6,000 kg/ha). Furthermore, its production can be completely mechanized, although the easily fermentable sugars may generate some trouble in the post-harvesting period: processing operations need to be performed in a short period of time after harvesting to prevent sugar losses. Some solutions to solve this drawback are being studied: scheduling the harvest using varieties of different cycle length (short, medium and long cycle), concentrating the juice, improving ensilage conditions.

Another favourable characteristic of sweet sorghum is that it is an annual crop, and due to its short growth cycle (4 to 6 months) rotational cropping or double cropping systems are possible under certain climate conditions: in fact, in adequate tropical or sub-tropical conditions can be grown twice per year, increasing its profitability. Chosen properly, this feature could be positive for the agro-diversity, due to increase the period of soil coverage which reduces erosion and can preserve soil organic matter.

Sweet sorghum has different by-products that can be exploited with energy purposes. Some varieties produce also grains that can be converted into first generation bioethanol (there is starch in the grain). Bagasse (stem residues originated after juice extraction) can be used in two ways: they can be converted into second generation bioethanol or can be used to generate heat or electricity during the bioethanol process, the same that is currently done with sugarcane. Therefore, sweet sorghum could be used for first and second generation biofuel production at the same time. Leaves and also bagasse could be used as forage too.

To sum up, sweet sorghum has been chosen as interesting feedstock for bioethanol production mainly because of its high biomass yield, its high fermentable sugar content, its adaptability to a wide soil range and environments, its water requirements (lower than other irrigated crops as maize or sugarcane), its drought resistance, its well-known mechanization, and the easy valorisation of the bagasse, by-product that can be also used for energy purposes.

## 6.2 Botanical description[8,9,10,11,12,13]

Systematic

Division: *Magnoliophyta*

Class: *Liliopsida*

Subclass: *Commelinidae*

Order: *Cyperales*

Family: *Poaceae*

Tribe: *Andropogoneae*

Subtribe: *Sorghinae*

Genus: *Sorghum* Moench

Species: *Sorghum bicolor* (L.) Moench

Subspecies: *Sorghum bicolor* subsp. *bicolor*

All sorghums identified botanically as *Sorghum bicolor* subsp. *bicolor* have 2n = 20 chromosomes.

Commercial varieties of *Sorghum bicolor* (L.) Moench are categorized into the following agronomic types: grain sorghum, fiber sorghum, forage (or fodder) sorghum, broomcorn and sweet sorghum. The agronomic orientation of the variety depends on its phenotypic characteristics.

*Sorghum bicolor* origin is supposed from rain-fed lands between Ethiopia and Sudan (Africa) and its domestication occurred probably around the years 4,000-3,000 BC. It was introduced in India (~ 1,500-1,000 BC), Middle East (~ 900-700 BC) and Far East (~ 400 BC). American introduction was more recent (~ 1850 AD).

Morphology

Sweet sorghum is an annual herbaceous species and, depending on the varieties, with a high ratoon capacity.


Figure 1: comparison between 2 varieties of sweet sorghum (source: CETA)


Figure 2: seeds of sweet sorghum (source: CETA)

### *Stalks*

Sorghum stems are usually solid like in sugarcane; this feature is an exception to the grass family. Stems are made up of a variable number of alternating nodes and internodes. The height ranges from 0.5 to 5.0 m and the width at the stalk base from 1.5 to 5.0 cm of diameter.

Regarding the cross-section structure, the stem consists of an external crown with numerous vascular bundles, densely arranged. Inside this crown there is a soft pith dominated by parenchyma tissue, where some scattered bundles appear. Most of the sugar, mainly sucrose, is accumulated in this pith.

One leaf arises from each node, which has a groove where the leaf grows. In this groove there is an axillary bud. All of the axillary buds are dormant except some of the lowest nodes of the stem, where tillers may grow from these axillary buds.

Either varietal characteristics or some cultivating conditions like plant arrangement and climate conditions (i.e. photoperiod and temperature) have a remarkable influence in sorghum tillering capacity.

### *Leaves*

Sweet sorghum usually develops from 7 to 24 opposite-decussate leaves along the stem, depending on the variety, the latitude and the final degree of development that the stem could reach. There is usually one leaf per node.

Leaves are bright green, parallel-veined, have a long sheath that embraces the stalk and a leaf-blade whose length is 30 to 135 cm and width is 1.5 to 13.0 cm. Leaf-blade is flat, although in water stress conditions can longitudinally roll up, as it happens in maize. Stomata can be found on both sides of the leaf.

### *Inflorescence*

Inflorescences are grouped in a panicle, which is usually apical. Its length is variable and when the inflorescence is well developed can reach 60 cm (peduncle included).

The inflorescence consists of several branches that at the end support some pedicellate and sessile spikelets, which have two sterile florets being only fertile the upper one. Each floret has three stamens and a single ovary with two styles with feathery stigmas.

### *Fruit*

It is caryopsis with a roughly rounded shape and differently coloured, depending on the variety. Sweet sorghum fruits are usually smaller than the grain sorghum ones. The weight of one thousand seeds is about 21g, varying between 16-28 g.

### *Root system*

Root system is adventitious with fibrous and branched roots and can extend up to 1.5 m while the primary root, as same as other plants from the grass family, has early senescence and is substituted by roots originated in the underground part of the stem. Moreover, sweet sorghum develops brace roots at the lowermost nodes in a similar way of maize, that help to support the stem.

Biological characteristics

Development stage: spring-summer in temperate climates. Development cycle lasts about 4 months, from May to September, depending on location and variety. The maximum growing rate stage (elongation stage) must be coincident with the maximum solar radiation period. Sweet sorghum has a very quick development cycle.

Main phenological stages: emergence, tillering, elongation, panicle emergence, flowering, maturity. If it is sown in spring, when temperature is mid, generally will emerge in 7-10 days. The duration from emergence to tillering is about 30-40 days, and from emergence to elongation, 47-55 days. Elongation stage depends on the variety and corresponds to 30-90 days. Flowering usually happens 5-7 days after panicle emergence. Maturity stage is also very variable, depending on the variety, but the common period is 30 days.

**Figure 3: sweet sorghum Sugargraze variety (source: CETA)**

Sugar accumulation: there is a correlation between maturity degree and sugar content in sorghum stems. Variety choice, sowing date and growing conditions are the main factors to optimize sugar accumulation. Maximum accumulation happens after panicle appearing, especially after flowering. In areas where the temperature in September is low, the development of sorghum is early interrupted and sugar accumulation is stopped. Sugars stored in stalks are glucose, fructose and mainly sucrose. The more mature is sorghum, the higher the sucrose content and the lower the glucose and fructose content.

## 6.3 Technologies in cultivation and harvesting[14,15,16,17,18,19,20]

Sweet sorghum is tolerant to drought and different soil conditions; varieties exhibit different response to photoperiod; there is a wide range of genotype diversification that allows adaptation for different growth lengths. Because of that, sweet sorghum can grow in a wide range of agricultural environments.

### 6.3.1 Soil preparation

Adequate seedbed preparation is needed to facilitate the emergence of plantlets and to remove weeds. Soil must be ploughed and finely harrowed for sowing. Compaction should be prevented.

It is also recommended to apply an herbicide (e.g. Gliphosate) to control weeds.

Soil preparation shall be made taking into account the irrigation system that will be available for the crop. Sorghum has a good response to furrow irrigation, which prevents lodging; in this case ridges would have to be made at the step of soil preparation. In case of sprinkler or drip irrigation, land surface is levelled or maintained flat.

### 6.3.2 Fertilization

The dose of fertilisation depends on soil fertility and wanted productivity. In Mediterranean climates, where soil fertility ranges from low to moderate, the fertilisation needs are about: 100-150 kg N, 60-100 kg $P_2O_5$ and 60-100 kg $K_2O$ per hectare. It is recommended a nitrogen application done in two times: before sowing and 20-30 days after the emergence.

### 6.3.3 Sowing

Temperatures should be higher than 10-12 °C for sorghum germination and there must not be any frost risk. Preferable soil moisture is the field capacity. Taking into account the cycle length and the fact that the stage of sugar accumulation is affected by low temperatures, in the Mediterranean climates sowing should be performed at the beginning of May so that sorghum can be able to complete its cycle. Sowing is usually performed in rows 0.75 m apart with a distance of 0.10-0.15 m in the row; ≥5 cm depth should be kept. The dose of sowing depends on the variety and seeds germination capacity; the specific weight usually ranges from 30 to 70 seeds/g. A germination test prior to sowing is recommended. After sowing it is essential to maintain good soil moisture conditions to ensure the emergence.

The election of the variety is extremely important to obtain good crop yields. Long cycle varieties are usually more productive than the short cycle ones. However, in some locations long cycle varieties are not advisable because temperatures should be warm during the whole cycle to express its potential. In Mediterranean climates this condition means that the temperature must be mild or warm in September.

- Short cycle varieties: cycle length of this type of varieties is about 70 to 90 days from emergence to flowering in Mediterranean climates. For instance, the varieties named Mer 60-2, Mer 78-13, Soave, Atlas, Madhura.
- Long cycle varieties: they may need about 110 days from emergence to flowering. For instance, the varieties named Keller, Dale, Wray.

**Figure 4: sowing of sweet sorghum in the Po Valley, Italy (source: CETA)**

### 6.3.4 Irrigation

Like for any other irrigated crop, the irrigation requirements of sweet sorghum depend on the site (i.e. water balance is affected by the temperature and rainfall regimes of the site) and the irrigation system used for the crop. Besides, there is the intrinsic factor of the variety requirements. Generally they may range between 500 and 1,000 mm.

For several varieties of sweet sorghum and within a compatible water availability range, the water use efficiency of the crop decreases at higher water regimes. Values of 3.7-6.1 kg db/$m^3$ evapotranspired water have been reported for the water use efficiency of Keller variety grown in the centre of Spain.

Sweet sorghum can grow in conditions of some water stress but yields are affected. In Mediterranean conditions, where water shortage is a fact during summer, a compromise between irrigation dose and expected yield should be reached.

### 6.3.5 Crop protection

Since the earliest stages of the crop, namely from sowing to canopy closure (approximately when the crop is 1m high), sorghum is very sensitive to weed competition. Consequently land must be carefully prepared before sowing with the objective of eliminating weeds. It is also useful to apply a herbicide before land preparation. Anyway, herbicide must be always applied in pre-emergence, immediately after sowing, because sorghum germination is very fast and the crop could be affected if the herbicide is applied late.

Pests and diseases are similar to corn and sugarcane in those areas where both are extensively cultivated, like in the South of the US. In places where those crops are not spread, no problems should arise. For instance, no pests or diseases have been observed in experiences carried out in central Spain, occasionally the presence of borers.

**Figure 5: sweet sorghum crop 1 month after sowing (source: CETA)**

The main abiotic damages that sweet sorghum could suffer are cold and lodging.

1. Cold. Adequate selection of varieties (cycle length) and sowing date are necessary to prevent cold damages.
2. Lodging. Adequate selection of varieties (plant height, stalk diameter, canopy density) is essential as well as the nitrogen fertilisation rate and harvesting date.
3. Setting. In places where damages by wind are possible, shorter varieties with low lodging tendency and low nitrogen rates are recommended. In addition, in order to avoid wind risks during autumn season it is better to harvest as soon as possible.

**Figure 6: sweet sorghum crop 2 months after sowing (source: CETA)**

### 6.3.6 Harvest

Harvest should be undertaken when biomass and sugar accumulation reaches its peak. The optimum harvest time is usually after panicle development since the highest sugar concentration happens after flowering. Obviously the date depends on the variety and the climate conditions. Whenever possible, frequent determination of sugar concentration in the stems is recommended after flowering, at least the first year of the variety growing, in order to determine its performance.

Sweet sorghum harvest is finalised to the recovery of all sugars which are concentrated most of all in the stalks. Therefore the way in which harvest is performed is by cutting the stems at their base; for bioethanol purposes, sorghum leaves are rejected.

There are a number of studies about the mechanization of sweet sorghum harvest. Some of the machinery used are: sugarcane combines, harvesters that cut and bale the stems, forage choppers and some prototypes. In the US, forage corn harvesters are recommended but the produced crop must be immediately delivered to the bioethanol plant for its processing. This is a convenient method because conventional machinery is used and thus, operation costs are cheaper. The main drawback is the high risk of sugar losses (juice loss and sucrose instability).


**Figure 7: mower-shredder-loader machine (source: CETA)**

**Figure 8: harvesting of sweet sorghum with mower-shredder-loader machine (source: CETA)**

### 6.3.7 Post- Harvesting

In spite of the fact that sweet sorghum is an interesting crop for bioethanol even in temperate climates, little progress has been made on the penetration of this crop. This happens, most of all, because the period of time comprised between harvesting and the processing phase is too short. Moisture content at harvest is very high (70-80%) and temperatures at harvest time are mild. Subsequently to mowing or chopping, juice losses happen. Moreover, sugar degradation (unwanted fermentations) is fast triggered because high biomass moisture is jointed to a high concentration in easily fermentable sugars. To prevent fermentations sweet sorghum must be harvested quickly and the produced crop must be immediately processed in the plant. In temperate climates (e.g. Mediterranean climates) the harvesting period is reduced by the fact that if the harvest is delayed the climate conditions become bad for this crop and damages by lodging, cold or sugar losses may happen. In other words, the problem is the impact of the high seasonality of this crop in the production and in the industrial process.

To prevent the above mentioned problems several measures have been suggested. One is to grow varieties of different cycle length (short to long cycle varieties) or to combine several sugar crops which help to make longer the harvesting and processing period. Another measure is to extract and preserve the stalk juice or sugars from fermentation. Additionally, it is recommended to use bagasse for further processing as feedstock for bioethanol production.

**Figure 9: chopped sweet sorghum (source: CETA)**

## 6.4 Breeding programs[21,22,23,24]

Sweet sorghum has been studied as an alternative crop for sugars/ethanol in temperate regions since the end of the nineteenth century. Breeding programs aim at the production of crystallized sugars and syrup, the improvement of the carbohydrate yields and also the prevention of leaf anthracnose and stalk red rot. Several attributes of sweet sorghum as juice extraction percentage, °Brix value, non-reducing sugars, total sugars and inversion enzyme activity are being studied nowadays. Presently sweet sorghum breeding activities are being carried out in the European SWEETFUEL project, supported by the European Commission (7$^{th}$ FP).

### 6.4.1 Breeding for temperature environments

Temperature is associated to the emerging and flowering period and it is also related to stalk production and sugar content. Sweet sorghum grows with high radiation and it is adapted to southern European climates but its growth is limited in North and Central Europe because of low temperatures, which affect the biomass yield. The main objective of this project is sweet sorghum adaptation to low temperatures. Biomass yield, tolerance to cold, fast and homogeneous germination, and disease resistance are pursued. Breeding and varietal testing is being carried out in European countries involved in the SWEETFUEL project: Germany, Italy and France.

#### 6.4.2 Breeding for drought prone environments

One of the main limiting factors for this crop is its water requirements, in spite of the fact that they are lower than sugarcane ones. Sweet sorghum may have a double purpose: grain and sugars, with a good drought adaptation, juicy stalks with sugar content and good digestibility. The breeding program objectives, also in the SWEETFUEL project, are the improvement of the juice in the stems, avoiding drought effects even if increasing sugar content. These activities are being carried out in India, Mexico and South Africa.

#### 6.4.3 Breeding for low fertility soil environments

Sorghum is a suitable crop for areas located in semi-arid to semi-humid climate regions of subtropical and tropical latitudes, as moist savannas. Soil acidity and aluminium toxicity are important existing constraints in these areas. Breeding programs are mainly lead to improve genetic tolerance to these restrictions that could allow to obtain higher biomass yields and higher stalks juice and sugar content. These objectives are also included in the SWEETFUEL project; experiences are being performed in countries such as Brazil or South Africa.

### 6.5. EU experiences on sweet sorghum cultivation

#### Italy[25,26,27,28,29,30,31,32,33,34,35,36]

Although in March 2011 the Italian law has acknowledged the Directives 2009/28/CE and 2009/29/CE (Legislative Decree n°28/2011), the national bioethanol production did not increase in the last year. The only existing plants are producing bioethanol using exhausted marcs and grapes from the distilleries of the wine industry or residues of the fruit juice production. Their capacities are still very small and consequently the national demand of bioethanol is covered mainly with the importations, in order of importance from Pakistan, Turkey and Brazil.

As regards with bioethanol crops, in Italy there is a long tradition in the agricultural researches about sorghum as alcoholic crop since the early 1930's due to the autarkic policies of that time. The knowledge of the crop and availability of the sweet sorghum varieties have had a development thanks to the studies and researches aimed to the genetic improvement. In fact, in absence of a world trade the natural hybridization made in the late 1930's and afterwards the breeding between the superior lines followed by the selection of segregating generations have been the only systems to obtain in Italy the sweet sorghum varieties.

Since the end of 1980's further studies and field trials with this crop have been done by A.Biotec. Starting from the fact that the commercial varieties, selected mainly in the US in very different conditions respect to those of Italy showed a not perfect adaptability, the researches were focused on the genetic improvement of these species with the objective of developing hybrids with high sugar content, suitable for pedoclimatic areas of the central and northern regions of Italy. The varietals trials carried out during all the 1990's allowed to obtain a high number of hybrids with high sugar content, and other with high yield in grain or fiber. One of the hybrid breeding (e.g. LP 34 M x LP 113) has shown of being very superior if compared to the better sugar varieties used as test, with a yield of 44 t/ha of dry matter. Pluriennial trials made by A.Biotec in different areas in the North Italy shown that some varieties (e.g. Wray, Dale, Keller, Mn 1500, M 81-E, Theis and Rio) gave production of stems between 55 and 70 t/ha wb and productions of fermentable sugars of 6-8 t/ha. The better varieties were the later because they had the capacity of exploiting a longer vegetative period. Nevertheless these varieties cultivated in the environments of southern regions of Italy, shown an instability of the production caused by a high sensibility for the low temperatures of Italian spring, a high predisposition to the lodging and a high tardiness that sometimes did not allow the harvesting.

Since the 1990's, ETA-Renewable Energy has coordinated some studies to apply sweet sorghum in the feed and energy chains under the typical Mediterranean climate of South Italy (i.e. Metaponto, Matera). In the framework of the ECHI-T project supported by the EC (i.e. 5thFP) the integrated production of electricity, bioethanol and pellets for animal feeds from sweet sorghum has been investigated at level of pre-feasibility study. Concerning the agricultural aspects, the relationship between water use, light interception and dry matter production were analysed in an environment characterised by clay and deep soil, high temperatures and elevated evaporative demand of the atmosphere. Sweet sorghum provided high values of WUE and RUE (4.8 kg/mm and 3.3 g/MJ, respectively) and the comparison between these parameters allowed to evaluate the crop capacity to utilise the water and energetic resources of the environment. The research showed, besides, that high irrigation regimes are necessary in this type of environment to obtain a satisfactory productive level. Furthermore during the same trials the salinity tolerance of sweet sorghum has been confirmed. In hilly environment or unfavourable ones in relation to the water availability, choosing precocious hybrids with short crop cycle resulted preferable. The most favourable period for cultivation in South Italy is half April-beginning of May, with the harvesting at half August-half September. The obtained crop yields are 35-40 t/ha with good water support and 20-25 t/ha with low water support.

Since the same period sweet sorghum has been also studied in Italy by other important research groups, such as the University of Catania, the University of Bologna and ENEA. These studies have been carried out through international and national collaborations like "Sweet Sorghum Network - JOUB 0036", "Sweet sorghum, a sustainable crop for energy production in Europe: agricultural, industrial improvement, optimisation and implementation - AIR CT92 0041", "Environmental studies on sweet and fiber sorghum, sustainable crops for biomass and energy - FAIR CT96 1913" and "Innovative sustainable techniques for the production and transformation of energy crops and non-food - TISEN". These researches have been focused on the response of sweet sorghum to environmental factors and to crop husbandry; moreover, different nutritional studies with particular focus on nitrogen and crop efficiency in the use of water resources, have been carried out too.

In the last years the results of these researches have been applied mainly for the production of animal feed (i.e. forage and grain varieties) and more recently also for the production of biogas through the anaerobic digestion with other organic substrates (e.g. manure).

As regards with the application in the biogas production, the studies of Crpa S.p.A. have evidenced that sorghum growth benefits from the fertirrigation with manure and digested matter (i.e. residue of the anaerobic digestion), allowing an integrated management of the chain and of its by-products.

In order to improve the application of sorghum in bioenergy sector, some researches carried out by CRA-CIN have been aimed to assess the differences between varieties of fiber sorghum and sweet sorghum in terms of biomass and sugar yields. The results obtained in fields in Marche and Emilia-Romagna regions (central Italy) have suggested that in these climate conditions the differences are not very high and then some of the considered varieties (i.e. H133, Bulldozer, Padana 1) have a dual purpose.

The mechanisation of the agricultural operations for sorghum varieties has been studied for a long time by CRA-ING. In the contest of the research activities some prototypes have been designed and tested for the harvesting and for the conditioning of biomass. Especially one prototype for fiber sorghum has been designed and recently the pre-commercial version is being used in experimental fields in Italy by Mossi & Ghisolfi Group and Coprob.

The application of sorghum in bioethanol chain is being especially studied by some research groups, such as Mossi & Ghisolfi Group (Chemtex Italia S.p.A.), the Universities of Bologna and Turin, CETA, ENEA and CRA-RPS.

The researches of Chemtex Italia S.p.A. have been carried out in Emilia-Romagnia in cooperation with the Regional Administration, the Province of Parma, the University of Parma and the University of Sacro Cuore. Different fiber and forage sorghum varieties have been compared in order to assess their yields and to study the logistics for the supplying of a processing plant to produce 2$^{nd}$ generation bioethanol. The results have confirmed satisfactory yields of the considered sorghum varieties with low input (chemicals -50% DPI, without irrigation): 20-25 t/ha db. Furthermore the possibility to introduce sorghum in the cropping systems of farms in rotation with autumn-winter crops has been verified.

Recently the University of Bologna are participating in the project “SWEETFUEL”, supported by the 7$^{th}$ FP. In Italy the research activities are aimed to select hybrids characterised by a high resistance to low temperature in order to anticipate the sowing, to dilate the cultivation period and to optimize the supplying of the processing plants.

In particular the opportunity to develop short chain to supply decentralised plants and to produce bioethanol and other energy commodities using sweet sorghum has been investigated since 2007 in different areas of Italy.

In Piedmont region different experimental trials like cultivating sweet sorghum for bioethanol production purpose, complementing it with the evaluation of ensiling strategy for the sugar preservation, have been carried out by CETA in collaboration with the Agrarian Faculty of the University of Turin in 2007-2008 with different field trials in North Italy.

The MULTISORGO project, supported by the MIPAAF and implemented by CETA in cooperation with ENEA and CRA-RPS, is aimed to test some commercial varieties of sweet sorghum in the South and North Italy climates conditions (Basilicata and Friuli Venezia Giulia regions, respectively) and to express the whole energetic potentialities of the crop, assessing the production of 2nd generation bioethanol from bagasse and the anaerobic digestion using residual vinasse. The field trials confirm that in the Mediterranean climate the irrigation is necessary to ensure the economic viability of the cultivation (i.e. 2.4-4.6 t/ha db without irrigation *versus* 7.6-11.3 t/ha db with irrigation in 2010) and that in the temperate oceanic climate the rainfall (e.g. 670 mm in the period May-Sept 2010) is sufficient to reach satisfactory yields (i.e. 14.3-19.0 t/ha db in 2010 and 16.3-21.1 t/ha db in 2011).

### Greece[37,38,39,40,41,42,43,44]

In Greece, as in most European countries, bioethanol was introduced in the market with the Directive 2003/30/CE, and special attention to it has recently been given in the RED. At the moment the bioethanol production is nonexistent. Already the use of bioethanol as an alternative fuel to petrol or a complement thereof can be encountered.

Among the important energy crops there are varieties of sorghum for bioethanol production because of its high fermentable sugars content and combustible organic substances, tolerance to water stress and low nutrient requirements. For the production of biomass and bioethanol, sweet sorghum holds a prominent position because of the high photosynthetic capacity due to the $C_4$ photosynthetic metabolism.

The EU has funded in recent years several research studies on sweet sorghum (programs such as AIR, FAIR, etc.), carried out by Greek research centres, because this crop is considered as an alternative and economically viable energy crop.

CRES in cooperation with the Agricultural University of Athens and the University of Patras, through the participation in national and European research projects, has cultivated experimental fields in many parts of Greece.

The results of these experiments are identical to the average values of yields under full irrigation and fertilisation in Mediterranean environments.

Dalianis *et al.* have studied the effect of plants density on the growth and on the yield of sweet sorghum Keller varieties. The plants were sown in rows with a distance of 0.7 m and the distances of the plants on the line were 5, 10, 15 and 20 cm. They found that the density of 71,000 plants/ha (i.e. distance of 20 cm) gave the best yields in fresh and dry biomass (about 113 t/ha wb). This density had also the largest number of leaves and the greater height of plants.

Also Dalianis *et al.*, as part of research team of CRES studied in the early 1990's the adaptability of varieties of sweet sorghum in several regions of the country and the influence of different levels of irrigation and nitrogen fertilisation on yields of fresh biomass, on sugar content in the stalks and the agronomic characteristics of different varieties of sweet sorghum. Sweet sorghum is well adapted throughout Greece and can be grown from southern to northern regions and from sea level to high altitudes (i.e. up to 800 meters). It can be cultivated in various soil types ranging from marginal to very fertile ones. The lowest values for biomass and sugar production were registered in marginal, abandoned and poor soils (in term of organic matter content), whereas the highest yields corresponded to fertile fields located in southern Greece.

Moreover, it was found that Keller variety evidenced the most efficient yields in terms of fresh biomass and sugars: the produced fresh biomass was in the range of 87 to 144 t/ha wb and the obtained sugars were in the range of 9 to 12 t/ha.

Irrigation seems to affect the agronomic characteristics of the cultivation and the yields of biomass and sugars. In contrast, the nitrogen fertilisation does not seem to affect the yields of fresh biomass and sugar content. Consequently the application of reduced nitrogen rates is justified. The team also studied the effects of abiotic factors on crop physiological parameters such as evapotranspiration, water use and solar radiation. Yields ranged from 10 to 12 tons fresh biomass/ha. The radiation use efficiency, RUE is 3,5 g db/MJ PAR and the water use efficiency, WUE is 55 kg/mm of water.

In more recent experiments in the late 1990's, research group of CRES studied the agronomic characteristics and performance as well as the effect of different levels of irrigation and nitrogen fertilization in a number of varieties (Sofra, Korral, Colley, Keller, Mn 1500*)* and sweet sorghum hybrids. They confirmed that the most profitable varieties were Keller and MN 1500. The yields of these varieties ranged from 105 to 115 t/ha wb with a density of 110,000 plants/ha. In these experiments they found effects of fertilization on agronomic characteristics of plants such as height and green leaf area index (6.2 *versus* 4.4 in the fertilization of the soil).

Dercas *et al*. in experimental fields of Vagias Viotia Kopaida located in central Greece, in 1993 and 1994 performed cultivation tests in the ambit of the European program AIR, with four levels of irrigation (i.e. IH, IM = 1/2 IH, IL = 1/4 IH and IHA = IH until flowering) and two levels of nitrogen fertilisation (i.e. NL = 40 kg N/ha and NH = 120 kg N/ha). In the experimental fields of Vagias harvested in 1993, yield was 12.2 kg/mm with no differences in performance between the levels of irrigation. In 1994 yields varied from 7.45 kg/mm in the high irrigation level (IH) to 11 kg/mm in the low irrigation level (IL). This difference was attributed by researchers to the fact that there was no underground water in the experimental field of Kopaida. The dry biomass was calculated at 3.2 kg/mm for the high irrigation level for both years of experiments. Fertilisation levels had no effect on the performance of either the fresh or dry biomass in both years. This was attributed to the high fertilisation of the field that had been applied in previous years and low requirements of nutrients of the cultivation.

## Spain[45,46,47]

Sweet sorghum as energy crop has been studied in Spain since the decade of 1980's. The research teams leaded by Centre for agricultural research & development of Málaga and Polytechnic University of Madrid have contributed substantially to the knowledge of this crop.

Significant R&D projects on sweet sorghum carried out in Spain (totally or partially) are the following:

- o 1981-1987. "Sweet sorghum: contribution to the study of its cultivation for sugars and/or bioethanol in Andalucía (Spain)". INIA and CAICYT. Programme of Agro-Energy of Spain.
- o 1990-1993. "Sweet sorghum, a sustainable crop for energy production in Europe. Agricultural, industrial improvement, optimisation and implementation".

Commission of the European Communities, D.G. XII, JOULE Programme, CEE, Contract JOUB-0036-C.

- o 1993-1995. "Coordinated R&D activity in the sector of biomass production - Sweet sorghum network". Commission of the European Communities, D.G. XII, AIR1 Programme, EU, Contract AIR1-CT92-0041.
- o 1997-2000. "Environmental studies on sweet and fiber sorghum sustainable crops for biomass production and energy". Commission of the European Communities, CE, FAIR Programme, Contract FAIR3-CT96 1913.
- o 2004-2005. "Study for the viability of the production and utilization of bioethanol as biofuel starting from new energy crops", Ministry Of Education and Science, Profit Project.
- o 2006-2007. "Singular strategic project for the development, demonstration and determination of the production of energy in Spain starting from biomass of energy crops". Ministry of Education and Science, subproject Agrobihol.
- o 2010-2011. "Initiative for the development of the cultivation of sweet sorghum with bioenergy purposes – SORGOSWEET", Ministry of the Science and Innovation, project PlanE.

A number of experiments on sweet sorghum cultivars from latitude 36° to 41°N in Spain have shown that in non-limiting water conditions, varieties and yields are highly influenced by the latitudinal gradient and climate conditions. Late varieties are suitable for southern areas provided with irrigation while early varieties are more suitable for Mediterranean-continental areas. It has been seen that variety selection is a key factor for growing sweet sorghum.

A recent research line is the use of sorghum as a second crop in Mediterranean environment. For that purpose, a key issue is the choice of a suitable variety. The assessment of commercial varieties of sorghum as short cycle crops for biomass and sugars production in one-year experiment by the Agro- Energy Group of the Polytechnic University of Madrid is presented in the Table 1.

| | Height | Lodging resistance | Development | | | | |
|---|---|---|---|---|---|---|---|
| | | | cycle | Panicle type | Grain | Biomass yield | Sucrose content |
| **Sugargraze** | M | * | L | O | --- | H | */*** |
| **SSG** | M | * | L | O | --- | M | * |
| **23402** | M | *** | L | SC | --- | L | * |
| **Biom. 133** | VT | *** | E | O | --- | VH | ** |
| **Sugar T** | T | *** | I | O | --- | M | */*** |
| **Autan** | T | *** | I | O | Y | H | * |
| **Such. 506** | T | *** | I | C | Y | VH | **/*** |
| **Such. 405** | S | *** | I | SC | Y | L | * |
| **Madhura** | T | ** | E | C | Y | VH | */*** |
| **Nectar** | M | ** | E | C | Y | M | **/*** |

**Table 1: results of the cultivation of commercial short cycle varieties. KEY: Height: very tall (VT), tall (T), medium (M), short (S); Lodging resistance: poor (*), intermediate (**), good (***); Development cycle: Early (E), intermediate (I), late (L) ; Panicle type: Open (O), semi-compact (SC), compact (C) ; Grain: yes (Y), no (N); Biomass yield: very high (VH), high (H), medium (M), low (L); Sucrose content: poor (*), intermediate (**), good (***). The slash refers first harvest (15th September , 85 DAS) and normal harvest (18th October,118 DAS)**

**EARLY HARVESTING**

**Sugargraze**

**Sugargraze**

**SSG**

**SSG**

**23402**

**23402**

**Figure 10: phenological state as a function of sorghum variety in trials carried out in Madrid, Spain. Sowing date: 22nd June 2010; harvest date: 15th September 2010 (source: Agro-Energy Group of the Polytechnic University of Spain)**

### TOPIC: BIOETHANOL AND BIO-ETBE

Bioethanol is ethylic alcohol used as transportation fuel and derived from the alcoholic fermentation of free sugars, such as glucose, sucrose, fructose, or hydrolysed polysaccharides, such as starch, cellulose, hemicellulose, fructans (i.e. inulin).

Basing on its own characteristics bioethanol is suitable to feed the Otto engines instead of petrol:

- the LHV is high: 27 MJ/kg
- the MON and RON values allow an effective combustion control during the compression in the piston: MON 96, RON 130, octane number (i.e. average between MON and RON) 113.

Alternatively bioethanol can be converted in bio-ETBE, which is an antiknock compound usable in the Otto engines instead of MTBE:

- the LHV is high: 35 MJ/kg
- the MON and RON values indicate a good behaviour as antiknock compound: MON 102, RON 118, octane number (i.e. average between MON and RON) 110.

Bioethanol contributes to reduce the GHGs emissions from the transport sector, because it derives from biomass, not from fossil sources; consequently the balance between carbon sink and emission is like zero.

Bio-ETBE is considered GHGs neutral only for the fraction of the molecules deriving from biomass: 47% w/w.

The main raw materials converted in bioethanol are:

- sugar matter: sugarcane, sugar beet, sweet sorghum, molasses, marc
- starch matter: grain of cereals, potato, sweet potato, cassava
- lignocellulosic matter: giant reed, straw, maize stalks, organic fraction of the MSW.

Basing on the converted raw materials and then on the complexity of the implemented technology, bioethanol is considered a 1$^{st}$ generation biofuel, a 2$^{nd}$ generation biofuel or a 3$^{rd}$ generation biofuel:

- 1$^{st}$ generation: converting sugar and starch matters
- 2$^{nd}$ generation: converting lignocellulosic crops (e.g. giant reed)
- 3$^{rd}$ generation: converting lignocellulosic residues (e.g. straw, MSW).

# 7. GUIDELINES FOR THE EU MODEL TO PROCESS SWEET SORGHUM AS ENERGY CROP

## 7.1 Introduction

Sorghum is a multipurpose crop because it supplies high yields in biomass, sugar and grain depending on the chosen varieties.

At the current time the sweet sorghum varieties provide mainly biomass and sugar, whereas its potentiality as grain crop is not yet expressed. Many agricultural researches are aimed to overcome this limit, selecting hybrids with high yields in biomass, sugar and grain at the same time. Actually, in order to express all the potentialities of the crop, other agricultural researches are directed to optimize the harvesting operations, separating all the products: biomass and sugar on one side, grain on the other side.

Since these researches are not yet finished, the model to process sweet sorghum foresees the exploitation of sugars and lignocellulosic biomass.

In accordance with the scheme in Figure 11, the sweet sorghum biomass is crushed and sugar juice is processed in bioethanol.

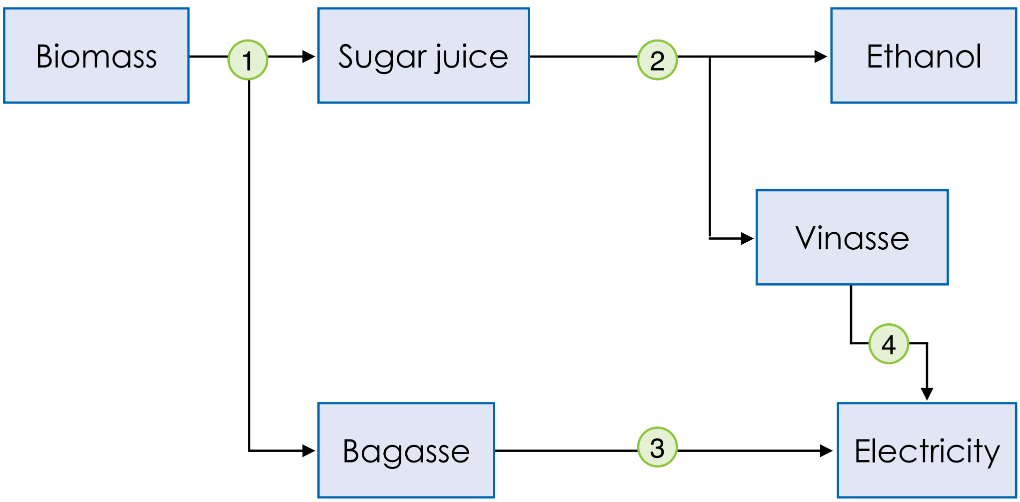


**Figure 11: scheme of the plant to process sweet sorghum in bioethanol and energy commodities (source: CETA)**

Bagasse, which is the lignocellulosic residue of the crushing unit, is dried and burnt in CHP plant to get electricity and heat.

Vinasse, which is the residue of the distillation and rectification unit, is a feedstock for the anaerobic digestion, to use in co-digestion eventually with other substrates like for example manure as microbial inoculum. The obtained biogas is purified and burnt in CHP plant to get electricity and heat.

This approach for processing sweet sorghum allows different variations that can be applied in the planning of a specific chain model to supply decentralised small-medium plants in the EU.

In fact, the conversion of the sugar juice in bioethanol and the energetic exploitation of bagasse and vinasse can be the sole production line or can be one of the production lines implemented in the plant.

These different strategies are explained in detail in the specific chapters. In particular, the use of sweet sorghum as sole feedstock is deepened in three case studies (i.e. in Italy, in Greece and in Spain) and the feasibility for processing sweet sorghum plus another raw material (i.e. sugar beet) in the same plant is reported in the Spanish conditions.

All these applications have some common elements regarding the dimensioning of the chain supply, the technological contents of the processing and the by-products exploitation. Consequently, the following paragraphs are aimed to give the main guidelines, which are common to the different applications. They are the indicative input data to perform a feasibility study and at this aim they require a contextualisation to each specific situation.

### 7.2 Dimensioning of the chain supply

In the creation of the EU model the capacity as anhydrous bioethanol obtained from the processing of sweet sorghum is assumed as criterion for the dimensioning of the chain supply.

As appropriate this dimensioning regards the whole plant (if sweet sorghum is the sole feedstock) or the specific production line to obtain 1$^{st}$ generation bioethanol from this crop (if the plant processes different raw materials).

Two elements are required in the assessment: the agricultural land cultivated with sweet sorghum and the range of supply.

Agricultural land requirement

The required agricultural land depends on the yields of biomass and sugars, which are consequent for example to the kind of soil, the water availability, the climate, the grown variety.

The main specificities have been traced to some reference scenarios, in order to give an indicative value to the stakeholders (Table 2).

The reported ranges for the yields concern some different sweet sorghum varieties, currently available in the EU market.

Two different types of environment are analysed and in each one the conditions to ensure the economic viability are considered.

The cultivation of sweet sorghum in marginal lands is taken into consideration for contexts where the economic viability is guaranteed and the related yields correspond to the lowest values in the reported range for each type of environment.

Especially in the Mediterranean environments (i.e. South Italy, Spain, Greece) the cultivation of sweet sorghum without irrigation is excluded because the biomass yields are too low (2.4-4.6 t/ha db). In the temperate environments (i.e. North Italy) only the eventual emergency irrigation is considered because the rainfall during the growing period is usually sufficient (e.g. 670 mm in May-Sept 2010).

These data are the input to calculate the hectares which must be cultivated with sweet sorghum in order to supply the plant, basing on its capacity. Nevertheless,

| Macro scenarios to plan the chain supply | | | |
|---|---|---|---|
| Type of environment | | Agricultural yield | |
| **Type MEDITERRANEAN**<br><br>**Low fertility soils**<br>**Dry climate** | Irrigation | Biomass yield | 10.3-35.0 t/ha db |
| | | Bioethanol yield | 1.5-4.6 t/ha<br>1.9-5.8 $m^3$/ha<br>40.5-123.6 GJ/ha |
| **Type TEMPERATE**<br><br>**Medium fertility soils**<br>**Temperate oceanic climate** | No irrigation | Biomass yield | 14.3-19.0 t/ha db |
| | | Bioethanol yield | 2.1-3.4 t/ha<br>2.8-4.4 $m^3$/ha<br>56.7-91.8 GJ/ha |
| | Irrigation (emergency) | Biomass yield | 30.0-40.0 t/ha db |
| | | Bioethanol yield | 4.3-6.1 t/ha<br>5.9-7.9 $m^3$/ha<br>116.1-164.7 GJ/ha |

**Table 2: yields in biomass and bioethanol obtainable from sweet sorghum in some reference type of environments**[48,49]

for each specific situation the calculated surface could require a wider area, for example if rotations with other crops are proposed in the considered region in order to protect the soil fertility.

These values of macro scenario, of course, require a following careful contextualisation to calculate the actual dimensioning of the chain supply.

Range of supply

Concerning the distance between the plant and the fields, different evaluations must be integrated. The main elements are the impact of the transport on the energy balance of the chain, the respect of specific limits to access to eventual national supports (e.g. short chain recognised for a maximum range of supplying), the logistics coherent with the requirements of the farms (e.g. the necessary number of agricultural machinery, number of driven kilometres) and the plants (e.g. timing of supply during the harvesting) and with the impact of the consequent traffic in the considered area.

In order to give some indications for the range of supply and its repercussions, in Table 3 the details for two simulations are reported.

| 3,700-3,800 hectares cultivated with sweet sorghum | | |
|---|---|---|
| **Maximum range** | **Harvesting in 40 days** | **Agricultural machineries** |
| **15 km** | **4 parallel yards** | 4 mower-shredder-charger machines<br>24 farm tractors |
| **20 km** | **6 parallel yards** | 6 mower-shredder-charger machines<br>24 farms tractors |

**Table 3: results of two simulations for the supply of a plant with capacity 10,000 t/y as anhydrous bioethanol**[50,51]

In the model creation the dimensioning of the units for the by-products exploitation is based on the amounts of obtained bagasse and vinasse, which are linked to the cultivated agricultural land and then to the assumed capacity as anhydrous bioethanol.

The main elements to dimension the related units are reported in the specific paragraph (7.4 Exploitation of by-products).

**Figure 12: harvesting yard (source: CETA)**

## 7.3 Processing of the sweet sorghum biomass to bioethanol

The technological sections for the production line of 1st generation bioethanol are: the sugar extraction unit, the concentration unit for the storage of the sugar juice, the fermentation unit, the distillation and rectification units and finally the dehydration unit.

### Sugar extraction unit

The extraction of free sugars from the chopped biomass can be carried out through direct pressing using the rolling mills or through a lixiviation system.

In both processes the extraction is carried out using hot water (75-85 °C) in the ratio between feedstock and hot water of 1:0.1-1:1. The extraction yield is in the range of 93-98%, considering a range of 85-93% of extraction yield using a rolling mills series (from 3 to 5 rolling mills) and a range of 93-98% of extraction yield using a continuous diffuser.

In case of crushing into horizontal or vertical power mills, the working principle is the application of high pressure, which is exercised by some couples of rollers (TRPF milling system): 3 couples in the small vertical crushers, up to 9 couples in the big horizontal ones. The speed of the top roller is usually 10-12 rpm in small mills, 6-8 rpm in large mills. In order to improve the extraction efficiency, the optimal addition of hot water is 10% w/w.

The working scheme of the crushing unit is reported in the following Figure 13.

Alternatively, the operation of the diffuser is based on systematic counter that puts the raw material under current washing by means of imbibition water. In practice, this is achieved by forming a bed of shredded stalk or first mill bagasse on a conveyor. Water is added at the discharge end of the conveyor and percolates through the bed of bagasse and the perforated slats of the conveyor. The water dissolves the sugar in the bagasse and the thin juice thus formed is collected in a hopper. This juice is moved forward one stage by pumping and the process is repeated until

**Topic: Production of bioethanol**

The bioethanol production is based on the alcoholic fermentation carried out by microorganisms in controlled conditions. The correspondent chemical reaction is described as follows:

$C_6H_{12}O_6 + H_2O \rightarrow 2C_2H_5OH + 2CO_2 + H_2O$

Although the fermentation is the core of the production, the complete processing depends on the kind of raw material: free sugars are directly fermentable, whereas polysaccharides require a previous hydrolysis.

Furthermore the complexity of the hydrolytic step depends on the kind of polysaccharides: free sugars can be easily obtained from starch, whereas cellulose and hemicellulose are structural carbohydrates, strongly tied to lignin, and then their hydrolysis is more difficult.

The kinds of processing are briefly summarised in:

- sugar matter:

1. extraction of free sugars from biomass
2. fermentation
3. distillation and rectification
4. dehydration

At the end of the processing 1st generation anhydrous bioethanol is produced.

- starch matter:

1. enzymatic hydrolysis: liquefaction with alpha-amylase and saccharification with gluco-amylase
2. fermentation
3. distillation and rectification
4. dehydration

At the end of the processing 1st generation anhydrous bioethanol is produced.

- lignocellulosic matter:

1. pre-treatment to separate lignin from the structural polysaccharides
2. enzymatic hydrolysis: endocellulase, exocellulase, hemicellulase
3. fermentation of C6 sugars (e.g. glucose)
4. fermentation of C5 sugars (e.g. xylose)
5. distillation and rectification
6. dehydration

At the end of the processing 2nd generation bioethanol is produced if lignocellulosic crops have been processed; in alternative, 3rd generation bioethanol is produced if lignocellulosic residues have been converted.

the juice reaches maximum concentration at the feed end of the diffuser. The diffuser may be conditioned either for single-flow or for parallel-flows juice circulation.

Usually the diffusers are designed from 35 m to 52 m long; the cross section is rectangular and diffusers of different capacities are made in different widths. The conveyor grids and screens

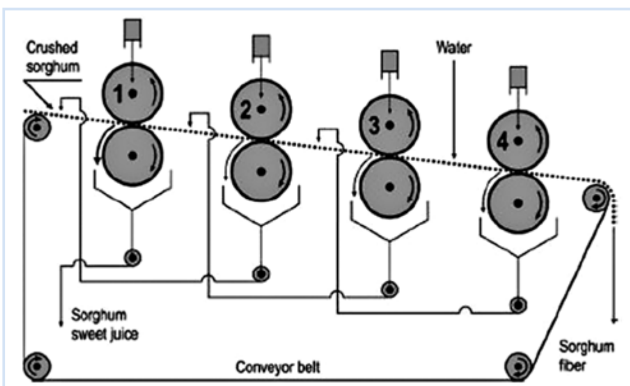


**Figure 13: crushing unit (source: Gnansounou E. *et al.*, 2005 )**[52]

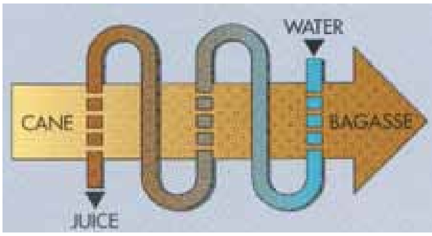

**Figure 14: continuous extraction (source: CARTIF)**

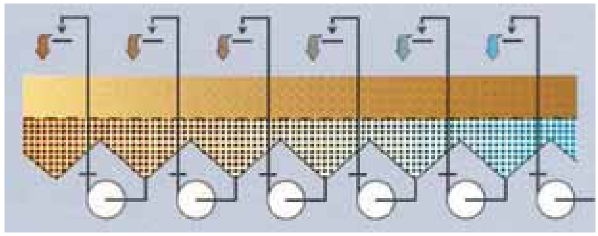
**Figure 15: continuous diffusion diagram (source: CARTIF)**


**Figure 16: continuous diffuser (source: CARTIF)**

are supported by 2 outboard type roller chains with a pitch of about 3 feet. These chains are supported at the extreme ends by sprockets. At the driven end, the sprockets are coupled through a gearwheel and pinion to a variable speed hydraulic drive or electric gear-motor drive.

The conveyor itself is made of articulated frames to which the screens are fixed. The screens and frames are rigidly attached to corresponding links of the 2 chains. These chains are fitted with self-lubricating bushings. The rollers ride on parallel rails. The return rails are completely exposed underneath the housing, giving full visibility and accessibility to the screens. The thickness of the bed varies from 1.5 m to 2 m. The space between the 2 conveyor spans is occupied by a large tank with a sloping bottom split into individual hoppers by means of vertical plates. These vertical plates have horizontal slots, at specified levels, through which the juice overflows to the next hopper. At the end of the conveyor, there is a revolving scraper to even out the flow of bagasse which falls in an outlet hopper. This hopper is provided with a conveyor for removing the bagasse. The diffuser is equipped with lifting screws in the press-water feedback area.

During the whole duration of its passage through the diffuser, the bed of stalks is submitted to intensive sprays of juice of progressively decreasing concentration.

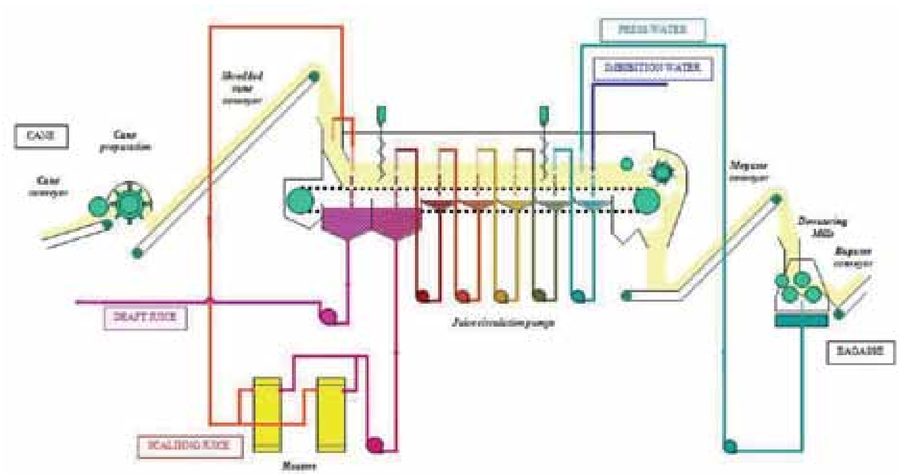

**Figure 17: extraction process from sweet sorghum stalks by process 1 (source: CARTIF)**

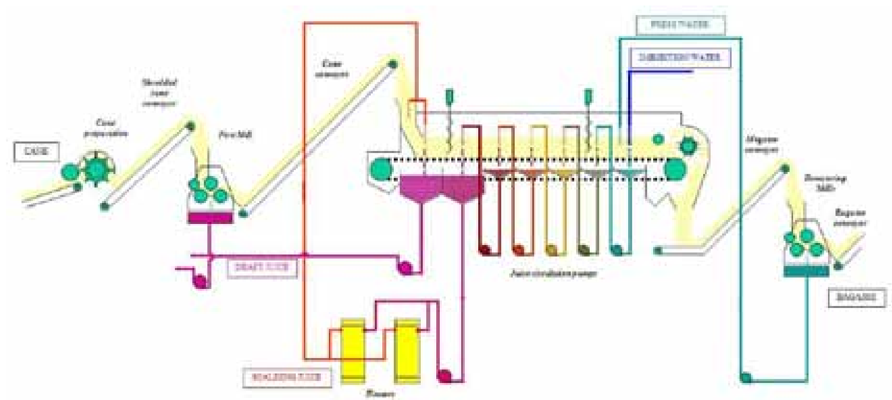

**Figure 18: extraction process from sweet sorghum stalks by process 2 (source: CARTIF)**

The juice is evenly sprayed above the bed by a series of overflowing troughs extending on the whole width of the housing. One of these troughs is fitted above each juice-collecting hopper and designed to distribute uniformly the juice across the bed, with an accuracy of 2%. The curve shows the decreasing concentration of the juice in the successive hoppers that is very steady (Figure 19).

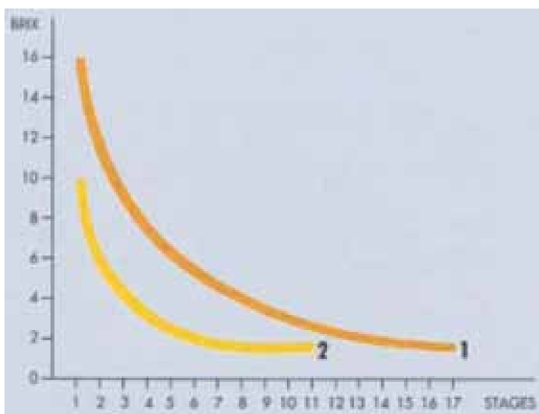


**Figure 19: degree Brix curves: (1) sweet sorghum stalks diffuser, (2) bagasse diffuser (source: CARTIF)**

The last trough is fed with pure water. All the juice hoppers have the same width. They collect the juice percolating from each juice distributor through the bed of stalks. Each hopper is piped to an individual high capacity centrifugal pump. Each pump is piped to take juice from one hopper and to spray it above the preceding hopper (in opposite direction to the movement of the bed). A last single pump feeds the richest juice to the rich juice tank. Another pump of great capacity continuously circulates rich juice on the fresh prepared stalks of sweet sorghum. The intensive flow of stalks or first mill bagasse is fed into the diffuser by a drag type cross conveyor so designed as to spread the feed evenly on the diffuser conveyor. Juice from the rich juice tank is pumped to the factory. The diffuser is operated and controlled by a central panel on which all instruments are grouped.

The main advantages of the continuous diffusion are:

- o high extraction achieved in combination with existing milling equipment or in completely new extraction plants;
- o low initial cost of the overall extraction plant because diffusers are designed to work with conventional sweet sorghum stalks preparation and milling equipment. The diffusers can be installed outdoors;
- o low maintenance costs because of massive design and extremely slow movement of the main conveyor;
- o low operational costs: diffusers are completely automated and can be operated by 1 man per shift. Lubrication costs are negligible;
- o low power requirements: live steam is not needed. Steam of low-pressure is used for juice heating in the diffuser. All moving parts are driven by electric motors;
- o very wide capacity range: diffusers can operate without modifications and without loss of efficiency from 30% to 10% over nominal capacity. By varying the bed height and conveyor speed, the capacity range may be extended even more. The design of the diffuser is such that unforeseen increases in capacity can, to a certain extent, be met by the addition of washing stages to existing diffusers;
- o absence of fermentation: the diffusers are designed to eliminate all static zones where fermentation could develop. The return span of the diffuser conveyor is washed at every cycle to prevent contamination of the feed by pieces of bagasse sticking to the screen. The diffuser is fitted for pH control and for operation at optimum temperature;
- o bagasse discharge is by gravity at the tail end of the diffuser: a special scraper is provided to even out the flow of bagasse and provide a continuous feed to the dewatering mills. The diffuser can be completely discharged for long stops and must not be cleaned manually;
- o juice quality is good: systematic clarification of last mill juice enables removal of impurities early in the process and contributes towards the production of juices which are easy to clarify and which present no problems in the boiling house;
- o heat economy: all heaters are of the type used for mixed juice heating in sugar factories. The diffuser is completely enclosed and insulated.

The continuous diffuser gives high yield on the extraction and low power consumption, and also the juice has low amount of interfering and contaminants that must be removed before the concentration step.

If sweet sorghum juice contains soluble solids (e.g. anthocyanins and chlorophyll)

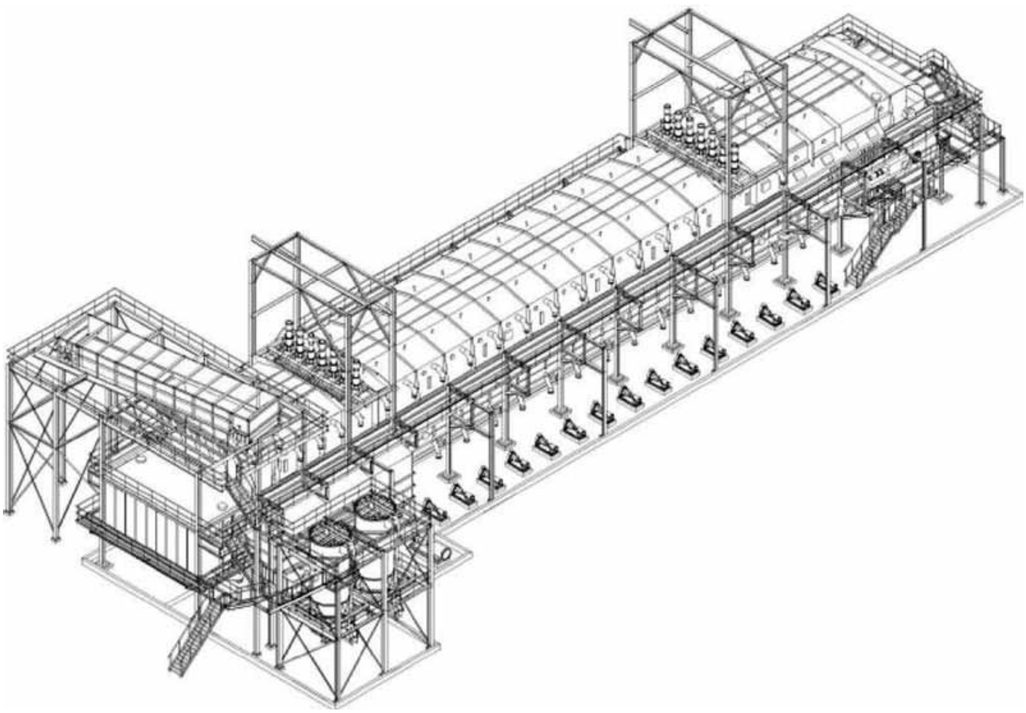

**Figure 20: continuous diffuser 1 (source: CARTIF)**

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NOMINAL CAPACITY | METRIC TONS/DAY | FROM 2,000 TO 15,000 | | | | | | | | | | | | | | | | | |
| PRINCIPAL OVERALL DIMENSIONS | WIDTH M<br>WIDTH FT | 2.8<br>9.2 | 3.3<br>10.7 | 4.2<br>13.8 | 4.7<br>15.4 | 5.2<br>17.0 | 5.7<br>18.7 | 6.2<br>19.6 | 6.7<br>22.0 | 7.2<br>23.6 | 7.7<br>25.3 | 8.2<br>26.9 | 8.7<br>28.6 | 9.2<br>30.2 | 9.7<br>31.8 | 10.9<br>35.7 | 11.4<br>37.4 | 11.9<br>39.0 | 13.4<br>44.0 |
| | LENGTH | FROM 48.3 M – 158 FT TO 61 M - 200 FT | | | | | | | | | | | | | | | | | |
| | HEIGHT | ABOUT 8 M – 25 FT | | | | | | | | | | | | | | | | | |
| INSTALLED POWER | AT FULL CAPACITY | APPROX. 110 HP/1,000 TONS/DAY | | | | | | APPROX. 100 HP/1,000 TONS/DAY | | | | | | | | | | | |
| STEAM CONSUMPTION | KG/TON OF CANE | 80 - 85 | | | | | | | | | | | | | | | | | |

**Figure 21: data for the design of a continuous diffuser (source: CARTIF)**

and insoluble solids (e.g. starch granules), these components must be separated to process the sugar juice to bioethanol.

Good quality juice can be made after carrying out evaporation with continuous skimming of coagulated materials, which have risen to the surface. Evaporation should be done with uniform heating. Initially coagulation starts when juice temperature increases. This scum should be removed during slow heating. Evaporation should not be done fast as scum gathered on the top of the juice may get dissolved during rapid boiling and then floating or settled mass problems may be seen in the syrup.

The evaporation of the sugar juice must be done with a good quality product, eliminating the solids content and other interfering. This purification can be done with the addition of lime and $CO_2$ for flocculating these compounds and eliminating them by filtration.

Once the juice is clarified, the evaporation process carries out. The evaporation process will be done in a falling film evaporator working under vacuum to ensure the minimum energetic consumption and the best quality of the sugar juice. The previously clarification is needed to ensure the reduction of incrustations and soiling on the pipes and on the concentration unit.

## Falling film evaporator

The concentration is the strategy chosen to preserve sugars and to supply the plant in the months after the harvesting of the sweet sorghum biomass. This section is required in both cases: sweet sorghum as sole feedstock and sweet sorghum and another raw material as feedstock.

The aim of this stage is the concentration of the sugar juice from 12-16 °Brix to 45-85 °Brix, depending on the storage period for the concentrated juice. This process increases the osmotic pressure in the liquid and avoids any bacterial or yeast development.

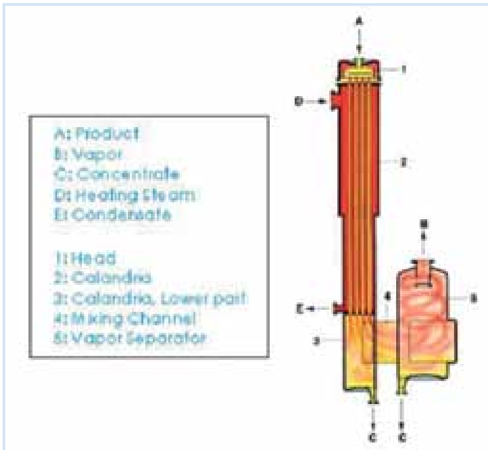


**Figure 22: Falling Film Evaporator (source: CARTIF)**

The falling film evaporator concentrates the sugar juice in several steps (between 2 and 4, depending on the final concentration), working under vacuum to ensure a low temperature process, lower steam consumption, and lower sugar degradation. At each concentration step, the diameter of the tubes of the falling film evaporator is increased to reduce fouling and to maintain the performance of concentration. From this step, the water condensed after the concentration could be used on the sugar extraction unit, minimizing the water consumption on the total process.

## Fermentation unit

The fermentation is carried out by yeasts (*Saccharomyces cerevisiae*) at the conditions which favour firstly their quick cell growth and division and afterwards their anaerobic metabolism.

Especially the following conditions are required:

- glucose concentration > 9 g/l (in order to benefit from the Crabtree effect and to ensure the alcoholic fermentation instead of the oxidative metabolism);
- pH 4-5;
- temperature in the range 30-35 °C;
- nitrogen concentration 150-180 mg/l (as ammonium).

| Temperature | Time | Pasteurisation type |
|---|---|---|
| 63 °C (145 °F) | 30 minutes | Vat Pasteurisation |
| 72 °C (161 °F) | 15 seconds | HTST |
| 89 °C (191 °F) | 1.0 seconds | HHST |
| 90 °C (194 °F) | 0.5 seconds | HHST |
| 94 °C (201 °F) | 0.1 seconds | HHST |
| 96 °C (204 °F) | 0.05 seconds | HHST |
| 100 °C (212 °F) | 0.01 seconds | HHST |
| 138 °C (280 °F) | 2.0 seconds | UP |

**Table 4: conditions for the pasteurisation of sugar juice**

The fermentation unit has five sections.

1. Pasteurisation of sugar juice: in order to avoid unchecked fermentations by bacteria, sugar juice is sterilised through the pasteurisation (Table 4)
2. Preparation of yeasts: yeasts are rehydrated and stabilized in order to obtain the suspension in the mother tank. This step is carried out with a solution rich in glucose, fructose or sucrose, an average temperature of 35 °C and with the addition of bactericide, oxygen and eventually ergosterol. At the beginning of each fermentation reaction, an amount of the mother suspension is flowed as inoculum in the fermentation tank.
3. Fermentation: it can be applied in a in batch process or in continuous one.
    - In batch fermentation: the fermentation reactions are performed in independent reactors without direct communications among them. The bioethanol yield of this process depends on the tolerance of yeast to the alcoholic concentration in the medium (maximum tolerance 19% v/v for selected strains). Although in this process the yield is lower than the yield of the continuous one, the control of contaminations is better and consequently the security is higher because this system allows an easy isolation of the contaminated tank, preventing that it can extend throughout all the unit.
    - Continuous fermentation. The continuous process is set up flowing the pasteurised sugar juice only to the first tank where yeasts is inoculated. From the first tank the partially fermented juice flows to the following ones; in this transit bioethanol is removed and its concentration in the medium maintains inferior to the inhibition level of yeasts. Then the fermentation by degrees continues until the last tank, where all the free sugars are converted in bioethanol. The yield of this process is higher than the yield of the batch one, because yeasts are not inhibited. Furthermore, the necessary capacity is less than the volume required by the other one. The main criticism is the contamination risk: in fact if one of the continuous tanks is contaminated with bacteria, the total system can be contaminated and the decontamination is more difficult.
4. Recovery of yeasts. The recovery of yeasts at the end of the fermentation process is a measure to increase the economic viability of the plant. Yeasts are recovered from the fermented medium through centrifugation. If yeasts are yet vital, they are reused in the fermentation process. If yeasts have finished their own lifetime, they are a source of proteins for the preparation of human and/or animal feed.

Distillation and rectification unit

The bioethanol concentration in the fermented medium is 9-14% v/v and the objective of this unit is to obtain the azeotropic bioethanol (i.e. 95-96% v/v).

At this aim the fermented medium flows through some distillation columns (i.e. multiple effect distillation) made of bubbling dishes, where water and alcohol are separated basing on their own specific boiling points as they run up the tower. The multiple effect technology allows to reduce the heat consumption of this unit, because the pressure on the column head is lower than the atmospheric value and the boiling point of the components to separate is inferior.

Dehydration unit

The dehydration process is necessary to produce anhydrous bioethanol (i.e. 99.7-99.8% w/w). This value of purity is required to produce bio-ETBE or to blend bioethanol directly with petrol.

The dehydration unit is based on the molecular sieve technology: zeolite, which is the component of the sieves, retains selectively the residual water molecules, increasing gradually the percentage of bioethanol in the flowing blending.

Anhydrous bioethanol has to be stored in tanks with controlled atmosphere (free of air, usually with $N_2$ or $CO_2$), in order to avoid the solubilization of water vapour.

The same conditions have to be applied in the transport phase.

## 7.4 Energetic exploitation of the by-products

Bagasse

Basing on its own characteristics (Table 5), the dried bagasse, residue of the extraction unit, can be burnt in CHP plant to produce electricity and heat.

The size of the CHP plant is correlated to the bagasse availability and then to the agricultural land cultivated with sweet sorghum and to its biomass yield.

Considering the biomass yields reported in Table 2 and the LHV of Table 5, the reference values in order to design the unit for the combustion of bagasse in CHP plant are reported in Table 6.

| Bagasse characterisation | |
|---|---|
| **Moisture after crushing** | 30-50% |
| **Residual sugars** | 6-7% db |
| **Cellulose** | 16-18% db |
| **Hemicellulose** | 11-13% db |
| **Lignin** | 7-9% db |
| **LHV** | 17-18 MJ/kg db<br>4.7-5.0 kWh/kg db |

**Table 5: main characteristics of bagasse, obtained in a TRPF milling system, to plan its energetic exploitation**[53]

As regards with the technical details of the CHP plant, it is kitted out with a biomass burner, suitable to the combustion of herbaceous feedstock, and a turbine, which could be for example a steam turbine based on the Rankine-Hirn cycle, a gas turbine based on the Brayton cycle, or a turbogenerator based on the ORC cycle.

The choice of the technology for the CHP plant depends, most of all, on the electric power. The Figure 23 summarises some situations for the power values in the range interesting for the EU model (0.1-10 MWe) with the related energy efficiency.

| Energy exploitation of bagasse | | | |
|---|---|---|---|
| **Type of environment** | | **Yield** | |
| **Type MEDITERRANEAN**<br>**Low fertility soils**<br>**Dry climate** | Irrigation | Bagasse yield | 6-20 t/ha db |
| | | Available energy | 100-340 GJ/ha<br>28-94 MWh/ha |
| **Type TEMPERATE**<br>**Medium fertility soils**<br>**Temperate oceanic climate** | No irrigation | Bagasse yield | 10-12 t/ha db |
| | | Available energy | 190-200 GJ/ha<br>53-56 MWh/ha |
| | Irrigation (emergency) | Bagasse yield | 18-25 t/ha db |
| | | Available energy | 312-442 GJ/ha<br>87-123 MWh/ha |

**Table 6: main elements for the dimensioning of the unit of bagasse exploitation in some reference type of environments**

The main criticism of the combustion of sorghum bagasse is the high content in ashes (3-5% db) that are characterised by a low melting point. Consequently, the technology applied in the biomass burner requires an adequate ash removal system and the special extended warranty has been issued by the manufacturer. The management of ashes depends on the law of the specific country.

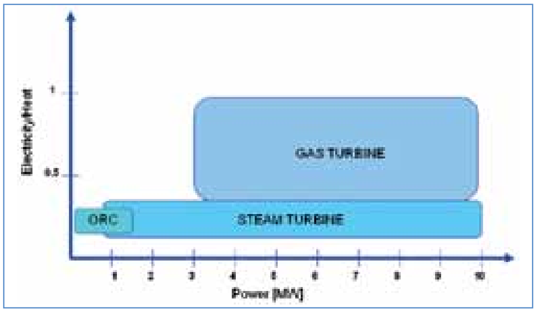


**Figure 23: application fields of the different cogeneration systems (source: A.A.V.V. 2006)**[54]

## Vinasse

Vinasse, residue of the distillation and rectification units, has a chemical composition which is suitable to the production of biogas through the anaerobic digestion (Table 7).

The dimensioning of the anaerobic digester is correlated to the vinasse availability and then to the capacity as anhydrous bioethanol and to the HRT.

Concerning the vinasse yield, the theoretical correlation coefficient is 7-8 litre of vinasse per litre of bioethanol.

| Vinasse characterisation | |
|---|---|
| **Dry matter** | 6-7% |
| **Volatile matter** | 85-90% |
| **$BOD_5$** | 40-50 $gO_2/l$ |
| **COD** | 70-90 $gO_2/l$ |
| **Nitrogen** | 750-850 mg/l |
| **Phosphorous** | 1.5-2.5 g/l |
| **pH** | 4.4-4.6 |

**Table 7: main characteristics of vinasse to plan the anaerobic digestion**[55]

As regards with the HRT to complete the biomethanation, it depends on the chemical composition of the feedstock: as a principle, lignin, cellulose, protein show a slower degradation than fats, starch and sugars. The methanogenesis of vinasse is carried out using also other substrates to start up and/or stabilise the process: for example manure is utilised as microbial inoculum at the beginning of the process and lignocellulosic feedstock can be mixed to vinasse to improve the ratio between carbon and nitrogen, if necessary. In this hypothesis the HRT for vinasse is 60 days approximately.

The typical chemical composition of biogas is reported in the Table 8.

The theoretical methane yield is 0.395 $Nm^3$ per kilogram of COD, if the content of methane in biogas is 60%.

Assuming the yields in vinasse and methane and the values of Table 7 and Table 8 for COD and LHV respectively, the elements to dimension this unit are summarised in Table 9.

The obtained biogas is burnt in a CHP plant which can be based on Diesel engine or gas microturbine.

| Biogas characterisation | |
|---|---|
| $CH_4$ | 50-70% |
| $CO_2$ | 25-45% |
| $H_2$ | 1-10% |
| $N_2$ | 0.5-3.0% |
| CO | 0.08-0.10 |
| $H_2S$ | 0.02-0.20 |
| $O_2$ | traces |
| LHV | 21-22 $MJ/Nm^3$<br>5.8-6.1 $kWh/Nm^3$ |

**Table 8: main characteristics of biogas**

The utilised Diesel engine requires some modifications in order to work with the Otto cycle in the combustion of methane: especially it is fitted out with a carburettor and the spark plugs. At the current time these modified engines are already available on the market. Heat is recovered through a exchanger from the flue gases and/or from the engine cooling.

The energy efficiency is correlated with the electric power of the CHP plant: in the range considered for the EU model (0.1-5.0 MWe) the electrical efficiency is 30-42%, the thermal efficiency is 45-50%. The highest powers are characterised by the most efficiency, above all in the electric conversion.

The digested matter, residue of the biomethanation, is a good fertiliser (nitrogen 800 g/t, mainly as ammonium) and it is applied in the fields in order to compensate the nitrogen removal carried out by sweet sorghum growth.

| Energy exploitation of vinasse | | | |
|---|---|---|---|
| Type of environment | | Yield * | |
| **Type MEDITERRANEAN**<br>**Low fertility soils**<br>**Dry climate** | Irrigation | Methane | 340-1,030 $Nm^3/ha$ |
| | | Available energy | 7.9-23.7 GJ/ha<br>2.2-6.6 MWh/ha |
| **Type TEMPERATE**<br>**Medium fertility soils**<br>**Temperate oceanic climate** | No irrigation | Methane | 500-790 $Nm^3/ha$ |
| | | Available energy | 11.6-18.4 GJ/ha<br>3.2-5.1 MWh/ha |
| | Irrigation (emergency) | Methane | 1,070-1,420 $Nm^3/ha$ |
| | | Available energy | 24.9-32.7 GJ/ha<br>6.9-9.1 MWh/ha |
| * calculations with the application of the actual methane yield | | | |

**Table 9: main elements to the dimensioning of the unit of vinasse exploitation in some reference type of environments**

# 8. THE EU MODEL 1: SWEET SORGHUM AS SOLE FEEDSTOCK OF THE PLANT

This model is aimed to develop a chain in the EU based only on sweet sorghum as feedstock.

The main advantage of this model is the utilisation of a crop which is characterised by low agricultural inputs (i.e. water and fertilisers).

The main disadvantage of this model is the dependence of the plant from a single type of raw material.

In order to explain this model for the EU, the guidelines described in the previous chapter are applied to an exemplifying plant with capacity as anhydrous bioethanol of 10,000 t/year.

The main details of this application are summarised in Table 10.

Concerning the agricultural land requirement, in the temperate climate characterised by medium fertility soils and rainfall of about 600-700 mm during the growth period, 3,000-4,800 hectares are required. If the emergency irrigation is foreseen, the higher yield allows to reduce the cultivated surface to 1,700-2,300 hectares, but in this situation the agricultural costs increase significantly and usually maize or other crops becomes more competitive. Consequently, this important variable has to be taken into consideration in choosing the fields to cultivate and in the related feasibility study.

On the contrary in the Mediterranean conditions the irrigation is necessary to obtain viable yields. A surface of 2,200-6,600 hectares is required; the high width of the range is due to the very different values in the yields, which depend on the inputs of water and fertilisers.

The decision about the range of supply is correlated to different factors, such as technical, logistical, energetic, economic ones. Firstly, the competitiveness of sweet sorghum compared to other crops depends by its economic viability which is the prerequisite, but also by the agricultural tradition of the specific area and by the propensity to innovation of the farmers. Some indicators can be utilised in this evaluation, for example the crop diversification and the farm structure. If the crop diversification in the considered area is high, it is plausible that the range of supply increases, because this suggests that numerous crops are competitive and the market repays all of them. On the contrary, the low age of farmers, the big size of farms and the application of innovative solutions in the agricultural practices usually indicate a possible decrease in the range of supply. Secondly, the decision must be subjected to the LCA and to the analysis of the logistics, evaluating the energetic and environmental impacts of each hypothesized value for the range of supply. Finally, the assumed range of supply must allow to benefit from eventual national incentives that the different countries make available for the RES.

As regards with the logistics, the harvesting operations are carried out in yards; each one of them is fitted out with 1 mower-shredder-loader machine and 4-6 farm tractors fitted out with dumper (i.e. capacity about 50 $m^3$) for the transport of the chopped biomass to the plant.

| Capacity 10,000 t/year (as anhydrous bioethanol) | | |
|---|---|---|
| **Dimensioning of chain supply** | **Agricultural land** | Type Mediterranean<br>2,200-6,700 ha |
| | | Type Temperate<br>3,000-4,800 ha (no irrigation)<br>1,700-2,300 ha (emergency irrigation) |
| | **Range of supply** | It depends on the specific region, for example in terms of crop diversification, farm structure, limits for the incentives to short agro-energy chains |
| **Processing of sugar juice** | **Operational details** | 330 working days per year<br>68,000-69,000 t db of sweet sorghum biomass crushed in 40 days<br>Crushing, fermentation, distillation, rectification and dehydration in accordance with the guidelines |
| | **Concentration unit** | Storage<br>Syrup at 45% storable up to 3 months<br>Syrup at 80% storable up to 11 months<br>Utilisation<br>Dilution to 18%<br>Water management<br>Waste water discharged into surface water body in accordance with the national and local laws<br>Purchase of water for the dilution<br>Thermal consumption<br>Self-consumption from the by-products exploitation<br>0.43 MWe available at the end of the harvesting period |
| **Energetic exploitation of by-products** | **Bagasse** | Availability<br>41,850- 42,460 t db of bagasse to store, dry and burn during all year<br>711.4-764.3 TJ/year<br>196.69-212.31 GWh/year |
| | | CHP plant<br>4.20 MWe |
| | | Ashes<br>2,040-3,450 t/year<br>Disposal in landfills or other management, depending on the different countries |
| | **Vinasse** | Availability<br>Capacity of the anaerobic digester 20,000-22,000 $m^3$ (HRT 60 days)<br>Capacity of the biogas storage 10,000-14,000 $m^3$<br>14.0-14.7 TJ/year<br>3.86-4.06 GWh/year |
| | | CHP plant<br>0.75 MWe |
| | | Digested matter<br>93,000-95,000 t/year<br>Use as fertiliser<br>74-76 t/year of nitrogen (mainly ammonium) |

**Table 10: main details related to the EU model to process sweet sorghum as sole feedstock in a plant with capacity 10,000 t/year as anhydrous bioethanol**

Regardless the number of hectares and the range of supplying, every year 68,000-69,000 tons of biomass are processed in the plant to obtain 1st generation bioethanol from the sugar juice and electricity and heat from the by-products.

The biomass supply to the plant occurs only during the harvesting period: 40 days at maximum between August and September in the South EU climate conditions.

On the contrary, the working period of the plant is 330 days per year; in fact one plant shutdown is foreseen approximately in July for the planned maintenance.

To preserve sugars during the entire working period of the plant, the chopped biomass is immediately crushed at the moment of the delivery and the obtained sugar juice is concentrated for the storage and processing in the period after the harvest. The final sugar concentrations of the syrup are 45% for the storage up to 3 months and 80% for the storage up to 11 months. The concentrated syrups are stored in adequate tanks at the plant.

The syrup is diluted before the inoculum with the mother suspension of yeasts; afterwards the fermentation is started up with an in batch process and the duration is set up in 22 hours.

As regards with the other technical aspects of the processing, the fermentation, distillation, rectification and dehydration phases are carried out in accordance with the guidelines described in the chapter 7.

A special explanation is necessary in this model for the water management, because a relevant amount of water is evaporated and then condensed and afterwards an important amount of water is required for the dilution of the syrup.

In the considered model this potential criticism is solved assuming that waste water of the concentration unit is discharged into surface water body (in accordance with the limits foreseen by the national and eventual local laws in terms of COD, nitrate, pH, phosphate, temperature and other chemical and physical parameters), whereas the potable water for the dilution is bought. This assumption appears preferable from technical and economic points of view if compared to the choice of storing waste water and using it the next dilution, because in this second case too high storage volumes are required.

Concerning the energetic exploitation of the by-products, bagasse is dried and then burnt in CHP plant fitted out with steam turbine (electric power 4.20 MWe), and biogas, obtained from vinasse through the anaerobic digestion, is burnt in a CHP plant based on a gas turbine (electric power 0.75 MWe). Electricity and heat, produced in these units, can be used for the self-consumption and the surplus of both of them is sold to the electric grid and distributed through a district heating network.

When the concentration unit stops working (i.e. at the end of harvesting period), a relevant thermal consumption lacks in the plant and consequently the correspondent energy can be converted in electricity with a small steam turbine (electric power 0.43 MWe), increasing the total production.

## 8.1 Case study: the development of the EU model 1 in the Po Valley in Italy

### Specific assumptions

The chain model to process sweet sorghum as sole feedstock in a plant of capacity 10,000 t/year (as anhydrous bioethanol) is applied in the case study contextualised to the Po Valley, in North East Italy. This area has an agricultural tradition and sowable crops are prevalent. The specific situation of the considered area is summarised in Table 11.

| Po Valley, North East Italy | |
|---|---|
| **Climatic characteristics** | Temperate oceanic |
| **Soil type** | Clay-loam, good depth and texture, good organic matter |
| **Rainfall in the growth period** | 600-700 mm |
| **Sowing time** | May |
| **Harvesting time** | September |
| **Crop diversification** | Quite low, prevalence of maize |
| **Farm structure** | Fragmentation of agricultural land |

**Table 11: main characteristics of the geographic area considered in the case study**

The agricultural land assumed in the case study is 3,800 hectares and the range of supply with the specific characteristics of the area is 15 km.

Taking into consideration the crop diversification and the farm structure of the area, the localisation of the fields is hypothesized as follows: 35% of the fields within 5 km from the plant, 44% of fields from 6 to 11 km from the plant, 21% of fields from 12 to 15 km from the plant. In this scenario the harvest requires 4 parallel yards; in each one 1 mower-shredder-loader machine and 6 farm tractor fitted out with dumper work; the consequent traffic is 15 tractor per hour during the 40 days of harvesting.

In this climate the duration of the harvesting period can last up to 40 days, if short cycle varieties and long cycle ones are cultivated at the same time in different fields of the considered agricultural surface.

The main details of the agricultural phase are reported in Table 12.

| Agricultural phase * | |
|---|---|
| **Fertilisation** | 100 kg N/ha<br>60 kg $P_2O_5$/ha<br>60 kg $K_2O$/ha |
| **Irrigation** | No |
| **Biomass yield** | 18.2 t/ha db |
| **Sugar yield** | 6.5 t/ha |
| **Anhydrous bioethanol yield** | 2.8 t/ha<br>3.5 m$^3$/ha<br>75.6 GJ/ha |
| **Previous land use** | Maize |
| * reference year: 2010 | |

**Table 12: main detail of the cultivation of sweet sorghum in the case study**

The production of 1st generation bioethanol is carried out in accordance with the guidelines. The utilised crusher has an efficiency of 93%; consequently the sugar concentration is 12.4% in the juice and 5.4% db in the bagasse. Bagasse has a residual moisture of 31%. As regards with the concentration unit, the continuous supply of the fermentation reactors is planned for concentrating at 80% most of the sugar juice (73% of the total amount) and at 45% the residual part (27% of the total amount). The following fermentation of the newly diluted sugar juice is carried out with a batch process. The applied efficiency of the alcoholic fermentation is 90% of the theoretical one.

The obtain anhydrous bioethanol has purity of 99.7% w/w and it is suitable to produce bio-ETBE or for bending with petrol.

Concerning the by-products exploitation, wet bagasse is stored and dried up to 10% immediately before the burning in the CHP plant. During the storage a biomass loss of 5% is hypothesized (mainly sugars). The CHP plant is fitted out with a biomass burner, a steam generator and a steam turbine; its thermal efficiency is 0.90. Unlike the other units, this CHP plant works for 340 days per year. Biogas obtained from vinasse supplies a gas microturbine with electrical efficiency of 34%.

In this case study, electricity is sold to the grid and heat is used for the self-consumption of the plant.

Electricity is sold to the grid because at the current time a relevant incentive system is available in Italy for the RES and especially for biomass. Consequently, the economic balance benefits from the selling of produced electricity and from the contextual purchase of the amount to consume in the plant.

Produced heat can cover the thermal consumption of the plant. The highest consumptions are relative to the following units: the concentration of the sugar juice (only during the harvesting period), the distillation and rectification units, the drying of the bagasse. In this case study the selling of heat through a district heating network is not considered, because there is a reasonable difficulty in the considered area in finding users.

Apart these assumptions, the case study applies the contents of the EU model 1.

## Economic analysis

The main costs and incomes considered in the economic analysis are summarised in Table 13.

| Economic analysis | | | |
|---|---|---|---|
| **Costs** | **Investment cost** | 30 million € | |
| | **Operative costs** | Biomass 20-35 €/t * | 4.94-8.64 million €/year |
| | | O&M | 2.69 million €/year |
| | | Other | 1.22 million €/year |
| **Incomes** | **Final products** | Bioethanol price 400-1,000 €/t * | 4.05-10.13 million €/year |
| | | Supported electricity price 0.18-0.28 €/kWh * | 7.78-12,11 million €/year |
| * variable subjected to the sensitivity analysis | | | |

**Table 13: main costs and incomes included in the economic analysis of the case study**

The investment costs include buildings, equipment, extraordinary maintenance, overheads (5%), technical costs (5%), unforeseen expenses (4%); land acquisition, eventual licenses and patents are not included.

In the operative costs the purchase of chemicals, the water management (i.e. discharge of waste water from the concentration unit, purchase of potable water for the syrup dilution), the disposal of ashes, the biomass moving and the insurance are included in the item called "Other".

The price of biomass and the values for the incomes are reported as range because these parameters are variables for the related sensitivity analyses.

The adequate reward of farmers as biomass suppliers is the prerequisite for the development of the chain. Consequently, the quantification of the biomass price requires a very precautionary approach. Assuming that in the considered area the agricultural costs correspond to 16-18 €/t wb (equivalent to 1,040-1,170 €/ha, including the transport to the plant with an average distance of 10 km), the affordability threshold is estimated at 30 €/t. In fact, in worse conditions other crops become more competitive than sweet sorghum and then the security of supply becomes critical.

However, the lower values of the range are included in the sensitivity analysis, because the economic viability of the chain model must foresee wide scenarios in order to evidence all the possible solutions in changing the market conditions (e.g. fall down of the bioethanol price, decrease of the national support to the RES).

The price of bioethanol depends on the energy market, especially on the oil price, and the considered range is believed precautionary.

As regards with the incomes from the electricity selling, at the current time in Italy the use of biomass allows to access to 2 alternative incentives, which are valid for 15 years:

a. the total income derives from the sum of the item due to the selling of electricity (based on the market price) and the value for the correspondent Green Certificates, the number of which is multiplied by a coefficient, which is specific for each RES (i.e. 1.8 for biomass and biogas);
b. the total income derives just from an all-inclusive tariff, the value of which depends on each RES (i.e. 0.28 €/kWh for biomass and biogas).

The second option is usually preferable, because it is not influenced by the energy market and consequently it allows incomes foreseeable for 15 years. Nevertheless at the current time this option is available only for electric power inferior to 1 MWe. The possibility to extend this incentive to higher electric powers (at least 5 MWe) is foreseen by the Italian law, but is not yet really applied because the regulations are lacking.

Taking into consideration the electric powers applied in this case study (i.e. 4.20 MWe from bagasse, 0.75 MWe from vinasse, 0.43 MWe from the concentration unit) and the related uncertainties, the range from 0.18 to 0.28 €/kWh is considered as precautionary.

The economic availability of the initiative is established for IRR values higher than 20%, because they ensure the bankability and significantly higher profits than the rate debit.

The results of the sensitivity analyses are summarised in the following four tables, where for each price of the biomass in the considered range (i.e. 20 €/t, 25 €/t, 30 €/t, 35 €/t) the IRR values are reported varying the market conditions: bioethanol and electricity prices in the rows and columns, respectively. In yellow the viable theses are evidenced; the darker cells indicate the conditions with IRR higher than 30%.

The threshold value for the adequate reward of farmers (i.e. 30 €/t) is viable for at least 900 €/t for bioethanol and 0.22 €/kWh for electricity or at least 1,000 €/t for bioethanol and 0.20 €/kWh. At the current time in Italy these scenarios are likely and then the certainty of supply could be ensured.

| IRR | | Bioethanol price [€/t] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 |
| Electricity price [€/MWh] | 180 | - 6.2% | 4.1% | 10.5% | 15.7% | 20.2% | 24.5% | 28.5% |
| | 200 | 1.4% | 8.7% | 14.3% | 19.1% | 23.4% | 27.5% | 31.4% |
| | 220 | 6.7% | 12.8% | 17.8% | 22.3% | 26.5% | 30.5% | 34.4% |
| | 240 | 11.2% | 16.5% | 21.2% | 25.5% | 29.6% | 33.5% | 37.3% |
| | 260 | 15.1% | 20.0% | 24.5% | 28.6% | 32.6% | 36.4% | 40.2% |
| | 280 | 18.8% | 23.4% | 27.6% | 31.7% | 35.6% | 39.4% | 43.1% |

**Table 14: IRR values varying the bioethanol and electricity market, if the price of biomass is 20 €/t**

| IRR | | Bioethanol price [€/t] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 |
| Electricity price [€/MWh] | 180 | - | -10.7% | 2.4% | 9.2% | 14.6% | 19.3% | 23.6% |
| | 200 | - | - 0.7% | 7.4% | 13.2% | 18.1% | 22.5% | 26.6% |
| | 220 | - 5.3% | 5.2% | 11.6% | 16.8% | 21.4% | 25.6% | 29.7% |
| | 240 | 2.5% | 9.9% | 15.4% | 20.2% | 24.6% | 28.7% | 32.6% |
| | 260 | 7.9% | 14.0% | 19.0% | 23.5% | 27.7% | 31.7% | 35.6% |
| | 280 | 12.4% | 17.7% | 22.4% | 26.7% | 30.8% | 34.7% | 38.6% |

**Table 15: IRR values varying the bioethanol and electricity market, if the price of biomass is 25 €/t**

| IRR | | Bioethanol price [€/t] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 |
| Electricity price [€/MWh] | 180 | - | - | - | 0.5% | 7.9% | 13.5% | 18.3% |
| | 200 | - | - | - 3.3% | 5.9% | 12.0% | 17.0% | 21.6% |
| | 220 | - | -10.1% | 3.5% | 10.3% | 15.7% | 20.4% | 24.7% |
| | 240 | - | 0.4% | 8.5% | 14.3% | 19.2% | 23.7% | 27.8% |
| | 260 | - 4.2% | 6.3% | 12.8% | 18.0% | 22.6% | 26.8% | 30.9% |
| | 280 | 3.7% | 11.0% | 16.6% | 21.4% | 25.8% | 29.9% | 33.9% |

**Table 16: IRR values varying the bioethanol and electricity market, if the price of biomass is 30 €/t**

| IRR | | Bioethanol price [€/t] | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 |
| Electricity price [€/MWh] | 180 | - | - | - | - | - 1.7% | 6.5% | 12.4% |
| | 200 | - | - | - | - 6.6% | 4.3% | 10.8% | 16.0% |
| | 220 | - | - | - | 1.5% | 9.0% | 14.6% | 19.4% |
| | 240 | - | - | - 2.2% | 7.0% | 13.1% | 18.2% | 22.7% |
| | 260 | - | - 9.3% | 4.6% | 11.5% | 16.9% | 21.6% | 25.9% |
| | 280 | - | 1.6% | 9.7% | 15.5% | 20.4% | 24.9% | 29.1% |

**Table 17: IRR values varying the bioethanol and electricity market, if the price of biomass is 35 €/t**

## GHGs emissions saving

### *Cultivation phase*

The emissions deriving from cultivation section include all the agronomic parts of the chain, as follows:

1. the input data of the biomass yield in the Po Valley (North East Italy) is 65 t/ha wb (moisture 72%), specifically expressed in 65,000 kg/ha/year, and the correspondent energetic output of 316,680 MJ sorghum/ha/year is calculated;
2. the energy consumption has been calculated considering the sum of primary energy, fuels and lubricants for the machineries for cultivation in the specific case study: it corresponds to 5,563 MJ/ha/year;
3. the agrochemicals inputs have been reported as really used in the case study for sorghum cultivation: N 100 kg/ha/year, $K_2O$ 60 kg/ha/year, $P_2O_5$ 60 kg/ha/year. Pesticides and herbicides have been calculated as 2 kg/ha/year;
4. the vinasse deriving from the distillation and rectification units is not considered to utilise as fertiliser because it is used in anaerobic digestion section for biogas production. Otherwise, the residual digested matter after biogas production is considered as source of organic fertilisation for sorghum cultivation. The amount has been calculated considering the production of digested matter which is 92,705 t/year to share in 3,800 ha, and the resulting amount is 24,396 kg/ha/year;
5. the seeding material used in the case study is 10 kg/ha/year;
6. the field $N_2O$ emissions have been calculated using the specific tool "$N_2O$ emissions IPCC". The biomass yield is 65,000 kg/ha/year wb (moisture 72%). The land use is from arable to arable land. In the direct $N_2O$ emissions from managed soils the inputs are 100 kgN/ha/year of synthetic fertiliser and 19.52 kgN/ha/year of organic fertiliser considering the application of digested matter that corresponds to 19.52 kgN/ha. The indirect $N_2O$ emissions are automatically calculated. The $N_2O$ resulted emissions are 3.06 $kgN_2O$/ha/year.

| Cultivation phase | kg/ha/year | $MJ_{sorghum}$/ha/year | MJ/ha/year | $gCO_2/MJ_{bioethanol}$ |
|---|---|---|---|---|
| **Biomass yield** | 65,000 | 316,680 | - | - |
| **Energy consumption** | - | - | 5,563 | 6.81 |
| **N**<br>**K**<br>**P**<br>**Pesticides** | 100<br>60<br>60<br>2 | -<br>-<br>-<br>- | -<br>-<br>-<br>- | 8.22<br>0.48<br>0.85<br>0.31 |
| **Digested matter** | 24,396 | - | - | 0 |
| **Seeding material** | 10 | - | - | 0 |
| **Field $N_2O$ emissions** | 3.06 | - | - | 12.66 |
| **Transport of digested matter** | - | - | - | 0.56 |
| **Total without allocation** | | | | **29.9 $gCO_2/MJ_{bioethanol}$** |
| **Total with allocation*** | | | | **26.7 $gCO_2/MJ_{bioethanol}$** |
| ***allocation factor 89%** | | | | |

**Table 18: GHGs emissions from the cultivation phase**

The emissions from cultivation phase correspond to 29.32 $gCO_2/MJ_{bioethanol}$.

The transport of digested matter to the fields for the organic fertilisation is included in the cultivation phase. The transport is considered with tanker trucks with water cannons for 20 km (this is the average value for the transport of biomass in the case study). The resulting amount is 0.56 $gCO_2/MJ_{bioethanol}$ which is summed to the previous number.

The emissions in GHGs for cultivation phase ($e_{ec}$) are 29.9 $gCO_2/MJ_{bioethanol}$. With the allocation, the emissions corresponds to 26.7 $gCO_2/MJ_{bioethanol}$ like reported in Table 18.

### *Transport and distribution phases*

For the transport phase, the quantity of product in megajoule is calculated in 316,680 $MJ_{sorghum}$/ha/year. The transport of biomass per truck for dry product with Diesel fuel is considered for the average value of 20 km. The partial value for emissions from this transport phase is 1.49 $gCO_2/MJ_{bioethanol}$ but this value must be summed with the transport of bioethanol from the plant to depot and then to filling stations. For this part of the transport the allocation factor must be considered (89%), so the emissions are 1.33 $gCO_2/MJ_{bioethanol}$.

For the transport of bioethanol from plant to and from depot:

1. the used trucks for liquids are considered of moving for 300 km as mean value of distance from the plant destinations inside EU;
2. the energy consumption depot has the same values reported for sugarcane bioethanol plants.

The resulting partial value is 1.31 $gCO_2/MJ_{bioethanol}$. The allocation is not considered for this phase, where all is allocated on bioethanol (100%).

For the filling station the values are the same of bioethanol from sugarcane or other feedstocks. Correspondent value in emissions is 0.44 $gCO_2/MJ_{bioethanol}$. The allocation is not considered for this phase, where all is allocated on bioethanol (100%).

For transport ($e_{td}$) the final value is 3.08 $gCO_2/MJ_{bioethanol}$ (Table 19).

### *Processing phase*

Basing on the data of the case study, 0.226 $MJ_{bioethanol}/MJ_{sorghum}$ are produced.

| Transport and distribution phase | km | Truck with Diesel fuel | $MJ/ MJ_{bioethanol}$ | $gCO_2/MJ_{bioethanol}$ |
|---|---|---|---|---|
| **Transport of harvested sweet sorghum*** | 20 | Truck for dry product | - | 1.49 |
| **Transport of bioethanol from plant** | 300 | Truck for liquids | - | 0.99 |
| **Energy consumption depot** | - | - | 0.00252 | 0.32 |
| **Filling station** | - | - | 0.0034 | 0.44 |
| **Total without allocation** | | | | **3.24 $gCO_2/MJ_{bioethanol}$** |
| **Total with allocation*** | | | | **3.08 $gCO_2/MJ_{bioethanol}$** |
| *allocation factor 89 % | | | | |

**Table 19: GHGs emissions from the transport and distribution phases**

In the sweet sorghum based model the total amount of electricity generated (CHP from bagasse burning, biogas burning and the turbine of the concentration section) is divided in electricity from by-products (biogas and concentration) that is allocated separately (89% bioethanol, 11% by-product), and electricity from CHP plant fed with the bagasse (this is totally attributed to bioethanol production). The large excess of electricity produced by CHP plant is sold to the grid. From the total amount of electricity a part is re-used in the plant for the bioethanol production: it corresponds to 0.108 $MJ/MJ_{bioethanol}$.

Since electricity is produced in a larger amount than the requirement of the plant, this is not really a demand but a reduced electricity output. The output of electricity from the steam production is credited by the electricity from bagasse burnt in CHP plant with steam turbine for power generation. As a consequence, also the electricity demand in the bioethanol plant is considered to be electricity from bagasse burnt in CHP plant to acknowledge for the fact that in practice this is not a demand, but a reduced electricity output.

In the considered case study the total production (output) of electricity is 43,240 MWh (155,664 GJ) obtained from bagasse burning, biogas and concentration section. Subtracting the amount relative to by-products (8,996 MWh) the electricity produced just in the CHP with bagasse is 34,244 MWh (123,278 GJ), correspondent to 0.454 $MJ/MJ_{bioethanol}$ on annual basis. Subtracting the electrical consumptions of the plant, the obtained value is 0.346 $MJ/MJ_{bioethanol}$; this is the surplus of electricity and the credit is calculated following RED Annex V, C.16.

The heat production is not considered, because it is completely re-used in the plant for internal needs.

The chemicals of the plant are used in the production processes and a part of them are lubricants for the machineries.

The emissions from the processing ($e_p$) correspond to -1.12 $gCO2/MJ_{bioethanol}$. The details are summarised in Table 20.

| Processing phase | $MJ_{bioethanol}/MJ_{sorghum}$ | $MJ/MJ_{sorghum}$ | $MJ_{bioethanol}$/ha/year | $MJ/MJ_{bioethanol}$ | $gCO_2/MJ_{bioethanol}$ |
|---|---|---|---|---|---|
| **Yield bioethanol** | 0.226 | - | 71,570 | - | - |
| **By-products** | - | 0.027 | | - | - |
| **Electricity taken from CHP** | - | - | - | 0.108 | - |
| **Steam from CHP** | - | - | | 1.66 | - |
| **Electricity generation (total)** | - | - | - | -0.454** | - |
| **Electricity bagasse Steam Turbine*** | - | - | - | -0.346** | -1.98 |
| **Chemicals** | - | - | - | 0.00132 $kg/MJ_{bioethanol}$ | 0.85 |
| **Total without allocation** | **-1.12 $gCO_2/MJ_{bioethanol}$** | | | | |
| **Total with allocation*** ** | **-1.00 $gCO_2/MJ_{bioethanol}$** | | | | |

***** surplus electricity, credit is calculated following RED Annex V C.16
****** electricity output, so it is negative
*******allocation factor 89 %

**Table 20: GHGs emissions from the processing phase**

### *Land use change and improved agricultural management*

Concerning the LUC in the sweet sorghum cultivation, the assumption is “no LUC”, because the cultivation of sweet sorghum in the case study is done in fields where usually maize is cultivated. In fact the same techniques for maize are used for sweet sorghum and also the machineries and the type of soils are similar.

The improved agricultural management, the $CO_2$ capture and replacement and for $CO_2$ capture and geological storage are not considered.

### *GHGs emission saving in the case study*

The final value of emissions per megajoule of bioethanol obtained from sweet sorghum corresponds to 32.00 $gCO_2/MJ_{bioethanol}$. The fossil fuel reference (i.e. petrol) has the emission value of 83.8 $gCO_2/MJ_{petrol}$. The allocated result corresponds to 28.8 $gCO_2/MJ_{bioethanol}$.

The emission reduction resulting from the calculation foreseen in the RED corresponds to 66%. It complies with the objective to 2018.

This result is comparable to the values for bioethanol from sugarcane (i.e. 71% GHG emissions saving as default value) and the bioethanol from wheat with straw burnt in CHP (i.e. 69% GHG emissions saving as default value).

## TOPIC: METHODOLOGY FOR THE CALCULATION OF GHGS EMISSIONS SAVING

An important aspect of the model is relative to the GHGs emissions in the bioethanol production from sweet sorghum and in the power generation. The calculation of the LCA of this chain and the emissions of grams of $CO_2$ equivalents per megajoule of produced bioethanol can give the percentage of emissions saving of the bioethanol produced from sweet sorghum in Italy. The values are compared with the values given in the Annex V of the RED for other energy crops used for biofuels production.

For this purpose, the public "BioGrace greenhouse gas calculation tool" (www.biograce.net) is the instrument that can be used for the calculation of the GHGs saving producing bioethanol from sweet sorghum (as 1st generation ethanol) and heat and power from the exploitation of by-products of the chain.

The BioGrace tool allows reproduction of the calculation of the Annex V default values of the RED for biofuels production pathways and also allows to perform individually adapted calculations.

In accordance with the guidelines for the EU model and especially with the assumptions of the case study of the model 1, the BioGrace tool has been used integrating the already created pathways of bioethanol from sugarcane, from maize, from wheat with the residual straw burnt in CHP plant. Integrating these three pathways and taking the parts of interest relatively to sweet sorghum, the final results were obtained for this crop.

An important consideration regards the fact that the model foresees a concept of biorefinery, where integrated chain is deriving from the 1st generation bioethanol production and the use of by-products for power generation in large excess if considered the requirements for the biofuel production.

Sweet sorghum is processed similarly to sugarcane, transporting the fresh harvested biomass to the plant, extracting the sugar juice to ferment to bioethanol, burning the bagasse in CHP unit. Consequently the main part of the values can be similar and/or compared to those of sugarcane.

In order to verify the goodness of the results obtained for sweet sorghum, which is a sowable crop unlike sugarcane, the cultivation data (e.g. fertilisers, period of sowing and harvesting, energy consumption in terms of machineries) have been compared to those of maize.

Furthermore, the burning of bagasse in CHP plant is similar to the burning of bagasse of sugarcane but also to the burning of wheat straw (i.e. also the LHV of straw and bagasse are similar).

The electricity generated from the bagasse combustion is considered in the emissions of the plant: a part is reused in the bioethanol production, but a large amount is excess electricity that is counted in the emissions of the bioethanol plant section.

The biogas obtained from the anaerobic digestion of the vinasse is then burnt in CHP plant and the electricity is sold to the grid; the same happens for the electricity generated from concentration section with the condensation turbine. For these two sections, the electricity is not considered part of the bioethanol plant but like a by-product of the chain.

Basing on these premises, the allocation on bioethanol is 89% and the rest is by-products.

Inserting the data obtained from the sweet sorghum cultivation in Italy and from the elaborated model in terms of energy input and outputs of the entire chain, the final results were obtained.

The used tool is structured in order to work in already prepared pathways inserting own data to finally get values for emissions deriving from cultivation phase ($e_{ec}$), from transport and distribution phase ($e_{td}$), from processing phase ($e_p$), from eventual land use change ($e_l$), from improved agriculture management ($e_{sca}$) or carbon dioxide capture and replacement ($e_{ccr}$) or carbon dioxide capture and geological storage ($e_{ccs}$) and automatically it is possible to obtain the GHGs emissions saving expressed in percentage and the grams of $CO_2$ emitted per megajoule of bioethanol produced.

For adapting the considered model, the starting point is the sheet of bioethanol from sugarcane because this is a model which process a biomass that produces simple fermentable sugars like sweet sorghum.

## 8.2 Case study: the development of the EU model in the industrial area of Thessaloniki in Greece

### Specific assumptions

The chain model to process sweet sorghum as sole feedstock in a plant of capacity 10,000 t/year (as anhydrous bioethanol) is applied in the following case.

| Industrial area of Thessaloniki, Greece | |
|---|---|
| **Climatic characteristics** | Mediterranean |
| **Soil type** | Clay-loam, good depth and texture, good organic matter |
| **Rainfall in the growth period**[56] | 33.5 mm |
| **Sowing time** | May |
| **Harvesting time** | September |
| **Crop diversification** | Quite low, prevalence of rice |
| **Farm structure** | Fragmentation of agricultural land |

**Table 21: main characteristics of the geographic area considered in the case study**

The biomass yield in fresh and dry basis, as well as the juice and total sugar yields used in this case study are in accordance to the results of a pilot case study conducted in Northern Greece by the Technological Institute of Thessaloniki. These values are presented in Table 22.

| Cultivar | Fresh Biomass [t/ha] | Dry Biomass [t/ha] | Juice [t/ha] | Degree Brix [%] | Total sugar [t/ha] | Theoretical ethanol [l/ha] | Theoretical ethanol [t/ha] |
|---|---|---|---|---|---|---|---|
| Urja | 97.3 | 33.5 | 34.4 | 14.4 | 3.86 | 7620 | 6 |

**Table 22: fresh biomass yields, dry biomass yields, juice yields, Brix degree of juice, total sugar yield and theoretical bioethanol yield of "Urja" cultivar grown in soil salinity of 3,.2 $dSm^{-1}$ and received irrigation of 210 mm**

From the 4 sweet sorghum cultivars that were tested in the 2 years study conducted in Northern Greece, one cultivar and more specifically the "Urja" cultivar had the greatest theoretical bioethanol yield.

The agricultural land assumed in the case study is 1,660 hectares and the range of supply of the feedstock is an area at a distance of 20 km from the bioethanol plant. The agricultural fields are located next to the Industrial Area of Thessaloniki where the plant will be hosted. The members of the Agricultural Cooperative of Halastra own an agricultural surface of 6,000 hectares.

**Figure 24: location of bioethanol plant, sweet sorghum fields and refining oil company (source: REACM)**

In this scenario, according to the EU model the harvesting requires 6 parallel yards;

each one of them has 1 mower-shredder-charger machines and 6 farm tractors.

In this climate the duration of the harvesting period can be up to 40 days, if short cycle varieties and long cycle ones are cultivated at the same time in different fields of the considered agricultural surface.

The main details of the agricultural phase are reported in Table 23.

**Fertilisation:** 2 days before sorghum sowing, 130 kgN/ha, as ammonium sulphate $[(NH_4)_2SO_4]$ 50 kgP/ha as super phosphate $[Ca(H_2PO_4)_2]$ and 65 kgK/ha as potassium sulphate $(K_2SO_4)$ are broadcast applied.

**Biomass:** the plant's goal is to produce 10,000 t (12,649,200 liters) of bioethanol per year by using sweet sorghum as feedstock. Biomass's efficiency is estimated at 97.3 t/ha, the agricultural surface at 1,660 ha and bioethanol efficiency is estimated at 6 t/ha or 7.6 m³/ha. In order to produce 10,000 t of bioethanol 161,518 t of fresh biomass are needed. As regards the costs, there is no available data about the price of sweet sorghum, as a feedstock for bioethanol production in Greece, because so far there are only pilot crops and no regular production. According to the EU model the agricultural costs are estimated at 16-18 €/t wb, while the final net income for the farmers is estimated at 12-14€/t wb.

| | |
|---|---|
| **Fertilisation** | 130 kgN/ha<br>50 kgP/ha<br>65 kgK/ha |
| **Irrigation** | 210 mm<br>(supplemented with 142-261mm of rainfall during growth) |
| **Moisture content** | 65.6% |
| **Anhydrous bioethanol yield** | 6 t/ha<br>7.6 m³/ha<br>164.8 GJ/ha |
| **Bioethanol production** | 10,000 t/year<br>12,649 m³/year |
| **Processed fresh biomass** | 161,518 t/year |
| **Processed dry biomass** | 55,610 t/year |
| **Agricultural Surface** | 1,660 ha |

**Table 23: detailed characteristics of the cultivation of sweet sorghum and bioethanol production in the case study**

**Anhydrous bioethanol yield:** for the calculation of the theoretical bioethanol production from sweet sorghum fresh biomass, the equations reported by Sakellariou-Makrantonaki *et al.* (2007) and Zhao *et al.* (2009) were modified as follows[57,58]:

total bioethanol yield [l/ha] = total sugar content [%] x fresh biomass [t/ha] x 6.5 (conversion factor of bioethanol from sugar) x 0.85 (process efficiency of bioethanol from sugar) x (1.00/0.79) (specific gravity of bioethanol in g/ml).

The processing is carried out in accordance with the guidelines reported in the chapter 7.

As regards with the exploitation of the by-products, the electricity is sold to the grid and heat is used for the self-consumption of the plant.

The most important factor for the success of such a project is the suitable location for the bioethanol plant to be installed. However, the possible alternative sites can be various. The most optimal solution would be the result of a methodology based on a systematic research, analysis and evaluation of specific alternatives.

### *Basic requirements for site collection*

The possible sites where the plant should be located must meet the following requirements:

- availability of human resources
- cost for land purchase
- easy supply of raw materials
- sufficient environmental conditions
- availability of transport facilities
- proximity to markets
- availability of auxiliary materials and services of public utilities
- acceptance by the local community
- adequate financial, administrative and social infrastructure
- special services and facilities provided by the development law n. 3908/2011.

The starting point for a preliminary selection or rejection of some sites is the location of raw materials. The bioethanol plant should be located near the cultivated land of sweet sorghum.

The second point is the existence of an industrial park in the area. The industrial parks provide specific advantages to the companies located there such as integrated infrastructures, organized industrial activities, infrastructures for water supply, for energy supply, communication network (telephone, internet services), wastewater treatment, road networks.

Furthermore, the installation of a plant inside an industrial park provides the following technical and business advantages to the future investors:

- concession terms of layout
- developed network of technical infrastructure
- added-value services (natural gas, broadband network, fire station)
- transport access
- easy installation with fewer bureaucratic requirements
- preferential subsidy through development law.

### *Industrial Park of Thessaloniki*

The Industrial Park of Thessaloniki is located northwest of the city (18 km) at the area of Sindos, and complies with the above requirements. The Industrial Park has a total surface area of 395 hectares covering 12 blocks with streets and common use areas, whereas approximately 187 hectares of building plots are currently available. Private-use vehicles or other heavy-duty vehicles can pass through the VIPATHE S.A. via the road network that is currently being

**Figure 25: Industrial Park of Thessaloniki for the potential location of the plant (source: http://www.vipathe.gr/en/index.asp)**

built between the 12 blocks. Also, in order to facilitate the companies that are to be co-housed in the park, there is a railway platform linking the park with the railway lines leading to Thessaloniki, Athens and the urban centres of northern and north-eastern Greece, Bulgaria and FYROM.

Characteristics of the industrial Park of Thessaloniki

1. Availability of human resources

   The Regional unit of Thessaloniki has a population of 1,104,460. The unemployment rate in the region of Central Macedonia is 18.8%[59,60].

2. Cost of site

   The cost for land purchase amounts to 160 €/m$^2$ [61].

3. Easy supply of raw materials

   The total cultivable land in the Regional unit of Thessaloniki is around to 412,747 hectares[62].

4. Sufficient environmental conditions

   The average temperature in Thessaloniki is 5.2 °C in January and 26.6 °C in July. The average rainfall for the same months is 36.8 mm and 23.9 mm, respectively.

5. Availability of transportation facilities

   The Industrial Park of Thessaloniki is located near the highway Athens-Thessaloniki and the Egnatia Road and the refining oil industry "HELLENIC PETROLEUM S.A". The railway, the airport, the port and the bus line are close to the area as well.

6. Proximity to markets

   The Industrial Park is on the verge of the second largest market in Greece, Thessaloniki, and is facilitated by the port of Thessaloniki.

7. Availability of auxiliary materials and services of public utility

   The Industrial Park has water supply, waste treatment, pollution control laboratory. It also offers telephone and electricity networks, broadband communications, fire service and connection to the natural gas network.

8. Adequate financial, administrative and social infrastructures

   The Industrial Park has an administration and management department, while the city of Thessaloniki offers all the necessary administrative, economic and social services.

9. Special services and facilities provided by the development law n. 3908/2011

   For the Industrial Area of Thessaloniki the development law provides 35% subsidy or leasing subsidy or grant for the employment cost.

## Economic analysis

The main costs considered in the production line of bioethanol from sweet sorghum are according to the model 1 and are summarised in Table 24.

The investment costs is estimated at 30 million €, including buildings, equipment, extraordinary maintenance, overheads (5%), technical costs (5%), unforeseen expenses (4%); land acquisition, eventual licenses and patents are not included. The operative costs include the purchase of chemicals, the water management, disposal of ashes, biomass transportation, insurance and other cost categories.

| | |
|---|---|
| **Biomass** | ~160,000 t/year x 30€/t=4,800,000€/year |
| **Investment cost** | 30 million € |
| • **Operative costs** | 1,220,000 €/year |
| • **O&M** | 2,690,000 €/year |
| **Other** | 1,220,000 €/year |

**Table 24: main costs included in the economic analysis of the case study**

| | | | |
|---|---|---|---|
| **Incomes** | **Final products** | Bioethanol price 400-1,000 €/t | 4.0-10.0 million €/year |
| | | Supported electricity price 0.15-0.20 €/kWh | 7.78-12,11 million €/year |

**Table 25: main incomes included in the economic analysis of the case study**

Concerning the incomes, the price of bioethanol depends on the energy market, especially on the price of oil, and the considered range is depended on the oil prices. The values are reported as average values in Table 25.

As regards with the incomes from the electricity selling, the FIT rate(1), in Greece, is ranged from 0.15-0.20 €/KWh.

In Greece for biomass is foreseen the FIT, whose values are guaranteed for 20 years:

- o 200 €/MWh for power inferior to 1 MW
- o 175 €/MWh for power from 1 MW to 5 MW
- o 150 €/MWh for power higher than 5 MW.

As regards with the number of jobs, it is estimated that 14 people will be working each hour in the bioethanol plant (Table 26).

## GHGs emissions saving

Bioethanol production facility, as any industrial process, faces a big challenge. This challenge is to protect the environment not only during the period of construction, but during the operation as well. As a result, one of the main goals of the plant is to decrease GHGs emissions, throughout the LCA.

### *Cultivation phase*

The emissions deriving from cultivation section include all the agronomic parts of the chain, as follows:

1. the input data of the biomass yield in the area western of Thessaloniki's Regional District (North Greece) is 97.3 t/ha wb (moisture 65.6%), specifically expressed in 97,300 kg/ha/year, and the correspondent energetic output of 582,399 $MJ_{sorghum}$/ha/year is automatically calculated;

(1) Such schemes pay renewable energy producers a set rate (tariff) for each unit of electricity fed into the grid, and generally oblige power companies to purchase all electricity from eligible producers in their service area over a long period of time.

| | | |
|---|---|---|
| **Working days of the plant per year** | 330 days | |
| **Daily production of bioethanol** | Q=30.7 t/day | |
| **Calculation method** | $L=K/Q^{-0.76}$ | |
| **Processes** | K | L=Staff hours per ton of product |
| **1. Milling** | 10 | 1.384 |
| **2. Extraction** | 17 | 2.352 |
| **3. Fermentation** | 23 | 3.182 |
| **4. Distillation** | 10 | 1.384 |
| **5. Dehydration** | 10 | 1.384 |
| **6. By-products elaboration** | 10 | 1.384 |
| **Total staff hours per ton of product** | 11.07 hr/t d | |
| **Staff hours per day** | 340 hr/d | |
| K=constant, corresponding at a value of "23" for discontinuous processes, "17" for processes with low requirement in work and "10" for continuous automatic processes | | |

**Table 26: staff hours per day**

2. the energy consumption has been calculated considering the sum of primary energy, fuels and lubricants for the machineries for cultivation in the specific case study: it corresponds to 5,563 MJ/ha/year;
3. the agrochemicals inputs have been reported as actually used in the case study for sorghum cultivation: N 130 kg/ha/year, $K_2O$ 50 kg/ha/year, $P_2O_5$ 65 kg/ha/year. Pesticides and herbicides have been calculated as 2 kg/ha/year;
4. the vinasse deriving from the distillation and rectification unit is not considered to be utilised as fertiliser because it is used in anaerobic digestion section for biogas production. Otherwise, the residual digested matter after biogas production is considered as source of organic fertilisation for sorghum cultivation. The amount has been calculated considering the production of digested matter which is 60,621.5 t/year to share in 1,660 ha, and the resulting amount is 36,519 kg/ha/year;
5. the seeding material used in the case study is 10 kg/ha/year;
6. the field $N_2O$ emissions have been calculated using the specific part of "$N_2O$ emissions IPCC". The biomass yield reported is 97,300 kg/ha/year wb (moisture 65.6%). The land use is from arable to arable land. In the direct $N_2O$ emissions from managed soils the inputs are 130 kgN/ha/year of synthetic fertiliser. The indirect $N_2O$ emissions are automatically calculated. The $N_2O$ resulted emissions are 3.51 kg$N_2O$/ha/year.

The emissions from cultivation phase correspond to 15.09 g$CO_2$/$MJ_{bioethanol}$.

The digested matter is transferred to the fields for the organic fertilisation. The resulting amount is 0.37gCO2/$MJ_{bioethanol}$ which is summed to the previous number.

With the allocation the emissions correspond to 13.75 g$CO_2$/MJbioethanol as it is shown in Table 27.

| Cultivation phase | kg/ha/year | $MJ_{sorghum}$/ha/year | MJ/ha/year | $gCO_2/MJ_{bioethanol}$ |
|---|---|---|---|---|
| **Biomass yield** | 97,300 | 582,399 | - | - |
| **Energy consumption** | - | - | 5,563 | 3.02 |
| **N**<br>**K**<br>**P**<br>**Pesticides** | 130<br>50<br>65<br>2 | -<br>-<br>-<br>- | -<br>-<br>-<br>- | 4.74<br>0.23<br>0.52<br>0.14 |
| **Digested matter** | 36,519 | - | - | 0 |
| **Seeding material** | 10 | - | - | 0 |
| **Field $N_2O$ emissions** | 3.51 | - | - | 6.44 |
| **Transport of digested matter** | - | - | - | 0.37 |
| **Total without allocation** | **15.46 $gCO_2/MJ_{bioethanol}$** | | | |
| **Total with allocation*** | **13.75 $gCO_2/MJ_{bioethanol}$** | | | |
| *allocation factor 89% | | | | |

**Table 27: GHGs emissions from the cultivation phase**

## *Transport and distribution phases*

For the transport phase, the quantity of product in mega joule is automatically calculated in 582,399 $MJ_{sorghum}$ /ha/year. The transport per truck for dry product with Diesel fuel is considered for the average value of 20 km. The partial value for emissions from this transport phase is 1.46 $gCO_2/MJ_{bioethanol}$ but this value must be summed with the transport of bioethanol from the plant to depot and then to filling stations. For this part of the transport the allocation factor must be considered (89%), so the emissions are 0.88 $gCO_2/MJ_{bioethanol}$.

For Transport (etd) the final value is 1.77 $gCO_2/MJ_{bioethanol}$ (Table 28).

| GHGs emissions Transport and distribution | km | Truck with Diesel fuel | $MJ/MJ_{bioethanol}$ | $gCO_2/MJ_{bioethanol}$ |
|---|---|---|---|---|
| **Transport of harvested sweet sorghum** | 20 | Truck for dry product | - | 0.88 |
| **Transport of bioethanol from plant** | 9 | Truck for liquids | - | 0.35 |
| **Energy consumption depot** | - | - | 0.00252 | 0.32 |
| **Filling station** | - | - | 0.0034 | 0.44 |
| **Total without allocation** | **1.99 $gCO_2/MJ_{bioethanol}$** | | | |
| **Total with allocation*** | **1.77 $gCO_2/MJ_{bioethanol}$** | | | |
| *allocation factor 89 % | | | | |

**Table 28: GHGs emissions from the transport and distribution phases**

### *Processing phase*

Based on the data of the case study 0.277 $MJ_{bioethanol}/MJ_{sorghum}$ is produced.

In the sweet sorghum based model the large excess of electricity produced by CHP plant plus the biogas combustion is sold to the grid. The electricity taken from CHP plant for the bioethanol production corresponds to 0.108 $MJ/MJ_{bioethanol}$.

Since electricity is produced in a larger amount than the requirement of the plant, this is not really a demand but a reduced electricity output. The output of electricity from the steam production is credited by the electricity from bagasse burnt in CHP plant with steam turbine for power generation. As a consequence, also the electricity demand in the bioethanol plant is considered to be electricity from bagasse burnt in CHP plant to acknowledge for the fact that in practice this is not a demand, but a reduced electricity output.

In the considered case study the total production (output) of electricity is 43,240 MWh (155,664 GJ) obtained from bagasse burning, biogas and concentration section. Subtracting the amount relative to by-products (8,996 MWh) the electricity produced just in the CHP with bagasse is 34,244 MWh (123,278 GJ), correspondent to -0.454 $MJ/MJ_{bioethanol}$ on an annual basis. Subtracting the electrical consumptions of the plant, the obtained value is -0.346 $MJ/MJ_{bioethanol}$; this is the surplus of electricity and the credit is calculated following RED Annex V, C.16.

The thermal energy produced in form of heat is completely re-used in the plant for internal needs.

In the part relative to the chemicals used in the plant, the values are the same of sugarcane bioethanol: chemicals used in the production processes and lubricants for the machineries.

The emissions from the processing (ep) is -1.12 $gCO_2/MJ_{bioethanol}$. The details are summarised in Table 29.

| Processing phase | $MJ_{bioethanol}/MJ_{sorghum}$ | $MJ/MJ_{sorghum}$ | $MJ_{bioethanol}$/ha/year | $MJ/MJ_{bioethanol}$ | $gCO_2/MJ_{bioethanol}$ |
|---|---|---|---|---|---|
| **Yield bioethanol** | 0.277 | - | 161,324 | - | - |
| **By-products** | - | 0.027 | | - | - |
| **Electricity taken from CHP** | - | - | - | 0.108 | - |
| **Steam from CHP** | - | - | | 1.660 | - |
| **Electricity generation (total)** | - | - | - | -0.454** | - |
| **Electricity bagasse Steam Turbine*** | - | - | - | -0.346** | -1.98 |
| **Chemicals** | - | - | - | 0.00132 $kg/MJ_{bioethanol}$ | 0.85 |
| **Total without allocation** | **-1.12 $gCO_2/MJ_{bioethanol}$** | | | | |
| **Total with allocation*** ** | **-1.00 $gCO_2/MJ_{bioethanol}$** | | | | |

* surplus electricity, credit is calculated following RED Annex V C.16
** electricity output, so it is negative
***allocation factor 89 %

**Table 29: GHGs emissions from the processing phase**

### *Land use change and improved agricultural management*

The LUC, the improved agricultural management, the $CO_2$ capture and replacement and for $CO_2$ capture and geological storage, are not considered.

### *GHGs emission saving in the case study*

The final value of emissions per megajoule of bioethanol obtained from sweet sorghum corresponds to 14.66 $gCO_2/ MJ_{bioethanol}$. The allocated result corresponds to 13.04 $gCO_2/ MJ_{bioethanol}$

The emission reduction resulting from the calculation foreseen in the RED corresponds to 82.5 %.

## 8.3 Case study: the development of the EU model in Andalusia in Spain

### Specific assumptions

The chain model to process sweet sorghum as sole feedstock in a plant of capacity 10,000 t/year (as anhydrous bioethanol) is applied in the case study contextualised to the Jédula (Cádiz) in South of Spain (Andalusia). In fact the Ministry of industry, tourism and trade of Spain, in compliance of EU instructions, has just released a document on the "Assessment of the Balance of Greenhouse Gasses Emissions from Biofuels Production", in which the production of bioethanol from sweet sorghum in Andalusia (South Spain) is evaluated[63]. The specific situation of the considered area is summarised in Table 30.

The agricultural land assumed in the case study is 2,147 hectares and the range of supply with the specific characteristics of the area is 15 km. The number of hectares is indicated considering that the biomass production per hectare is 31 t/ha db and the percentage of sugar per ton is 38%.

This crop area produces approximately 214,750 tonnes of fresh sweet sorghum with 10% of sugars. Finally the amount of sugar of 21,475 tonnes is needed to produce 12,500 $m^3$ of bioethanol. With these data, the amount of bagasse used in the power generation unit is 77,310 tonnes per year with a 10% of moisture.

| Jédula (Cadiz), South Spain | |
|---|---|
| **Climatic characteristics** | Temperate Mediterranean maritime |
| **Rainfall in the growth period** | 600-800 mm |
| **Sowing time** | May |
| **Harvesting time** | September |
| **Crop diversification** | Sugar beet |
| **Farm structure** | Fragmentation of agricultural land |

**Table 30: main characteristics of the geographic area considered in the case study**

Taking into consideration the crop diversification and farm structure of the area, the localisation of the fields is hypothesized as follows: 35% of the fields within 5 km from the plant, 44% of fields from 6 to 11 km from the plant, 21% of fields from 12 to 15 km from the plant. In this scenario the harvesting requires 4 parallel yards; in each one of them 1 mower-shredder-charger machine and 6 farm tractor fitted out with dumper work; the consequent traffic is 15 tractor per hour during the 40 days of harvesting.

In this climate the duration of the harvesting period can be up to 40 days, if short cycle varieties and long cycle ones are cultivated at the same time in different fields of the considered agricultural surface.

The main details of the agricultural phase are reported in Table 31.

| Agricultural phase * | |
|---|---|
| **Fertilisation** | 31 kgN/ha<br>273 kgUrea (46% N)/ha<br>60 kg$P_2O_5$/ha<br>31 kg$K_2O$/ha |
| **Irrigation** | Yes (4,478.5 $m^3$/ha) |
| **Biomass yield** | 31 t/ha db |
| **Sugar yield** | 6-12 t/ha |
| **Anhydrous bioethanol yield** | 2.8 – 5.6 t/ha<br>3.5 – 7.0 $m^3$/ha<br>84 - 168 GJ/ha |
| **Previous land use** | Sugar beet |
| * reference year: 2010 | |

**Table 31: main details of the cultivation of sweet sorghum in the case study**

The production of 1st generation bioethanol is carried out in accordance with the guidelines of the chapter 7. The utilised continuous diffuser has an efficiency of 97%; consequently the sugar concentration is 12% in the juice and 5% db in the bagasse. Bagasse has residual moisture than can vary between 31% and 50%. As regards with the concentration unit, the continuous supply of the fermentation reactors is planned concentrating at 80% the most of the sugar juice (54.5% of the total amount) and at 45% only a 27.3% of the total amount, and without any concentration or a reduced concentration (15-18%) and used directly to produce bioethanol the 18.2%. The following fermentation of the newly diluted sugar juice is carried out with a batch process. The applied efficiency of the alcoholic fermentation is 90% of the theoretical one.

The obtained anhydrous bioethanol has a purity of 99.7% w/w and it is suitable to produce bio-ETBE or for blending with petrol.

Concerning the by-products exploitation, wet bagasse is stored and dried up to 10-20% immediately before the burning in the CHP plant. During the storage a biomass loss of 5% is hypothesized (mainly sugars). The CHP plant is fitted out with a biomass burner, a steam generator and a steam turbine; its thermal efficiency is 0.90 and power efficiency is 0.29. Unlike the other units, this CHP plant works for 360 days per year. Biogas obtained from vinasse supplies a gas micro-turbine with electrical efficiency 34%.

In this case study, electricity is sold to the grid and heat is used for the self-consumption of the plant.

In Spain, there are incentives to the power generation from renewable energy, and specifically from biomass, with a price of 16.81 c€/kWh from biomass (when the cogeneration plant has more than 2 MW installed) if this bagasse is considered as an energy crop, and 11.38 c€/kWh if bagasse is considered as biomass waste from industrial plants.

Considering the amount of 77,310 tonnes per year of bagasse, the power installation can be 10 MWe.

Heat is able to cover the thermal consumption of the plant. The highest consumptions concern the following units: the concentration of sugar juice (only during the harvesting period), the distillation and rectification units, the drying of the bagasse. In this case study the selling of heat through a district heating network is not considered, because there is a reasonable difficulty in the considered area in finding users.

Apart these assumptions, the case study apply the contents of the EU model 1.

## Economic analysis

The main costs and incomes considered in the economic analysis are summarised in Table 32.

| Economic analysis | | | |
|---|---|---|---|
| **Costs** | **Investment cost** | 30 million € | |
| | **Operative costs** | Biomass 29-34 €/t (34 €/t db with a 38% of sugar in the stalk db) | 6.23-7.30 million €/year |
| | | O&M | 2.69 million €/year |
| | | Other | 1.22 million €/year |
| **Incomes** | **Final products** | Bioethanol price 450-800 €/m$^3$ | 5.63-10.00 million €/year |
| | | Supported electricity price from biomass 16.81 – 11.38 c€/kWh (10 MWe installed has a production of 86,400 MWh per year, 360 days and 24 h per day) | 14.52 – 9.83 million €/year |

**Table 32: main costs and incomes included in the economic analysis of the case study**

The investment costs include buildings, equipment, extraordinary maintenance, overheads (5%), technical costs (5%), unforeseen expenses (4%); land acquisition, eventual licenses and patents are not included.

In the operative costs the purchase of chemicals, the water management (i.e. discharge of waste water from the concentration unit, purchase of drinking water for the dilution of syrup), the disposal of ashes, the biomass moving and the insurance are included in the item named "Other".

The price of biomass and the values for the incomes are reported as range.

The adequate reward of farmers as biomass suppliers is the prerequisite for the development of the chain. Consequently the quantification of the price of biomass requires a very precautionary approach. Assuming that in the considered area the agricultural costs are 16-18 €/t wb (correspondent to 1,040-1,170 €/ha, included the transport to the plant with an average distance of 10 km), the affordability threshold is estimated at 30 €/t. In fact in worse conditions other crops become more competitive than sweet sorghum and then the security of supply becomes critical. Depending on the concentration of sugar in the sweet sorghum stalks, the price of the biomass can vary, increasing this price per tonne if the amount of sugar is higher.

The price of bioethanol depends on the international energy market, considering the international price of bioethanol from Brazil, the US or India. Considering this price and the transport cost to Europe or the duty in Europe for the external bioethanol, the final price must have a maximum value of 80-85 c€/l. On the other hand, the minimum price of bioethanol can be fixed on 45 c€/l. This value can be evaluated with the data of production cost in Brazil, that is about 30 c€/l.

Considering the cost evaluation of the bioethanol production process, the objective of the plant manager must be the use of the maximum amount of sweet sorghum biomass for power generation.

Considering the information showed on Table 33, the range of total cost is 10.14-11.21 million €/year and the range of incomes is 15.46 – 24.52 million €/year.

If the total investment cost is fixed on 30 million €, the payback can vary between 2.5 years (the best case) and 7.5 years (the worst case).

## GHGs emissions saving

### *Cultivation phase*

The evaluation has been made considering the crop area of Jédula (Cádiz) in Spain, where the sweet sorghum yield is 31 t/ha db.

In Figure 26, the production yield in Andalusia is indicated.

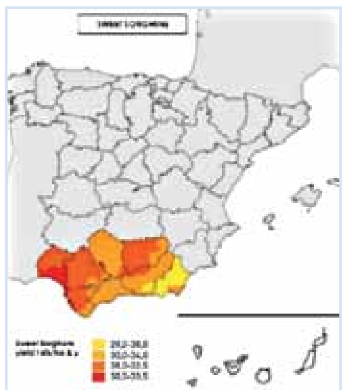

**Figure 26: sweet sorghum production in Andalusia (source: IDAE 2011 on page 28)**

The production of sweet sorghum in Andalusia has a very good result only with irrigation. The irrigation data obtained for this crop in Andalusia can vary between 4.0 and 4.3 $m^3$/ha. Thus, if the water use efficiency for this crop is 0.16-0.27 $m^3$/kg db, the total amount of water needed for the crop (with a production of 31 t/ha) is 4.96-8.37 $m^3$/ha, that is the sum of irrigation and rainfall.

With the information beforementioned, the calculation of GHG emissions and energy consumptions has been made, obtaining the saving on these aspects due to the use of sweet sorghum as feedstock for the production of bioethanol.

| Biofuel | Crop | Energy consumption by the fertilizers production | Energy consumption by the fuel consumption on crop works | Energy consumption by the production of plants | Energy consumption by the power use | Energy by the sowing seed | Total |
|---|---|---|---|---|---|---|---|
| Bioethanol | Sweet sorghum (irrigation) in Andalusia | 49.59 | 17.53 | 2.80 | 0.03 | 0.13 | 70.08 |

**Table 33: fossil energy consumption in the agricultural steps (as megajoule of fossil energy by gigajoule of biofuel produced)[64]**

| Biofuel | Crop | Emissions by the fertilizers production | Emissions by the fuel consumption on crop works | Emissions by the production of plants | Emissions by the power consumption | Emissions by the $N_2O$ of the land | Emissions by the sowing seed | Total |
|---|---|---|---|---|---|---|---|---|
| Bioethanol | Sweet sorghum (irrigation) in Andalusia | 5.70 | 1.20 | 0.10 | 1.81 | 5.65 | 0.03 | 14 |

**Table 34: GHG emissions in the crops steps (as $gCO_{2eq}/MJ_{bioethanol}$)[65]**

## *Transport and distribution phases*

The calculations of transport cost and consumption of the raw material transport have been executed, considering the type of roads and distance between the crops and the production plant.

Figure 27 shows the positioning of the production plant and the crops area that can be used for the bioethanol production.

Considering these aspects, the energy consumption and the GHG emissions calculation have been executed and showed in Table 35.

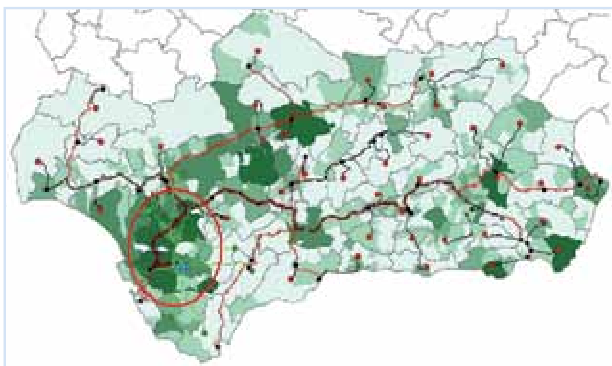

**Figure 27: area considered in the case study (source: IDEA 2011 on page 39)**

| | Fossil energy Consumption [MJf/MJ] | GHG [$gCO_{2eq}$/MJ] |
|---|---|---|
| Sweet Sorghum (irrigation) in Andalusia | 0.014 | 1.9 |

**Table 35: energy consumption and GHG emissions due to the transport of the raw materials in the case study[66]**

### *Processing phase*

In the processing phase, the evaluation of the production process has been done considering the standard production process described before.

The inputs and outputs of the production process are indicated in Table 36. This information allows the subsequent calculation of the GHG emissions and the energy balance of the bioethanol production process.

Considering the use of bagasse to produce all the energy that the process needs, the GHG emissions are produced by the raw materials as indicated in Table 37.

| | |
|---|---|
| **Bioethanol anhydrous** | 1 kg |
| **Power** | 0.74 kWh |
| **Bagasse (excess)** | 0.32 kg |
| **Vinasse** | 13.20 kg |
| **Sulfuric acid** | 0.04 kg |
| **Ammonium sulfate** | 0.01 kg |
| **Di-ammonium phosphate** | 0.01 kg |
| **Sweet sorghum stalks** | 17.18 kg |

**Table 36: energetic and raw materials consumption in the bioethanol production from sweet sorghum**[67]

| | |
|---|---|
| **Raw materials** | 0.4 |
| **Energy consumption** | 0 |
| ***Power*** | 0 |
| ***Thermal Energy*** | 0 |
| $e_p$ | 0.4 |
| $e_{ee}$ | 0 |
| $e_{ccr}$ | 0 |

**Table 37: GHG Emissions in the bioethanol production process from sweet sorghum (as $gCO_{2eq}/MJ_{bioethanol}$)**[68]

### *GHGs emission saving in the case study*

After the evaluation of all the information referred to the bioethanol production process from sweet sorghum in Jédula, the most important results are the savings calculated due to the use of sweet sorghum as feedstock instead of fossil fuels. This aspect is very important and ensures the sustainability of the bioethanol production from sweet sorghum.

The specific results obtained in the bioethanol production from sweet sorghum are showed in Table 39 and Table 40. The GHG emissions saving of this case study corresponds to 79%.

| | |
|---|---|
| **Raw materials** | 0.1 |
| **Energy consumption** | 0 |
| ***Power*** | 0 |
| ***Thermal Energy*** | 0 |
| **Total** | 0.1 |

**Table 38: energy balance in the bioethanol production process from sweet sorghum (as $MJf/M_{bioethanol}$)**[69]

| Biofuel | Crop | Energy consumption by agricultural steps | Energy consumption by transport steps | Energy consumption by bioethanol production | Total [MJ/MJ] | Saving [%] |
|---|---|---|---|---|---|---|
| Bioethanol | Sweet sorghum (irrigation) in Andalusia | 0.07 | 0.021 | 0.01 | 0.10 | 92 |

**Table 39: fossil energy consumption of the bioethanol production in Spain (Jédula) (as MJf/MJbioethanol)**[70]

| Biofuel | Crop | Emissions by agricultural steps $e_{ec}$ | Emissions by transport steps | Emissions by bioethanol production $e_p$ | Emissions power credit $e_{ee}$ | $CO_2$ captured $e_{ccr}$ | Total [$gCO_{2eq}$/MJ] | Saving [%] |
|---|---|---|---|---|---|---|---|---|
| Bioethanol | Sweet sorghum (irrigation) in Andalusia | 14.3 | 2.3 | 0.4 | - | - | 17.2 | 79 |

**Table 40: GHG emissions in the bioethanol production in Spain (Jédula) (as $gCO_{2eq}/MJ_{bioethanol}$)**[71]

# 9. THE EU MODEL 2: SWEET SORGHUM AND SUGAR BEET AS FEEDSTOCK OF THE PLANT

This model is aimed to develop in the EU a chain based on sweet sorghum and another bioethanol crop as feedstock for the same decentralised small-medium plant.

This model has been studied as alternative to the first one, because the model 1 is penalised by the dependence from just one feedstock. Furthermore, the model 2 has the advantage to allow to process mainly fresh raw material and consequently to minimize the concentration of the sugar juice. In fact the short number of days of the harvesting period obliges to make a high concentration of the sugar juice to maintain the production process of the bioethanol plant (fermentation, distillation and dehydration) during almost all the year (11 months per year). On the contrary using also another fresh biomass the required concentration level can be significantly reduced.

The disadvantage of the model 2 is due to the necessity that in one area two bioethanol crops must be cultivated in different period of the year. This condition can be satisfied or not in different regions.

## 9.1 Case study: the development of the EU model in Andalusia in Spain

In order to explain this model for the EU, the guidelines described in previous chapter 7 are applied to an exemplifying plant with capacity as anhydrous bioethanol of 10,000 t/year.

Specifically the case study is contextualised in Jédula (Spain, Andalusia), and sugar beet is considered as complementary to sweet sorghum.

Sugar beet in Andalusia has a harvesting period from June to July and the storage of the sugar beet can be done during one month without losing more than 3-4% of sugars. Thus, the bioethanol production plant can work with fresh raw material from June to November, combining sugar beet during June, July and August, and early sweet sorghum on September, and standard sweet sorghum on October and November.

From December to April (5 months) the bioethanol plant works with concentrated sugar juice. In the month of May the maintenance of the plant and the equipment is carried out.

### Agronomic phase

The same conditions in Jédula indicated in Table 30 are taken into consideration.

The production of sugar beet can vary between 80,000 – 120,000 kg/ha with irrigation. Considering the percentage of sugar per kilogram of sugar beet, the variation can be between 13% and 16% of the fresh samples. Usually, the amount of sugar can be fixed on 14%.

This amount of sugar per kilogram and the productivity of sugar beet per hectare is indicating a variation of 6,600 – 10,000 litres per hectare of bioethanol.

The calculations of the model have been done considering a bioethanol plant with a capacity of 12,500 $m^3$/year (i.e. 10,000 t/year). Thus, if the sugar beet is the raw material for three months per year, the amount of bioethanol from sugar beet must be approximately 3,500 $m^3$/year. This production requires from 350 to 525 hectares of sugar beet, depending on their productivity.

### Logistics

The logistic system of this model is similar for both raw materials as regard with the transport from the fields to the production plant.

An important difference between the 2 crops is the time needed from the harvest to the process.

Apart from the density of the crops, the type of machinery to make the harvest and so on, the main difference is that the storage of the sweet sorghum is not possible due to the sugar loss and the beginning of fermentation after 7-8 hours, but, on the other hand, in the case of sugar beet, the storage can be done in the field or in the production plant during one month. Apart from this, the maintenance of the sugar beet in the fields without harvesting it is possible without losing the sugars.

Thus, sugar beet can be used as feedstock increasing the time between the harvest and the process. This allows making a better structuring of the transport from the fields to the production plant and reducing the transport cost using bigger trucks and trailers.

### Processing

The production process must be adapted to the use of sugar beet and sweet sorghum as feedstock. This is not an important problem, due to the fact that the types of sugar stored in the sugar beet and in the stalks of sweet sorghum are sucrose, glucose and fructose. Thus, the fermentation, distillation and dehydration are similar.

The main difference between the use of sugar beet or sweet sorghum is on the first step of the process, during the cleaning of the raw material, cutting and sugar extraction.

In this model the incorporation of a cleaning line is necessary to eliminate sludge and stones from the sugar beet before the cutting step. In the case of sweet sorghum, there is not a cleaning step, and after the reception of the stalks, these are shredded before the extraction.

The extraction process must be done with a continuous diffuser to ensure the best yield on the extraction process and the use of the same equipment for extracting from sweet sorghum and sugar beet. On the contrary the rolling mill cannot be used in the extraction of sugar from sugar beet.

After the extraction, the other steps of the process are similar regardless the type of raw material.

### Economic analysis

The economic analysis can be similar to the analysis indicated in the evaluation of the model 1 in the case study in Spain.

## GHGs emission saving

The calculation of the GHG emissions saving has been done considering 2 alternatives. The first is considering the use of natural gas as fuel to obtain the energy required by the production plant. The second option is the use of biomass as fuel in the boiler. This biomass could be the bagasse obtained from sweet sorghum sugar extraction phase. This means that the biomass must be stored during all the year

**Production of Ethanol from Sugarbeet (steam from NG boiler)**

**Overview Results**

| All results in $g\ CO_{2,eq}\ /\ MJ_{Ethanol}$ | Non- allocated results | Allocation factor | Allocated results | Total | Actual/ Default | Default values RED Annex V.D |
|---|---|---|---|---|---|---|
| Cultivation $e_{ec}$ | | | | 7,2 | A | 12 |
| Cultivation of sugarbeet | 10,07 | 71,3% | 7,18 | | | 11,54 |
| Processing $e_p$ | | | | 26,3 | A | 26 |
| Ethanol plant | 36,82 | 71,3% | 26,26 | | | 26,42 |
| Transport $e_{td}$ | | | | 2,9 | A | 2 |
| Transport of sugarbeet | 1,85 | 71,3% | 1,32 | | | 0,84 |
| Transport of ethanol | 1,10 | 100% | 1,10 | | | 1,10 |
| Filling station | 0,44 | 100% | 0,44 | | | 0,44 |
| Land use change $e_l$ | 0,0 | 71,3% | 0,0 | 0,0 | | 0 |
| $e_{sca} + e_{ccs} + e_{ccr}$ | 0,0 | 100% | 0,0 | 0,0 | | 0 |
| Totals | 50,3 | | | 36,3 | | 40 |

| Allocation factors | |
|---|---|
| Ethanol plant | |
| 71,3% | to ethanol |
| 28,7% | to Sugar beet pulp |

| Emission reduction | |
|---|---|
| Fossil fuel reference (petrol) | |
| 83,8 | $g\ CO_{2,eq}/MJ$ |
| GHG emission reduction | |
| 57% | |

**Figure 28: GHG emissions of bioethanol obtained from sugar beet using natural gas as fuel (source: www.biograce.eu)**

to be used regardless the raw material, sweet sorghum or sugar beet, that has no biomass on the crop.

If the production process uses natural gas as fuel on the production plant, the emissions reduction is 57% by the use of sugar beet as raw material for producing bioethanol. Then, considering the amount of hectares of sugar beet, the final calculation for all the process applies a 57% of reduction for a 27.3% of the total production and a 79% of reduction for the 72.7% produced from sweet sorghum.

**Production of Ethanol from Sugarbeet (steam from biomass boiler)**

**Overview Results**

| All results in $g\ CO_{2,eq}\ /\ MJ_{Ethanol}$ | Non- allocated results | Allocation factor | Allocated results | Total | Actual/ Default | Default values RED Annex V.D |
|---|---|---|---|---|---|---|
| Cultivation $e_{ec}$ | | | | 7,2 | A | 12 |
| Cultivation of sugarbeet | 10,07 | 71,3% | 7,18 | | | 11,54 |
| Processing $e_p$ | | | | 4,5 | A | 26 |
| Ethanol plant | 6,32 | 71,3% | 4,51 | | | 26,42 |
| Transport $e_{td}$ | | | | 2,9 | A | 2 |
| Transport of sugarbeet | 1,85 | 71,2% | 1,32 | | | 0,84 |
| Transport of ethanol | 1,10 | 100% | 1,10 | | | 1,10 |
| Filling station | 0,44 | 100% | 0,44 | | | 0,44 |
| Land use change $e_l$ | 0,0 | 71,3% | 0,0 | 0,0 | | 0 |
| $e_{sca} + e_{ccs} + e_{ccr}$ | 0,0 | 100% | 0,0 | 0,0 | | 0 |
| Totals | 19,8 | | | 14,5 | | 40 |

| Allocation factors | |
|---|---|
| Ethanol plant | |
| 71,3% | to ethanol |
| 28,7% | to Sugar beet pulp |

| Emission reduction | |
|---|---|
| Fossil fuel reference (petrol) | |
| 83,8 | $g\ CO_{2,eq}/MJ$ |
| GHG emission reduction | |
| 83% | |

**Figure 29: GHG emissions of bioethanol obtained from sugar beet using biomass as fuel (source: www.biograce.eu)**

The average of the total production process, considering this alternative, is 73% of reduction of the GHG emissions using sugar beet and sweet sorghum combined. This calculation has been done using natural gas as fuel in the production plant during the bioethanol production from sugar beet and bagasse during the bioethanol production from sweet sorghum.

The second option for the bioethanol production from sugar beet and sweet sorghum is the use of biomass for all the year and for all the bioethanol production regardless the type of raw material.

If the fuel used on the bioethanol from sugar beet is biomass (i.e. bagasse from the sweet sorghum of the previous production period), the GHG emissions from the bioethanol production process using sugar beet as raw material are lower. The emissions saving with sugar beet as raw material is 83%.

Thus, if the amount of bioethanol produced from sugar beet is a 27.3% from the total production, and the emissions reduction with sweet sorghum is 79% for 72.7 % of the total capacity of the plant, the average of the emissions reduction for the total process is 80%.

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# NOTE

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This technical handbook contains the technical guidelines to start up in the EU the chain to produce energy (i.e. bioethanol, electricity and heat) from sweet sorghum.
The guidelines are applied in some case studies in Italy, Greece and Spain, in order to complete the technical description with economic and environmental data to use these guidelines in feasibility studies.

The handbook is mainly target at farmers, agricultural associations, fuel processors, SMEs, seeds and agricultural companies.

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