sweethanol

SUSTAINABLE ETHANOL FOR EU

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

Early Manual

Supported by
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2. FOREWORD

The 1st generation bioethanol produced from sweet sorghum presents a high environmental, economic and energetic sustainability: the ascribed GHGs saving is 70-71%, the technical simplicity of the processing and the exploitation of by-products guarantee the economic viability also for decentralised small-medium plants (max 15,000 t/y) and its energy ratio is 1.7-7.3.

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, funded by the Intelligent Energy programme of the European Commission, is aimed to change the current situation concerning the raw material diversification, decentralisation and sustainability of 1st generation bioethanol from sweet sorghum, which can be grown in the southern regions of the EU.

At the moment the bioethanol chain from sweet sorghum is not taken in account because of the absence of know-how about its potentialities.

As a consequence of the know-how refining about the bioethanol production from sweet sorghum, obtained through the visits to agricultural institutes, existing plants and fields in India, Spain and Peru, the “*Sweethanol - Early manual*” is created in order to use it as a background for the discussion of an European model during the following phases of the project.

The collected information, data and details about the agricultural, technical, logistic, economic and energetic sides are summarised in this “*Sweethanol - Early manual*”.

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 “*Sweethanol - Early manual*” contains the agricultural, technical, energetic and economic information and data about the current processing into bioethanol, comparing the models to produce bioethanol also from other raw materials which are present in Asia, South America and Europe.

The text of the “*Sweethanol – Early manual*” was produced by Michela Pin, Denis Picco and Alessia Vecchiet (C.E.T.A. – Centre for theoretical and applied ecology, Italy), Oscar Leòn, Paloma Gonzàlez and Roberto Marcos (Foundation Cartif – Technological centre, Spain), Irene Tsakiridou and Kostas Konstantinou (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 Mª Dolores Curt (ADABE – Association for the diffusion of biomass, Spain), Fernando Mosquera Escribano (Agro-Energy Group of Polytechnic University of Madrid, Spain), Athanasios Bartsios and Eleni Papoulia (Agricultural co-operative of Halastra, Greece).

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3. LIST OF ACRONYMS AND ABBREVIATIONS

ABI Agri Business Incubator (India)

AEBIOM European Association of Biomass

AFEX Ammonia Fiber EXplosion

AIC Agri biotech Innovation Centre (India)

ASP Agri Science Park (India)

BRC Bio-products Research Consortium (India)

CAP Common Agricultural Policy

CHP Combined Heat and Power production

CO carbon monoxide

CO_2 carbon dioxide

CRES Centre for Renewable Energy Sources (Greece)

DCU Decentralized Crushing Unit (India)

DDG Distillers Dried Grains

DDGS Distillers Dried Grains with Solubles

db dry basis

E100 Bioethanol 100%

EC European Commission

E85 Bioethanol 85% blend

ETBE Ethyl-Ter-Butyl-Ether

FFV Flexible Fuel Vehicles

GHGs Green House Gases

HMF Hydroxy-Methyl-Furfural

HPRC Hybrid Parents Research Consortium (India)

ICAR Indian Council of Agriculture Research (India)

ICRISAT International Crop Research Institute for the Semi-Arid Tropics (India)

IEE Intelligent Energy Europe programme

LHV Low Heating Value

MAG Maximum Guaranteed Area

MIPAAF Ministry of Agricultural, Food and Forestry politics (Italy)

MSE Ministry for Economic Development (Italy)

MTBE Methyl-Ter-Butyl-Ether

NAIP National Agricultural Innovation Program (India)

NAP National Action Plans

NARS National Agricultural Research Systems (India)

NO$_x$ nitrogen oxides

ORC Organic Rankine Cycle

O&M Operative and Maintenance

R.D. Royal Decree (Spain)

R&D Research and Development

REP Renewable Energy Plan

RES Renewable Energy Sources

rpm revolutions per minute

RPV Reid Vapour Pressure

RUE Radiation Use Efficiency

SHPRC Sorghum Hybrid Parents Research Consortium (India)

SMEs Small Medium Enterprises

SSC Supreme Chemical Council (Greece)

SSERC Sweet Sorghum Ethanol Research Consortium (India)

toe tons of oil equivalent

TRPF Toothed Roller Pressure Feeder

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 1st generation bioethanol 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 1st generation bioethanol (mainly as GHGs saving). The proposed wide discussion about the production of 1st generation 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*

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) through the "*Esse Community*". 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

C.E.T.A. – Centre for theoretical and applied ecology - Italy
C.E.T.A. was created in 1987 in Gorizia (Italy) and is a non-profit association which carries out research, applied experimentation and innovative technology development in different environmental sectors: sustainable management of environmental and natural resources; promotion and diffusion of renewable energy technologies (biomass, biogas, biofuels, solar energy – photovoltaic); energy efficiency and energy planning; scientific dissemination. Moreover, C.E.T.A. carries out multidisciplinary activities employing high-degree professionals: 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. BIOETHANOL

6.1 What is bioethanol? History and definitions

Bioethanol is derived from the alcoholic fermentation of sugars or hydrolysed polysaccharides (e.g. starch, cellulose).
In this process glucose, along with water, is converted into ethanol, CO_2 and water.
Its use as a fuel is realised by the exothermic reaction when burnt, producing CO_2 and water.
The chemical reactions of sugar into ethanol and burning of ethanol, respectively, are described as follows:

$C_6H_{12}O_6 + H_2O \rightarrow 2C_2H_5OH + 2CO_2 + H_2O$ alcoholic fermentation to produce bioethanol
$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$ bioethanol combustion to use it as fuel

Generally the term bioethanol is applied specifically for ethanol used as a component in transportation fuel.
Bioethanol is used as a fuel because it is non-petroleum based, thereby reducing the dependence on crude oil resources, and is considered as carbon neutral, thus reducing net carbon emissions that are thought to contribute to climate change.
Bioethanol may be produced from many energy crops such as corn, wheat, barley, sugarcane, sugar beet, and of course sweet sorghum. Developing fuels that reduce the need for petroleum substances or burn with less CO_2 production is seen as a major step in battling on-going climate change.
The use of bioethanol for transport started in the beginning of the 20th century, but was abandoned after the Second World War. Interest in bioethanol revived after the first oil crisis.
In 1975 Brazil started a large government-sponsored programme for fuel-ethanol production from sugarcane. Since then, the Brazilian bioethanol industry has grown considerably.
In the US, large-scale bioethanol production from corn began in 1978 with steady growth, which has accelerated in recent years due to government policies and financial incentives.
More recently, countries like Canada, Australia, China, France, Spain and Sweden started to promote the production and use of bioethanol.
In the EU the production of fuel ethanol will expand substantially in the coming years due to European Commission policies.
Various EU countries will either expand existing production capacity (i.e. Spain, France, Sweden) or will implement new production facilities (e.g. UK, Germany, The Netherlands, Belgium, Poland).

6.2 European politic and legislation

The European biofuels market has enjoyed excellent European Commission support by way of the Kyoto agreement as well as Directives 2003/30/EC and 2003/96/EC, which specifically aimed to promote the increased use of biofuels and set indicative targets for their use in the transport industry.

The Directive 2003/30/EC of 8th May 2003 “on the promotion of the use of biofuels or other renewable fuels for transport” laid the foundation for the promotion of alternative fuels in the EU. In particular, it specified that Member States should ensure that a minimum share of biofuels and other renewable fuels is placed on the market and, to that effect, shall set national indicative targets.
Reference values for these targets were given, as calculated on the basis of energy content, namely:

- 2% of all petrol and diesel for transport purposes placed on their markets by 31st December 2005;
- 5.75% of all petrol and diesel for transport purposes placed on their markets by 31st December 2010.

The Directive aimed at increasing the share of renewable energy in the transportation sector (currently dominated almost entirely by fossil fuels) and reducing emissions of CO_2, CO, NO_X, VOC and other particles harmful to human health and the environment.

In accordance with this Directive, the different types of biofuels are as follows: bioethanol, biodiesel (diesel-quality methyl ester produced from biomass or used vegetable oils and used as biofuel), biogas (fuel gas produced from biomass and/or waste by anaerobic fermentation, purified to natural gas quality), biomethanol, bio-dimethyl-ether, bio-ETBE, bio-MTBE, synthetic biofuels (synthetic hydrocarbons or mixtures of synthetic hydrocarbons produced from biomass), biohydrogen, and oil produced from oil plants by pressing, extraction or comparable procedures, crude or refined but chemically unmodified, when compatible with the type of engines involved and the corresponding emission requirements.
Biofuels may be made available in any of the following forms:

- as pure biofuels or at high concentration in oil derivatives, in accordance with quality standards for transport applications;
- as biofuels blended in mineral oil derivatives, in accordance with the appropriate European norms describing the technical specifications for transport fuels (EN 228 and EN 590);
- as liquids derived from biofuels, such as ETBE (resp. MTBE) where the percentage of biofuel is 47% vol. (resp. 36% v/v).

The Directive 2003/96/CE of 27th October 2003 has been focused mainly on the tax applied over the biofuels. This Directive modified the Community's Tax for the energetic products and power. In this Directive were been established the following aspects:

- art. 16.1: the Member States can apply the exemption or reduced tax over the biofuels;
- art. 16.3: the exemption or reduction of the tax can be modulated in function of the evolution of the price of the raw materials;
- art.16.5: the application period is of six years, although this period can be prorogued until before 31/12/2012.

This Directive allowed applying the exemption or reduction of the tax since 1st January 2003 (art.28.2)

The Directive 2009/28/EC of 23rd April 2009 (RES Directive) indicates an updated objective for the reduction of the GHGs emission in the transport sector:

- 10% of the final consumption must be covered with RES within 2020.

Furthermore the Directive introduces for the first time a reduction target for the GHGs emissions from fuels:

- the GHGs saving due to the use of biofuels and bioliquids shall be at least 35%;
- with effect from 1st January 2017, the GHGs emission saving from the use of biofuels and bioliquids shall be at least 50%;
- from 1st January 2018, the GHGs gas emission saving shall be at least 60% for biofuels and bioliquids produced in installations in which production started on, or after, 1st January 2017.

Furthermore this Directive indicates that the development of the RES must be united to the increase of the energy efficiency as an aim for reducing the GHGs emissions in the EU. In fact the increase of 20% in the energy efficiency from now to 2020 is another essential objective of the Directive.
Further objectives and applications of the Directive are the following:

- to establish a common framework for the promotion of the energy obtained by RES;
- to fix the obligated national objectives related to the energy production from RES in the final consumption of the energy and related with the renewable energy for the transport;
- to establish the norms of statistics transference among the Member States, the common projects among the Member States and with outside, the origin guarantees, the administration procedures, information and formation and the access to the power net for the renewable energy.

The Directive 2009/30/EC of 23rd April 2009 aims at improving air quality and reducing greenhouse gas emissions through environmental standards for fuel. It will also facilitate the more widespread blending of biofuels into petrol and diesel and, to avoid negative consequences, set ambitious sustainability criteria for biofuels.

The revised Directive indicates that by 2020 fuel suppliers must decrease by 6% climate-harming emissions over the entire life-cycle of their products. This can be reached in particular by admixing biofuels to petrol and diesel as well as by improving production technology in refineries. Member States may require an additional 4% reduction from fuel companies, achieved through the supply of energy for electric vehicles or other clean technologies, including carbon credits from third (so-called "Clean Development Mechanism").
To enable these GHGs emissions cuts, petrol may have higher biofuel content. From 2011, petrol may contain up to 10% (v/v) ethanol. In order to avoid damage to old cars, however, fuel with 5% (v/v) ethanol will continue to be available until 2013, with the possibility for Member states to extend that period.
The Directive also incorporates the same environmental and social sustainability criteria for biofuels as in the Directive 2009/28/EC. It imposes limits on the content of sulphur and metallic additives in engine fuel. Finally, the maximum vapour pressure of fuel is also prescribed in order to minimise emissions of volatile air pollutants. The revised environmental quality standards as well as the sustainability criteria for biofuels will apply from 2011.
Member States are required to transpose the Directive into national law by the end of 2010.

6.3 Bioethanol production in Europe

Bioethanol is regarded as one of the main biofuels in Europe, now and in the future. The current production is largely based on fermentation of sugar and starch crops. In the following table the production data in the EU countries are reported.

Country	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Austria	-	-	-	15	89	180
Belgium	-	-	-	-	-	143
Czech Republic	-	-	15	33	76	112
Finland	3	13	-	-	50	4
France	101	144	293	539	1,000	1,250
Germany	25	165	431	394	568	750
Hungary	-	35	34	30	150	150
Ireland	-	-	-	7	10	2
Italy	-	8	128	60	60	72
Latvia	12	12	12	18	20	15
Lithuania	-	8	18	20	20	30
The Netherlands	14	8	15	14	9	-
Poland	48	64	120	155	200	166
Slovakia	-	-	-	30	94	118
Spain	254	303	402	348	317	465
Sweden	71	153	140	120	78	175
UK	-	-	-	20	75	70
TOTAL	528	913	1,608	1,803	2,816	3,702

Table 1: production data of bioethanol in Europe (in millions of litres)[1]

The fulfilment of the EC Directive target for 2010 to substitute 5.75% of diesel and petrol transport fuels should have required an amount of 760 PJ of biofuels. Assuming that bioethanol has accounted for half of that amount, the demand for ethanol in 2010 in Europe should have been approximately 14.5 million tons (or 18 million m^3).
Furthermore the bioethanol demand will increase in the next years due to the RES Directive.

In order to fulfil the rapidly growing demand of bioethanol, two strategies can be applied:

- the use of new processes using lignocellulosic biomass as feedstock (i.e. 2nd generation bioethanol)
- the utilisation of innovative sugar crops to produce conventional bioethanol (i.e. 1st generation bioethanol), but through sustainable processes.

Lignocellulosic biomass is available in large amounts and at low cost in the form of agricultural (e.g. straw) and forestry residues or can be cultivated with a high yield per hectare and low energy inputs if compared to currently used starch and sugar crops. Bioethanol produced from lignocellulose is therefore expected to be more cost-effective in reducing GHGs emissions than current bioethanol production.

Currently, three types of new lignocellulosic based production processes are under development:

- the production of bioethanol from lignocellulosic biomass by physical-chemical pre-treatment followed by enzymatic hydrolysis, fermentation and distillation;
- the production of bioethanol or a mixture of alcohols from lignocellulosic biomass by gasification and subsequent catalytic conversion of syngas to alcohols;
- the production of bioethanol from lignocellulosic biomass by gasification and subsequent fermentation of syngas to ethanol, a combination of thermochemical and biochemical techniques.

The SWEETHANOL project is aimed to the utilisation of sweet sorghum as innovative sugar crop to produce sustainable 1st generation bioethanol and to the diffusion of small-medium decentralised plants in order to diversify the bioethanol market in the EU. The sustainability of the obtained bioethanol is due to the low requirement of this crop (i.e. water and fertilisers) and to the availability of abundant by-products; these elements determine a high GHGs saving for the bioethanol obtained from sweet sorghum. Furthermore sweet sorghum allows to link the bioethanol production to the territory where the feedstock is produced because it cannot tolerate a long transportation. This is the presupposition to reduce the capacity of the plants and to introduce the idea of decentralised production of bioethanol. In case of the processes evaluation for large plants, with a capacity of 240,000 m^3 bioethanol/year, the current production costs in Europe are estimated at 0.50-0.55 €/l for sugar beet based processes, 0.55-0.60 €/l for grain based processes, 0.85-0.90 €/l for potato based processes, and 0.45-0.55 €/l for processes using residual starch streams. Production costs are strongly dependent on the feedstock costs, which make up 50-70% of the overall costs. Future costs are expected to decrease due to process improvements. However, the high demand for bioethanol will likely increase the cost of sugar and starch feedstock. Bioethanol production costs in 2020 are estimated at 0.45-0.50 €/l for sugar beet based processes, 0.50-0.55 €/l for grain based processes 0.80-0.85 €/l for potato based processes, and 0.40-0.50 €/l for processes using residual starch streams.

The EU actively pursues its Directive target of 10% substitution of petrol and diesel fuels with RES in 2020. This leads to a high demand of biofuels in the European market. It is not necessarily true that only the processes with lowest costs are competitive when demand for bioethanol is high. The current ethanol market where demand exceeds supply illustrates this. At present the European market demand is fulfilled by low-cost Brazilian bioethanol as well as more costly bioethanol and biodiesel produced in Europe.

6.3.1 Raw materials

For bioethanol production different raw materials can be used. The practical use will be determined by performance on bioethanol and related costs.

Three types of raw materials for bioethanol production are defined.

A. Materials containing directly fermentable sugars (such as sugarcane juice, molasses). Sugarcane is one of the most important bioethanol crops and it is cultivated in tropical regions. Brazil is the world's leading producer and at wide distance remains India. In 2002, Brazil harvested 372 million tons of sugarcane and India 279 million tons. Brazil dedicates to the sugarcane crop 5,215,000 ha with a production that reaches 93 t/ha of total biomass from which 21.6 tons correspond to the sugar production itself. The juice obtained by squeezing the cane contains about 44% of sucrose and 7% of other sugars, as dry weight. In total 51% of the dry biomass of the stems of sugarcane is constituted by sugars that could be subjected to fermentation for bioethanol production. The remaining fraction is made up of fiber: cellulose, hemicellulose and lignin (dry biomass up to 10.6 t/ha). One hectare of crop has allowed obtaining 11 tons of sugars, mostly sucrose that could be transformed to obtain, on average, 5,700 litres of bioethanol. Indeed, each ton of cane, from which 770 kg correspond to the sugarcane' stalks, allows to extract slightly less than 400 kg of sugars that with the fermentation are transformed into 160 kg of bioethanol. The cultivation of one hectare of cane requires more than 16.7 GJ.
B. Materials containing starch as source of carbohydrates (such as cassava, corn, wheat, barley). Corn is one of the most bioethanol crops in the EU and US and its cultivation produces a great amount of biomass, from which about 50% is used as grain form. The remainder corresponds to different plant structures, for example cobs and stalks. With mechanised agriculture the production per hectare, on average, is around 9 t/ha (fresh weight of grain, containing 15% of water) and, on very favourable terms, it can reaches values of 10-13 t/ha. On average, in the composition of corn grain, which is the raw material for bioethanol production, 66% of its own biomass (dry weight, after deducting the 15% of humidity which is considered a standard value) corresponds to starch, 3.9% corresponds to oils and nearly 29% is the gluten with different proportions of proteins. The production of residual biomass fluctuates between 7 and 10 tons of dry weight per hectare. Obviously, such high productions are only possible by investing high amounts of energy for the cultivation of the crop. First of all corn crop requires high amounts of nitrogen. Besides, corn requires high amounts of water which means that a portion of production is obtained in irrigated crops. Consequently the corn production is only achieved by investing a considerable amount of fossil fuels in fertilisers form, herbicides and insecticides, diesel used in agricultural machinery, electricity or petroleum used in irrigation and transport associated to the crop.
C. Materials containing cellulose and hemicellulose as source of carbohydrates (such as giant reed, mischantus, poplar, but also all agricultural residues and wastes). The alternative of using lignocellulosic wastes in bioethanol production today is a highly promising option for their wide availability in the world and for the solution of the problem "Food *versus* Fuel". The existence of abundant lignocellulosic resources justifies the dedication of a major effort by many nations (i.e. Latin America, US, EU) to the development and adaptation of technologies tending to the integral and rational use of them. In this group of raw materials is located also the bagasse as agro-industrial waste. The idea of producing bioethanol from these materials comes from the 1940 and 1950 decades and its production has led to a commercial scale in some, mainly in the developed world.

Bioethanol is produced by fermentation of these raw materials with yeast or other micro-organisms. The first class directly ferments. The second type contains starch which firstly must be converted into fermentable sugars by enzymes. Cellulosic materials of the third class become fermentable sugars by hydrolysis with inorganic acids or alkali or with specific enzymes.

Other crops that are being investigated for bioethanol production are sweet sorghum and

Jerusalem artichoke. These products, apart from the lower cost of production, would be profitable for bioethanol production because the dried bagasse (i.e. sweet sorghum) and dried stems (i.e. Jerusalem artichoke) are picked up during the harvesting, unlike corn, and they can be used to produce steam and electricity required in the bioethanol production process.

6.3.2 Production process

The bioethanol production process is based on the alcoholic fermentation, but it consists on several stages: pre-treatment of raw materials, hydrolysis of the polysaccharides phase or sugar extraction phase, fermentation, distillation and dehydration. Taking these steps, the variation of raw materials used for bioethanol production involves modifications in the first steps of the process, such as pre-treatment, hydrolysis of the polysaccharides, extraction of the sugars, whereas the remaining steps can be considered common to all cases.

Pre-treatment of raw materials

This stage includes the preparation of raw materials necessary to make available the carbohydrates and their subsequent use for the production of bioethanol. Depending on the type of raw material this pre-treatment may vary.

For example in the case of sugar beet, important bioethanol crop in the EU, after the harvesting the cleaned beets are processed in the cutting machine to obtain the thin slices (i.e. cossettes) and they are subjected to the continuous diffusion for extracting the sugars.

In the case of cereals, after a preliminary storage in silos, the pre-treatment includes the crushing process with the hammer mills for obtaining a powder that is then processed in the following stage of hydrolysis. The dry milling is the most widely used process for the cereals, even though it might be possible to make a wet milling obtaining from the cereals, through a large number of intermediate stages, many interesting products. Although with this technology a lot of products could be obtained, the costs and the complexity of the methodology have discouraged their production in the field of bioethanol production.

Hydrolysis

The hydrolysis process is applied when the raw materials do not contain fermentable sugars directly, but polysaccharides (e.g. starch, inulin, cellulose, hemicellulose).

The hydrolysis process depends on the type of polysaccharides to hydrolyze and on the raw material used; consequently the following examples can be distinguished.

- Starch hydrolysis. The hydrolysis of the starch is performed by adding alpha-amylase enzyme and glucoamylase enzyme. The process is divided into the stage of liquefaction, where the crushed grains are dissolved in water and the viscosity is reduced with the help of some enzymes. The second stage is the cooking, where the used enzyme is the alpha-amylase. The last stage is saccharification, where the enzymes added are glucoamylases. In this stage, the dextran obtained from the first hydrolysis is broken into monomers of glucose. This process can be carried out at a temperature between 70 and 90 °C, although nowadays there are heat-resistant enzymes capable of operating at temperatures above 125-130 °C.
- Inulin hydrolysis. Inulin, present in Jerusalem artichoke, is a long-chain fructo-oligosaccharide, formed by an end-glucose and a chain of fructose linked by Beta,1-6 link. This sugar is hydrolyzed enzymatically or by heat treatment at acidic pH. In the case of enzymatic hydrolysis of inulin, the types of enzymes used are exoinulinase and endoinulinase. The endoinulinase breaks the chain in intermediate points, and in the case of exoinulinase, it breaks the inulin in the end-fructose. The combination of both enzymes can perform the most appropriate process. As an alternative to enzymatic hydrolysis, the acid hydrolysis can be performed. Thus, the acid hydrolysis can be done with a pH of 3 or 4, more acid than the enzymatic process. Apart from the pH, the temperature of the juice can be increased until 130 to 180 °C. Depending on the temperature and pH, the time required for hydrolysis may vary between 3-4 minutes to 2 hours. In any case acid hydrolysis is a process faster than the enzymatic hydrolysis, but it requires higher temperature and can generate toxic secondary metabolites that affect to the fermentation processes, such as HMF.

- o <u>Lignocellulosic hydrolysis</u>. In the case of the hydrolysis of lignocellulosic compounds, the required process combines different types of hydrolysis, including a previous chemical (e.g. with acid) or physical-chemical hydrolysis (e.g. steam explosion, AFEX) and a secondary enzymatic hydrolysis (i.e. with exocellulase, endocellulase, hemicellulose) to produce adequate results. The first hydrolysis phase made at high temperature and pressure makes a partial rupture of the cell structure allowing further access of the cellulolytic enzymes during the enzymatic hydrolysis stage.

Extraction
The extraction is applied when the raw materials contain directly fermentable sugars.
The extraction process may vary depending on the raw materials and applied technology. In general, the extraction can be carried out by direct pressing using the rolling mills, applied in the industry of sugarcane and sweet sorghum, or by continuous diffusion, which can be done using without-end transport equipment for sugar beet or by a lixiviation system used as an alternative to the extraction of sugar from sugarcane with rolling mills.
In all these processes the extraction is made using hot water, controlling the temperature (75 - 85 °C), the pH (between 6 and 7), the ratio raw material/quantity of water (1:0.3 - 1:1) and the residence time (45 to 65 minutes). Thus, the extraction yield may be around a 93-94% by rolling mill and up to 98% by diffusion.

Fermentation
The fermentation of sugars will be done using active yeasts in ideal conditions. In the case of bioethanol production, the aim of the process is to achieve high productivity in a very short time in order to make possible the reduction of the phase of cell growth and cell division in which ethanol is not produced, whereas sugars are consumed to increase the density per meter cube of yeasts.

1. <u>Preparation of yeasts</u>. The process begins with the preparation of yeasts by rehydration and stabilization, and further preparation of the mother tanks. These mother tanks are used to dispense yeasts to the fermentation tanks. The preparation process of yeasts is carried out with a solution rich in glucose, fructose or sucrose sugar, an average temperature of 35 °C and with the addition of bactericide and oxygen. The oxygen may be supplemented by the addition of ergosterol. Once yeasts are prepared and adapted, the fermentation process can be done in a batch process or in a continuous one. The recovery of yeasts after the fermentation process can increase the viability, reducing the total production costs.
2. <u>Fermentation</u>. Continuous and in batch solutions can be applied.
   - <u>Continuous fermentation</u>. The continuous process is done loading the sugar juice only to the first thank where, at the same time, the yeasts solution is added. From the first thank the juice, fermented in a low percentage, passes to the following thank where it ferments continuously until the last tank: here the juice must be fermented completely. In this system the fermentation yield is higher than the batch process and the total volume necessary is less than the other alternative; the main problem with this system is the contamination risk. If one of the continuous tanks is contaminated with bacteria, the total system can be contaminated. In this case, the decontamination is more difficult.
   - <u>In batch fermentation</u>. It is a process performed in independent reactors with no direct communication among them. In this case, although the process fermentation yield can be lower than the continuous fermentation, the control of contaminations is better and the security is higher because this system allows an easy isolation of the contaminated tank, preventing that it extends throughout all the system.
3. <u>Recovery of yeasts</u>. After fermentation yeasts are recovered by centrifugation, improving the overall performance and economy of the process and reducing the production costs. If yeasts have finished their lifetime they can be used as a source of protein, applying them to obtain various types of products for animal feed or human consumption.

Distillation

The bioethanol concentration in the fermented juice is 9-14% v/v and the objective of the distillation process is to obtain the azeotropic ethanol with a purity of 95-96%. At this aim the fermented juice passes through several distillation columns made of bubbling dishes, where water and ethanol are separated as they run up the tower.

The energy consumption in this stage is critical. For this reason, the combination with concentration step is common, alternating vacuum zones and atmospheric pressure zones in order to minimize the total final consumption of the process.

Dehydration

The dehydration process is necessary to produce ethanol at 99.8% of purity, called the absolute ethanol. This type of ethanol is the raw material for the production of ETBE or it can be blended directly with petrol.

The dehydration process occurs after the distillation of fermented juice, using as feedstock the azeotropic ethanol. The ethanol, after evaporation, is passed through a molecular sieve made of zeolites. This type of molecular sieve retains selectively the residual water molecules increasing the percentage of ethanol over the azeotropic point.

After the dehydration process, the obtained absolute ethanol must be isolated to avoid any contact with the atmosphere. In fact it is able to absorb ambient water increasing its moisture content. For this reason, once dehydrated, the storage and transport should be conducted in an atmosphere free of air, usually made up of nitrogen and CO_2.

6.3.3 Products and by-products

The main product of the described processes is bioethanol, but nowadays the biorefinery concept is indicating the way to follow for increasing the type of by-products to obtained in the bioethanol plants. In fact also CO_2, heating power, electricity, biomethane, lignin, bio-plastics can be obtained.

Bioethanol

Bioethanol is the main product of this type of process. The bioethanol purity grade will vary depending on the application: for blending it with petrol or for producing ETBE in refineries, it is necessary to use absolute ethanol with a purity of 99.6-99.8%. However, in the case of using 100% bioethanol fuel (E100), the ethanol needed is not going to be absolute alcohol. Thus, the use of azeotropic ethanol would be enough.

Considering the use of ethanol for blending with petrol or for ETBE production as the most common applications, before leaving the factory, an additive is added to bioethanol to prevent fraudulent use as drinking alcohol; usually this additive is the petrol itself, or small compounds portions that provide a very bad taste and colour.

CO_2

During the fermentation process CO_2 is also generated as one of the main products. This gas is used in the food industry for the manufacture of carbonated beverages, as well as to obtain other products of interest such as dry ice, or to improve the condition of packaged food and perishables.

Power and heat generation

Power generation is one of the key factors to ensure the profitability of installations for producing bioethanol considering the high power consumption of the process. Consequently, the use of by-products to feed a CHP is considered as a need in all these type of plants. The power generation can have two different applications, whether for its own use in the production plant and/or for sale to the electric companies.

The generation process is done with a high steam pressure to feed the generation turbines (with a pressure between 25 to 68 bar) using the final steam for producing electricity.

The residual heat, not converted in electricity, can be used to cover the thermal requirement of the same bioethanol plant (e.g. distillation phase).

DDG and DDGS

The DDG and DDGS are the residuals obtained from the liquefaction of cereal grains prior to fermentation. The DDG are made from the solid waste obtained from the grains used in the bioethanol production and DDGS are formed by the solid wastes of grains mixed with the concentrated vinasse and fermentation lees. In both cases, these types of products are rich in proteins and fiber of high quality which can be used for animal feed.

Considering other raw materials for producing bioethanol apart from cereals, the solid wastes obtained after the sugar extraction can be used as animal feed. For example, the exhausted beet pulp obtained after the sugar extraction by diffusion of the beet cossettes, once they are pressed and dried, is used with this purpose; after mixing it with vinasse or lees, is a feed rich in proteins.

In the processing of sugarcane and sweet sorghum, the suggested exploitation for the bagasse is the combustion in CHP to produce heat and electricity; consequently this type of by-product is not usually used for animal feed. On the contrary, products for animal feed can be obtained from the concentrated vinasse and fermentation lees.

6.4 Bioethanol production in the world: raw materials and new opportunities

Brazil has been the world's leader (and primary user) of bioethanol for more than 25 years, producing slightly less than half of the world's total production in 2004. All fuelling stations in Brazil sell bioethanol or gasohol, at 25% bioethanol/75% petrol blend (E25).

The US is the world's second largest consumer and producer of bioethanol. The growth of the US market is a relatively recent trend; bioethanol production capacity increased from 4 billion litres in 1996 to 14 billion litres in 2004.

Other countries which are producing and using bioethanol include Australia, Canada, China, Columbia, Dominican Republic, France, Germany, India, Jamaica, Malawi, Poland, South Africa, Spain, Sweden, Thailand, Philippines and Zambia.

In 2009, the production of bioethanol reached the estimated 76 billion litres, with an increase of 10% over 2008. The US and Brazil accounted for 88% of global bioethanol production in 2009. Most of the increased production occurred in the US, but significant increases in Canada, Germany, and France have occurred too; the production in Brazil declined. Both Belgium (up 230%) and the United Kingdom (up 160%) have shown significant expansions, although their totals (120 million litres and 110 million litres, respectively) have remained relatively low.

After a significant downturn in the US bioethanol market in 2008, the US production increased of 16%, reaching the amount of about 41 billion litres in 2009. According to one estimate, the US bioethanol (which is mostly corn-based) displaced more than 360 million barrels of imported oil for petrol production.

The highest sugar prices of the last years, combined with adverse weather conditions in a major producing region, resulted in a drop in Brazil's bioethanol production from 27.1 billion litres in 2008 to 26.3 billion litres in 2009. In fact almost all ethanol produced in Brazil is from sugarcane, with a very small amount from corn. In the last years sweet sorghum was being taken into consideration for the possibility to process it in the plants alternately with the sugarcane, in order to minimize the plant shutdown.

All fuelling stations in Brazil sell both pure bioethanol and gasohol, at 25% ethanol/75% petrol blend (v/v). The FFV, which can use pure bioethanol, petrol, or any blend of the two, provide the flexibility to choose fuel basing on the price at the pump. They have been widely agreed by the drivers and represent more than 95% of all new cars sold in Brazil. In recent years, significant global trade in fuel ethanol has emerged, with Brazil being the leading exporter. However, Brazilian export of bioethanol declined by almost 31% in 2009. International demand declined in a great part because of the global economic crisis.

7. BIOETHANOL STRATEGIES

7.1. European Union

Biofuels represent a fundamental element in preventing pollution and in supporting the use of renewable energy: globally about 40% of CO_2 emissions are caused by transport sector.

In order to understand the strategies that the EU has put in place to increase the use of biofuels and bioethanol in particular, it is necessary to analyze the European legislation and the strategies adopted by each country.

Specifically, the strategies of the Commission about the biofuels can be summarized in three main points[2]:

1. promoting the use of biofuels both in the EU countries and in the developing countries;
2. promoting large-scale biofuels use by improving competitiveness in terms of cost, by optimizing dedicated feedstock agriculture, by sponsoring research for 2nd generation biofuels, by supporting the market penetration and scaling up demonstration projects;
3. analyzing the available option for the EU countries encouraging the development of biofuels.

The document highlights how the strategy can be implemented with seven specific actions:

1. stimulating demand for biofuels, with an emphasis on tax breaks;
2. ensuring environmental benefits by evidencing the advantages of biofuels in terms of reducing greenhouse gas emissions and ensuring protection of biodiversity;
3. developing the production and distribution of biofuels highlighting the opportunities offered by biofuels themselves in terms of economic activity and creation of new jobs;
4. expanding the supply of raw materials, reviewing the policy of aid, such as the CAP;
5. increasing the opportunities for trade in biofuels, studying the possibility of separating customs codes for biofuels;
6. supporting developing countries and European ones, in particular with the creation of national platforms for biofuels;
7. continuing to support research and development in particular in order to improve production processes and reduce costs.

Basing on these strategies, the Member States have the flexibility to promote the most suitable renewable energy sources and biofuels, according to their potential and their specific priorities.

Concerning the production and consumption of bioethanol, consequent to the European strategy, the data for the EU, Greece, Italy and Spain are reported in the following table.

Country	Production on 2008	Consumption on 2008	Production on 2009	Consumption on 2009
Greece	0	0	0	0
Italy	30,471	58,040	36,566	118,014
Spain	189,431	93,179	221,934	152,193
EU 27	1,148,265	1,773,788	1,865,766	2,339,241

Table 2: comparison of production and consumption of bioethanol between 2008-2009, in Greece, Italy, Spain, EU 27 (in toe)[3]

The rate of consumption of biofuels in the transport has been 3.4% in 2008, 4.0% in 2009, and EurObserv'ER has estimated for 4.8% 2010. The table shows the failure to achieve the target of Directive 2003/30/EC of 5.75%.

In the current situation the EU ethanol 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. The situation will change if the production will be made in decentralized small-medium plants, which is an objective of the SWEETHANOL project.

7.2 Greece

In 2005, following the Directive 2003/30/CE, the Greek Government adopted the Law 3423/2005 "Introduction of biofuels and other renewable fuels in the Greek market". Since December 2005 pure biodiesel was distributed in the country, which was blended in oil refineries or in oil supplying companies with diesel used in transport, in a percentage up to 5% v/v (according to EN 590:2004).

The Law aimed to bring the share of biofuels and other renewable fuels in the Greek market to 5.75% of the total petrol and diesel consumed in the transport sector, by 31st December 2010.

The distribution of biodiesel in the Greek market is implemented through an annual quota system, which determined the blending obligations of the oil refineries and oil supplying companies. Biodiesel in Greece is produced in accordance with the norm EN 14214, adopted with the Greek Joint Ministerial Decision 334/2004.

Financial and legal instruments of national biofuels strategy included support to the biofuels crop production and to the investments on biofuels plants, as well as obligatory use of all biodiesel produced under the "Annual program of biofuel quantity distribution". To stimulate national production of raw material, the biodiesel produced under contract agreements between the farmers and the oil-seed companies is a priority included in the annual distribution program. More specifically, with Law 3423/2005:

- a subsidy of 45 €/ha of energy plant cultivation was given to the farmers;
- a subsidy of 60 €/ha of energy plant cultivation was offered to the biodiesel production facility for seed processing;
- biofuels were not subjected to the fossil fuel tax;
- biorefineries were obliged to use all the detaxed biodiesel;
- encouraged contract agreements between the farmers and the oil-seed companies that determine the purchase of oil-seeds. In order to benefit from the tax reduction, the 30% of the processed raw materials must be produced in the ambit of chain agreements between fuel processors and farmers.

In 2008, the Law 3653/2008, by which tax exemption and subsidies for biofuels have been abolished and a new methodology for sharing the annual dispensable quality of biodiesel has been introduced (Article 55), was approved. Furthermore the introduction of bioethanol in Greek transport market is foreseen for the period 2010-2016 (Law 3653/2008, Article 56).

In 2009, in order to further promote the distribution of higher blends (biodiesel in diesel and bioethanol in petrol), the Law 3769/2009 has passed: this Law allows the distribution of blends higher than the blends set by the Supreme Chemical Council (SCC) in the condition that the rest of the blends characteristics fulfils the standards as set by the SCC for the biofuels or other renewable fuels and the fossil fuel, and additionally there is a special labelling in the fuel stations.

As part of the national strategy to promote biofuels, any investment in the field was subsidized under the National Development Law on promotion of investments (Law 3299/04 as amended by the Law 3522/2006). Subsidies up to 35% were granted according to region and the type of enterprise (in case of SMEs an additional 10-20% is granted). The New National Development Law has to be announced in late January 2011. Moreover, the

"Greek Operational Program for Competitiveness" for 2007-2013 supports investments for biofuels production offering subsidies between 25-50%.

In 2010 the EN 590:2009, which allows to blend biodiesel into diesel for transport with a proportion of 7% v/v, has been adopted; however, the European technical standard for bioethanol (EN15376) has not been adopted yet in the Greek legislation. At present, pure ethanol is produced or imported only for the preparation of alcoholic beverages and not for use as automotive fuel.

The blending of bioethanol with petrol presents technical difficulties and the most significant of them are the separation of water which occurs in conditions of cold, and a high RVP, particularly in the summer. Therefore its conversion to ETBE and subsequently ETBE's use in petrol blends is proposed, instead of MTBE which is used at present. Moreover, according to the norm ELOT EN 228:2004, bioethanol can be used up to 5% blends, while ETBE up to 15%.

In Greece the estimated consumption for year 2009, according to the 6th Greek National Report, of petrol and diesel was 4,376,240 and 2,375,000 toe respectively. In Greece there are thirteen biodiesel plants which produced in 2009 approximately 116,832 toe of biodiesel and three biodiesel companies which imported 14,705 toe of biodiesel during the same year. So far there are no bioethanol plants in the country[4].

7.3. Italy

The Italian strategy that regulates the use of biofuels is based on:

- o implementation of the European reference standard in order to reach the EU targets;
- o provision of appropriate forms of incentives.

In particular, there is the reference to the Biofuel Directive 2003/30/EC, implemented by the Finance Law 2007, which establishes a clear and precise legal framework that traces a path from 2008 with targets for releasing of 2% biofuels in 2010 and ended with a rate of 5.75%.

In the end of 2009 these objectives have been revised for the 2010 target, which became 3.5%.

The achievement of the objectives is based on taxation against individuals who enter the consumption of liquid fuel.

In addition to the strategy used by the Finance Law, the Government has provided guarantees to the use of biofuels also with the adoption of the following two decrees:

- o National Decree N.110, April 29th 2008, of MIPAAF, has made explicit procedures for implementing the obligation of use of biofuels by identifying both the quality and the entities subjected to;
- o National Decree N.100, April 23rd 2008, of MSE, has laid down a framework of penalties for those who do not blend the fuel.

The way chosen by Italy, to stimulate the demand, was to use the quantities of biofuels by preferential duty, in particular with regard to bioethanol, and the first incentives went back to 2001. But it is only with the Financial Law years 2007 and 2008 that funds have been allocated for 2007-2010: 73 million € for the partial reduction of excise duty on bioethanol for a quantity of 250,000 tons.

Unfortunately the picture on the horizon is not good, because during 2009 the Government reduced the available incentives. In 2010 the budget has been further reduced and the incentives passed from 73 million € to only 3.8 million €.

Recently, Italy has transposed the Directive 2009/28/EC, with the NAP and with the approval of the draft legislative decree to promote the use of biofuels for transport purposes. The goal of replacement fuel for transport is 2.53 Mtoe by 2020. The national legislation currently provides for an obligation to make a quota of biofuels available for consumption.

The most recent obligatory quotas have been set by the Ministerial Decree of 25th January 2010: 3.5% for 2010, 4.0% for 2011, 4.5% for 2012.

The Italian production of bioethanol was 36,565 toe in 2009 made by agricultural raw materials (i.e. marc from wine industry) with a capacity of 138,214 toe; the state of plants are represented in the table 3[5].

Current incentives mechanisms did not activate yet a national chain of agricultural production of bioethanol by energy crops, but only experimentation. In fact to improve this chain it is important to involve farmers, develop plants for small and medium scale into the energy district, improve research and develop technologies for 2nd generation bioethanol.

Name	**Location**	**Department**	**Capacity (t/y)**	**Situation**
I.M.A. S.r.l.	Trapani	Sicily	172.000	Working
CAVIRO S.r.l.	Faenza	Emilia- Romagna	43.000	Working
Mossi & Ghisolfi S.r.l.	Tortona	Piedmont	45.000	Project
TOTAL			260.000	

Table 3: list of bioethanol plants in Italy[6]

7.4 Spain

Spain has been working on bioethanol legislation since 1992 with several published laws that affect over the biofuels production and promotion. Each law, order or decree has been developing considering the European Legislation.

In Spain, can be found specifics laws about the use of bioethanol and biodiesel mixed with fuels. For example, the following Laws and Royal Decrees are noted:

- Law 38/1992 on excise;
- R.D. 1165/1995 of taxes and regulations;
- Law 40/1995 of exemptions for biofuels pilot projects;
- R.D. 1739/2003, of 19th December, amending the Excise Regulations;
- amendment of Article 105 of biofuels used in pilot projects;
- pilot project will be considered when the amount of biofuel produced does not exceed 5,000 litres per year. The agreement for recognition of exemption will be valid no more than 5 years. Ethyl alcohol is applied to the tax on alcohol and derived beverages while still maintaining its nature;
- R.D. 1700/2003. Fuel specifications and use of biofuels. Labeling for blends above 5% v/v;
- R.D. 218/2004. Area payments to producers of energy crops;
- it is an aid of 45 € per year per hectare of energy crops;
- MGA benefited from the help: 1,500,000 ha;
- in 2006, R.D. 61/2006 and 774/2006 established specifications for liquid fuels and amending excise regime;
- R.D. 61/2006 of 31st January, for determining the specifications of petrol, diesel, fuel oil and liquefied petroleum gases and for regulating the use of certain biofuels. Article 8. Use of Biofuels, mixtures of biofuels and fossil fuels: meets the general specifications of the latter;
- R.D. 774/2006 of 23rd June, amending the Excise Regulations.

Apart from the Royal Decrees and Laws, the government tries to promote the biofuels production and use, and other renewable energies, through the REP in Spain for 2005-2010, approved by the Council of Ministers in August 2005.

The REP has had the aim of maintaining the commitment to the contribution of 12.1% renewable primary energy consumption in 2010, the electricity production from these sources of 30.3% of gross electricity consumption, and the consumption 5.83% of biofuels on the consumption of petrol and diesel.

It was estimated that employment generation due to the development of biofuels would be around 13,600 jobs (14% of predicted for RES). At the end, the promotion of this sector has been associated to a development on the employment generation as main aim.

In the case of the biofuel industry, the main public support has been provided by the zero rate of tax on hydrocarbons calculating a total amount of 2,855 million € over the entire period 2005–2010.

The Spanish situation concerning the bioethanol production is translated into several projects of biofuel plants, considering the bioethanol plants that are working and the new projects that will be ready in the next years.

Name	**Location**	**Department**	**Capacity (t/y)**	**Situation**
Albiex	Villanueva de la Serena	Badajoz	110,000	Construction
Ecobarcial	Barcial del Barco	Zamora	145,000	Construction
Sniace Biofuels	Torrelavega	Cantabria	126,000	Construction
Biocarburantes Castilla y León	Babilafuente	Salamanca	158,000	Working
Bioetanol de la Mancha	Alcázar de San Juan	Ciudad Real	26,000	Working
Bioetanol Galicia	Teixeiro	A Coruña	139,000	Working
Ecocarburantes Españoles	Cartagena	Murcia	118,000	Working
Villarejo Bioetanol (Experimental)	Villarejo de Orbigo	León	200,000	Working
Bio Europa 2	Puertollano	Ciudad Real	150,000	Project
Bioener Energía (EVE y Abengoa)	Zierbana	Vizcaya	126,000	Project
Bioetanol DosBio 2010 (Miranda)	Miranda de Ebro	Burgos	65,000	Project
TOTAL			1,363,000	

Table 4: list of bioethanol plants in Spain[7]

8. SWEET SORGHUM

8.1 Why sweet sorghum?[8,9,10,11,12,13,14]

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 corn;

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, named "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 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 liters 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, subtropical 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 corn 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 compared to sugarcane, which is propagated from stem cuttings (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 1st 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 2nd 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 1st and 2nd generation biofuel production at the same time. Leaves and also bagasse could be also used as forage.

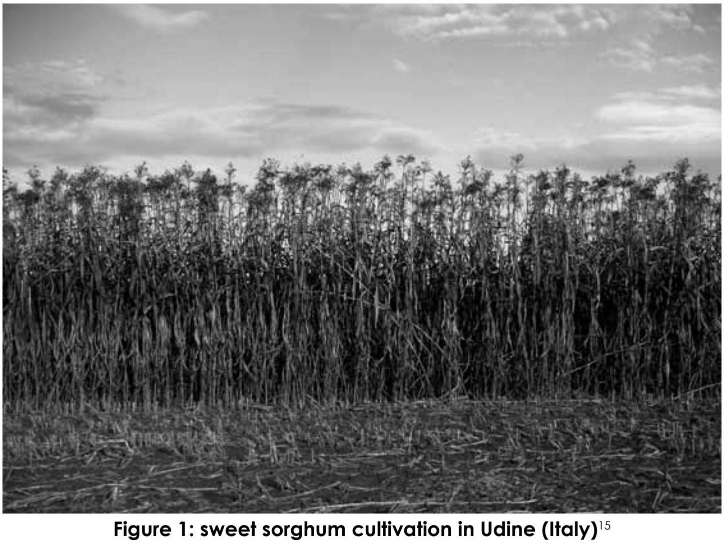

Figure 1: sweet sorghum cultivation in Udine (Italy)[15]

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 corn 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.

8.2 Botanical description[16,17,18,19,20,21]

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 rainfed lands between Ethiopia and Sudan (Africa) and its domestication occurred probably around the years 4000-3000 BC. It was introduced in India (~ 1500-1000 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.

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

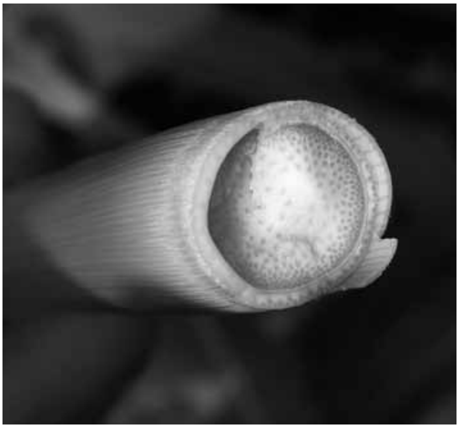

Figure 2: dissected stalk of sweet sorghum[22]

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 corn. 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 to corn, 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 is 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.

Sugar accumulation 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.

8.3 Technologies in cultivation and harvesting[23,24,25,26,27,28,29]

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.

8.3.1 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. glyphosate) 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.

8.3.2 Fertilisation

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.

8.3.3 Sowing

Temperatures should be higher than 10-12 ºC 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; $\geq$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.

- o 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.
- o Long cycle varieties: they may need about 110 days from emergence to flowering. For instance, the varieties named Keller, Dale, Wray.

8.3.4 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.

8.3.5 Crop protection

Since the earliest stages of the crop, namely from sowing to canopy closure (approximately when the crop is 1 m 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 sugar cane 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.

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.

8.3.6 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 is a number of studies about the mechanization of sweet sorghum harvest. Some of the machinery used is: 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 3: harvesting of sweet sorghum with mower-shredder-loader machine[30]

8.3.7 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.

8.4 Breeding programs[31,32,33,34]

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, degree Brix value, non-reducing sugars, total sugars and inverts 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 (7th Framework Programme).

8.4.1 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 SWEETFUEL project is sweet sorghum adaptation to low temperatures. Biomass yield, standability, 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.

8.4.2 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.

8.4.3 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.

8.5. EU experiences on sweet sorghum cultivation

Greece[35,36,37,38,39,40,41,42]

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 RES Directive. 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 ethanol, 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 centers, 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 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 also had the largest number of leaves and greater height of plants.

Also Dalianis *et al.* as part of research team of CRES studied in the early 90'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 from 87 to 144 t/ha wb and the obtained sugars were in the range 9-12 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 10-12 tons fresh biomass/ha. The RUE is 3,5 g db/MJ PAR and the WUE is 55 kg/mm of water.

In more recent experiments in the late 90's research group of CRES studied the agronomic characteristics and performance as well as the effect of different levels of irrigation and nitrogen fertilisation 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 for a density of 110,000 plants/ha. In these experiments they found effects of fertilisation 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.

Italy[43,44,45,46,47]

The bioethanol production in Italy is very limited because of absence of bioethanol production plants diffused on the territory. Actually there are some plants that are producing bioethanol using exhausted marcs and grapes from the distilleries of the wine industry; other case is the use of fruit juice production residues but the realities are very small. Mainly in Italy bioethanol is imported.

Sorghum and sweet sorghum varieties are known in Italy since the end of 30's when they had been studied as industrial crops, mainly in northern regions.

The development and studies on the sweet varieties have had a development thanks to the studies on the genetic improvement; in fact 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 for long time the only systems of genetic improvement applied to sweet sorghum in Italy. This had been due to the limited market of sweet sorghum seeds and also to the not availability of lines male-sterile with a high sugar content in the stems.

A further development of the studies and the field trials with this crop have been done at the end of 1980's and for all the 1990's 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 since 1987 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 in fiber. One of the hybrid breeding (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 as Wray, Dale, Keller, Mn 1500, M 81-E, Theis and Rio gave productions of stems between the 55 and 70 t/ha wb and in fermentable sugars of 6-8 t/ha. The better varieties were also the later because they had the capacity of exploiting a longer vegetative period. These varieties, selected for 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.

Field studies, coordinated by ETA-Renewable Energy, were conducted also under typical

Mediterranean climate in South Italy (Metaponto – Matera, where wide areas are available for cultivation of sorghum) during 1992-95 on sweet sorghum (project ECHI-T, 5thFP). The project has had the objective of analyzing and defining, at pre-feasibility study level, the integrated production of electricity, bioethanol and pellets for animal feeds from sweet sorghum. The relationship between water use, light interception and dry matter production were explained in an environment characterized by clay and deep soil, high temperatures and elevated evaporative demand of the atmosphere. The comparison between the values of WUE and of RUE allowed to evaluate the crop capacity to utilise water and energetic resources of the environment. Sweet sorghum provided elevated values of WUE and RUE (4.8 kg/mm and 3.3 g/MJ, respectively). The research showed, besides, that elevated irrigation regimes are necessary in order to obtain high productive level.

Also the salinity tolerance in sweet sorghum, with field performance under salt stress has been tested in Basilicata region in 1990's. In the southern regions climate there is the necessity of subsistence irrigation to have good productive yields. In hill environment or unfavourable environments 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 moisture content of the fresh biomass resulted about 75-80%. The crop yield that has been reached is 35-40 t/ha with good water support and 20-25 t/ha with low water support.

This energy crop has been also studied in Italy by other important research groups since the beginning of 1990's, 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", "Innovative sustainable techniques for the production and transformation of energy crops and non-food - TISEN".

The research has been focused by these groups 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 in Italy, the sorghum has been mainly cultivated for the production of feed for animals (forage and grain) and, with the diffusion of biogas plants, for the production of ensiled biomass for biogas production in co-digestion with other substrates.

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

In the contest of the MULTISORGO project, funded by MIPAAF and coordinated by C.E.T.A., some commercial varieties of sweet sorghum are being tested in the South and North Italy climates conditions and the produced biomass will be utilised to produce also 2nd generation bioethanol (from bagasse) and biogas (from bagasse and vinasse).

Spain[48,49]

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:

- 1981-1987. Sweet sorghum: contribution to the study of its cultivation for sugars and/or ethanol in Andalucía (Spain). INIA and CAICYT. Programme of Agro-Energy of Spain.
- 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.
- 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.
- 1997-2000. "Environmental studies on sweet and fiber sorghum sustainable crops for biomass production and energy". Commission of the European Communities, C.E., FAIR Programme, Contract FAIR3-CT96 1913.
- 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.
- 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.
- 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.

8.6 Indian experiences on sweet sorghum cultivation

Experiences on sweet sorghum cultivation in India are mainly being developed by ICRISAT. The special characteristics existing in semi-arid tropic areas (e.g. soil and climatic conditions, socio-economic structure) must be taken into account to have a better perspective about the researching lines developed by this institute. ICRISAT has been researching sorghum suitability, along other species, as a crop and as a human food for more than 30 years. Although the main researching line for sorghum has been for food, ICRISAT is also studying the possibility of producing ethanol from sorghum - sweet sorghum - because of the regulatory frame: it is mandatory in India to blend petrol with ethanol to comply Government policies. There are two distilleries using sweet sorghum for bioethanol production: Rusni Distilleries (Andhra Pradesh) and TATA Chemicals plant (Maharashtra). Most experiences developed by ICRISAT on sweet sorghum have been done focusing on linking food production from sorghum grains with ethanol production from sugar stalks, trying to make the most of sweet sorghum and producing at the same time food and energy.

Main research lines on sweet sorghum are developing improved hybrid parents and varieties, seed production, cropping systems analysis, crop management and mechanization improvement, post-harvesting operations, and facilitating incubation of sweet sorghum-based ethanol production technology by entrepreneurs' perspective.

The Landrace program has been developed in order to obtain new and improved varieties to increase sorghum yields. The program is trying to obtain either high stalks yields or sugar content in the stalks, to improve resistance to pest and diseases, to improve adaptability to soil and climatic conditions (type of soil, drought resistance), ratoon possibility. Besides, photoperiod and thermo-insensitiveness are essential to facilitate plantings at different dates and to ensure year-round supply of sweet sorghum stalks for ethanol production.

Research trials on cropping systems with sorghums are based on optimizing returns from a combination of crops and also on the fact that the overall productivity of the whole system must be the most successful possible. Trials on intercropping (e.g. pearl millet, pigeon pea, chickpeas) and on sequential, rotational or ratoon cropping have been conducted.

About crop management, research on machinery is being performed in order to maximise productivity and minimise costs (although it must be considered the lower development of the mechanization existing in India), minimise the use of fertilisers (mainly nitrogen) and herbicides to control weeds, and this research is also performed for spatial plant arrangement, water supply and surface mulch management.

<u>Synthesis of the model developed by ICRISAT</u>

A DCU is a place where the sugar juice is extracted from the sweet sorghum stalks. Each DCU can manage 70 ha of sweet sorghum. Sweet sorghum average yield is 30-35 t wb/ha. Juice extraction yield from stalks is 65-70% and losses percentage is estimated about 5-10%. Sugar content can reach 17 °Brix. Bagasse (30%) is burned in furnaces as a source of heat to concentrate the juice extracted from stalks and converted it into syrup (60% concentration) in order to improve the storage conditions and facilitate the transport to distilleries plants. One ton of juice produces 170 kg of syrup. The rest of bagasse is sold or used for domestic uses. Climate conditions allow to have two crop seasons, rainy and post-rainy season (4 months each one) and a rotation period of 4 months too. Fertilisers (NPK) are usually applied in three times and they are complemented with nitrogen fertiliser, 30 days after sowing. Spatial plant arrangement is 0.75-0.80 m x 0.10-0.15 m, and it is superficially sown (≈5cm) using ridge rows. Irrigation is applied but the water amount depends on the climate conditions. Land is ploughed before sowing and herbicides are used according to the requirements. Due to the low labour costs the degree of mechanization is very low; because of economic limitations, crop inputs (fertilizers, herbicides, pests) are low too.

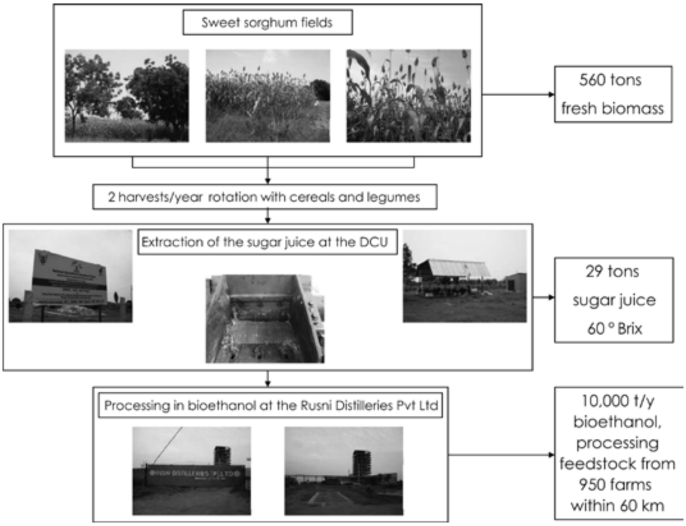

Figure 4: scheme of the ICRISAT's model[50]

9. DESCRIPTION OF A POTENTIAL EU MODEL – DECENTRALISED BIOETHANOL PLANTS

One of the main characteristics of sweet sorghum as bioethanol crop is the strong connection among the fields and the plant for the processing into biofuel: in fact its biomass, rich in sugars and water, cannot tolerate a long transport phase because of the perishability of the biomass. For this reason, in the model, the transport does not exceed 20 km.

In particular this characteristic makes sweet sorghum suitable to feed decentralised small-medium plants, enforcing the role of the local farmers in the bioethanol chain.

Consequently each plant must be rated on the basis of the specific area, such as for example the fields availability, the road network, the local farm structure (e.g. land fragmentation, wealth of farms, age of the farmers and related propensity to innovation).

The considered model for a decentralised plant has three production lines:

A. bioethanol production through the fermentation of the sugar juice extracted from the sweet sorghum biomass (stalks);
B. energetic exploitation of the bagasse, that is the by-product of the sugar juice extraction; the dried bagasse is burned in a CHP plant to produce electricity and heat;
C. energetic exploitation of the vinasse, that is the by-product of the bioethanol distillation; the vinasse is a co-substrate for the anaerobic digestion and the obtained biogas is burned in a CHP plant to produce electricity and heat.

The layout of the plant is shown in the figure 5.

On the basis of these assumptions, the decentralised bioethanol plant becomes a biorefinery. The bioethanol is just one of the final products and its selling is just one of the revenue items. In fact the electricity and heat not used for the internal consumptions (e.g. drying of the bagasse, extraction, distillation, anaerobic digestion, fermentation) are a surplus that can be sold: they are considered as revenue items.

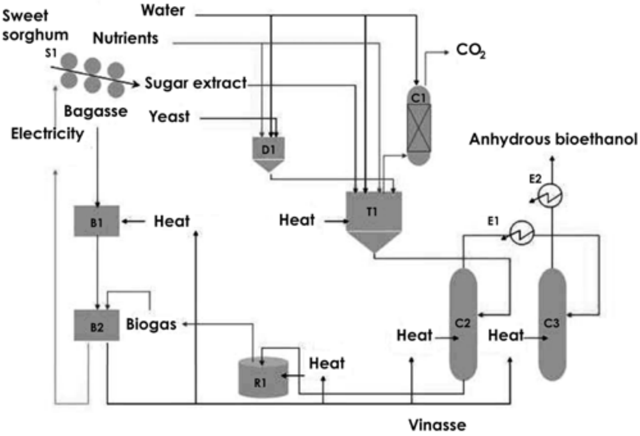

Figure 5: layout of the biorefinery[51]

In order to fit the plant on the territory, two plants size, and consequently two models, are following described and explained:

1. bioethanol production: 10,000 tons/year, correspondent to 3,700 hectares approximately;
2. bioethanol production: 3,200 tons/year, correspondent to 1,200 hectares approximately.

In the models, these working hypothesis are considered:

- fresh biomass yield: 65 t/ha wb (water content 75%);
- extraction yield: 78%;
- fermentation yield: 50%.

In the following explanation the critical points are evidenced, in order to set up the basis for the discussion.

9.1 Sweet sorghum cultivation

In the Mediterranean climates the sowing should be performed at the beginning of May and one harvest is foreseen. In order to prolong the harvesting time and consequently to optimise the rate of plant feeding, different varieties should be cultivated (i.e. short cycle varieties and long cycle ones). With this strategy the harvest can last forty days, usually in August and September in the Mediterranean climates; later harvesting can determine damages to the plants and loss of sugars.

In the harvesting process are involved some yards: each one is made up by one mower-shredder-loader machine and four farm tractors with dumper (capacity 18 t/dumper). Each yard has a work capacity of 15 hectares per day, if the distance among the fields and farm is at maximum 5 km.

The number of yards is based on the involved agricultural area: in the model 1 (3,700 hectares) at least six yards are required, in the model 2 (1,200 hectares) two yards are necessary.

Topic for the discussion: diffusion of sweet sorghum and availability of germplasms

The sweet sorghum cultivation does not belong to the European agricultural tradition and the conversion of the land use (e.g. replacement of corn, where irrigation is not possible, or use of marginal lands) can be seen by the farmers as a criticism.

Furthermore, at the moment, just few number of sweet sorghum varieties are available in the EU market and some trials have been carried out in experimental scale and in open field to use these varieties as bioethanol crops.

Some alternative varieties are being imported in the EU, most of all from India and China, in order to extend the harvesting time and to reconcile the production of bioethanol with the production of grain solving the problem "Food *versus* Fuel".

Chain actors for the discussion of this topic

Farmers, seeds and agricultural companies, agricultural associations.

9.2 Storage and processing of feedstock and sugars

If the sweet sorghum biomass is not cut up during the harvest, stalks are transported to the bioethanol plant unloaded on the feeder table and discharged on the carrier with the help of electrically operated stalk unloader. In this case the fibrization phase is required. Through a kicker which is fitted on the carrier stalks they are discharged to the fibrizer. This special equipment designed to chop the sweet sorghum stalks feeds the crusher section with the bagasse blanket. Automatic stalk feeding device is fitted on the carrier to control the feed.

Alternatively, sweet sorghum can be cut up during the harvesting and the obtained chopped biomass is directly processed.

The technology for the sugar extraction from the biomass is based on that used for sugarcane.

The extraction is carried out crushing the feedstock into horizontal or vertical power mills. The extraction principle is the application of high pressure 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 to 12 rpm in small mills, 6-8 rpm in large mills. In order to improve the extraction efficiency, hot water (about 65 °C) is added before one of the last couples of rollers (approximately 10% w/w).

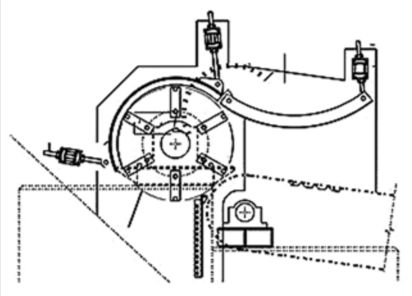

Figure 6: working scheme of the fibrizer[52]

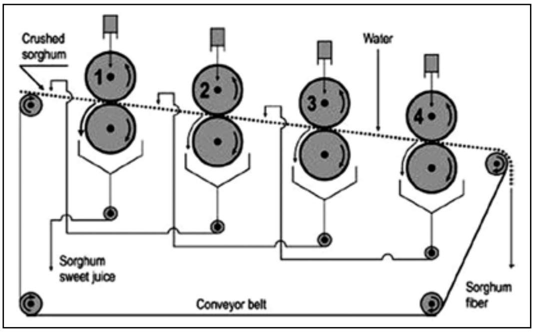

Figure 7: working scheme of the crusher[53,54]

The working scheme of the crusher is reported in the figure 7.

Apart from sugars, the sweet sorghum juice contains soluble solids (anthocyanins and chlorophyll) and insoluble solids (starch granules). The extracted juice should be filtered in order to get it clean. 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.

Although the choice of different varieties of sweet sorghum is able to prolong a little the availability of fresh biomass, in the Mediterranean climates further strategies are necessary to warrant a continuous feeding of the processing plants. In fact the objective is a plant which works for 330 working days per year, with a plant shutdown of one month (approximately in August before the harvesting).

To reach this aim two approaches are taken into consideration:

A. ensiling of the biomass and processing the ensiled biomass during the harvesting period (from October to July approximately);
B. concentration and storage of the produced syrup, and its progressive dilution before the processing.

Strategy A

If the silage strategy is chosen, in the considered area an adequate ensiling capacity is required. At this aim the silos dedicated for the corn silage can be used. The size of the silo must allow the consumption of the entire ensiled biomass in a short time (i.e. one day at maximum), in order to avoid its deterioration caused by the contact with the air; in the creation of the models, a capacity of 720 m^3/silo approximately is suggested.

The number of required silos and the rate of use are based on the plant size: in the model 1, about 510 silos are necessary and three silos are processed in two days, whereas in the model 2, about 160 silos should be available in the considered area and one silo per day is consumed.

The crucial element of the ensiling strategy is the adequate sugar conservation. In fact usually sugars are quickly fermented by the micro-organisms and the consequent decrease of the pH in the medium is one of the conditions for the stabilisation and conservation of the biomass. In order to reconcile the medium acidification and the sugar conservation, some addictives can be used. At the current time, the most promising results are obtained using formic acid (0.4-0.5% approximately); in fact experimental trials evidenced that the stability of the biomass in the opened silo is at least 50 hours, widely compatible with the logistic of the plant supplying.

The critical aspect of this strategy is the cost of the formic acid that weigh significantly upon the economic analysis.

Strategy B

The concentration of the sugar juice allows to stop the microbial activity, in order to process the substrate during eleven months. Different values for the final concentration of the sugar juice allow to modulate the storage time in the tanks.

After the extraction the sugar content is approximately 12 °Brix:

- the concentration up to 45 °Brix allows a storage time of one month at 20 °C;
- the concentration up to 60-65 °Brix allows a storage time of three months;
- the concentration up to 85 °Brix allows a storage time of about one year.

Since the concentration is a very expensive phase because of the energetic consumption, the differentiation in the concentration levels is able to reconcile the logistic in the plant supplying and the impact of this phase on the economic analysis.

The equipment required for the sugar juice concentration is composed by settling tank, motor for pumping juice, flat-bottomed aluminium or stainless steel vessel and conventional furnace with at least 10-15% overall efficiency or a gasifier-powered furnace.

At this level, the strategy A is applied in the model. During the discussion with the chain actors to optimize it, the settlement of the most strategic approach for the conservation of biomass or sugar will be treated.

TOPIC FOR THE DISCUSSION: HARVESTING TIME AND WORKING PERIOD OF THE BIOETHANOL PLANTS

Two alternative strategies can be applied in order to extend the working period of the biorefinery beyond the harvesting months:

A. ensiling of the biomass (at the farms or in one ensiling site);

B. concentration of the sugar juice.

In the discussion of the EU model this topic will be treated with the chain actors, analysing in depth both strategies, in terms of different investment and operative costs (most of all concerning the energy consumptions), logistic aspects (e.g. ensiling at the decentralised plant or at the farms) with the consequent different attributions of responsibility in the sugar preservation.

CHAIN ACTORS FOR THE DISCUSSION OF THIS TOPIC

Farmers, seeds and agricultural companies, agricultural associations, fuel processors and SMEs representatives.

9.3 Fermentation and distillation

In the considered models the fermentation in batch is foreseen, because the applied technology is simpler than that used for the continuous process and consequently it is more suitable for the decentralised plants.

Sugar juice is pasteurised at 100 °C for 30 minutes. The following alcoholic fermentation is carried out in stainless reactors, each one provided with conical roof and bottom, vertical cylindrical shell, stainless refrigeration circuit applied to the cylinder and conical bottom. The mixing (approximately 400 rpm) is guaranteed by an electrostirrer.

Wild strains of *Saccharomyces cerevisiae* are inoculated and their fermentation conditions are: temperature 30-32 °C, pH 4.0-4.5, duration 22 hours.

The bioethanol concentration in the fermented medium is 10% v/v approximately.

In order to separate and concentrate bioethanol, the distillation and dehydration phases are required.

Usually three distillation columns allow to reach a final bioethanol concentration of 50% v/v and the following rectification column increases the bioethanol concentration up to 96% v/v.

With the dehydration the final bioethanol concentration is 97% v/v, whereas the molecular sieve plant allows to obtain anhydrous bioethanol (i.e. 99.8% v/v).

Consequently the distillation and dehydration section has six columns.

9.4 Exploitation of by-products

In the settlement of the models the energetic exploitation of by-products has been chosen in order to make the plant self-sufficient from an energetic point of view.

Bagasse

The chemical composition of bagasse obtained from the processing of the ensiled or not-ensiled sweet sorghum shows that this material is suitable for the combustion, if it is preventively dried. After the extraction phase its moisture is about 50%, correspondent to a LHV of 5.8-6.3 GJ/t approximately. The LHV of the dried bagasse is 16.0-17.0 GJ/t.

Since the bagasse ashes are very rich in chlorine and sulphur, the boiler must be adjusted for this use and the extended warranties must be required to the manufacture. The boiler is connected with a CHP plant in order to convert the chemical energy of the feedstock in electricity and heat.

The required technology and power of boiler depend on the availability of bagasse.

Figure 8: bagasse of sweet sorghum[55]

In the model 1, one CHP boiler combined with a steam turbine (Rankine-Hirn cycle) with 6.4 MWe is suggested (μel 25%, μt 60%).

In the model 2, one CHP boiler combined with an ORC turbine (Rankine-ORC cycle) with 1 MWe is suggested (μel 14.4%, μt 80%).

Vinasse

The chemical composition of the vinasse obtained from the processing of the ensiled or not-ensiled sweet sorghum allows to use this feedstock as co-substrate for the anaerobic digestion. Its COD is 65-70 gO_2/l and the dry matter content is 20-25%.

The correction of the C/N values is required, mixing vinasse with other co-substrates: at this aim manure and whey can increase the nitrogen content, whereas lignocellulosic biomass decreases it.

At the same time the increase of dry matter content, which is usually low in this by-product, could be necessary.

The facilities for the anaerobic digestion of the vinasse are the digestor and CHP based on the modified diesel engine. The capacity of the digestor and the power of the engine depend on the availability of vinasse.

In the model 1 the required digestor capacity is 15,000 m^3 and the obtained biogas is burned in one CHP diesel engine with 4 MWe (μ_{el} 41%, μ_t 45%).

In the model 2 the required capacity digestor is 4,400 m^3 and the obtained biogas is burned in one CHP diesel engine with 1.2 MWe (μ_{el} 41%, μ_t 45%).

The electricity and heat exceeding the internal consumption of the biorefinery are final products which can be sold.

In the model 1 the surplus is: 83% of the produced electricity and 43% of the produced heat.

In the model 2 the surplus is: 77% of the produced electricity and 43% of the produced heat.

Alternatively bagasse and vinasse can be addressed to recovery as a matter, whereas the energy consumption of the processing plant can be covered with other biofuels (e.g. wood, lignocellulosic wastes). In this hypothesis, bagasse and vinasse can be used as fertiliser (i.e. bagasse: N 0.45%, P_2O_5 0.33%, K_2O 0.71%; vinasse N 0.2%, P_2O_5 0.22%, K_2O 0.30%) also through the composting process, and the compounds of the vinasse can be separated to produce chemicals (e.g. bioplastics, biopolymers, antioxidants).

The optimal exploitation strategy is an important subject of the discussion in order to optimise the model.

TOPIC FOR THE DISCUSSION: EXPLOITATION OF THE BY-PRODUCTS

The by-products of the sweet sorghum processing can be exploited through different pathways, for example:

A. conversion in electric power and heat;

B. production of animal feeds;

C. separation of molecules to obtain chemicals (e.g. bioplastics, biopolymers, antioxidants).

In the discussion of the EU model this topic will be treated with the chain actors, analysing in depth the alternative strategies, in terms of energy balance, sustainability of the obtained bioethanol, technical and economic feasibility.

CHAIN ACTORS FOR THE DISCUSSION OF THIS TOPIC

Farmers, agricultural associations, fuel processors and SMEs representatives.

9.5 Energetic evaluation

In the energetic evaluation the following direct and indirect consumptions are considered:

- direct consumptions: fuels, electricity and natural gas for the supplying of the agricultural machinery and for the working of the biorefinery (three lines, included the exploitation of by-products), in the hypothesis that the maximum distance among the fields and the plant is 20 km;
- indirect consumptions: production, packing, transport and storage of fertilisers, herbicides, addictives (i.e. formic acid for the ensiling) and seeds, nutrients for the fermentation, manufacture, transport and maintenance of the agricultural machinery and components of the biorefinery, considering the average life cycle and the utilisation time of each mean.

The total consumption of the agricultural and ensiling phases is about 24.0 GJ/ha (Table 5), but this value can change significantly in relation to the applied agricultural techniques and the length of the transportation.

The total consumption of the processing phase is 10.5 GJ/t, correspondent to the 39% of the bioethanol energy content (LHV 27 GJ/t). The consumption of the distillation and dehydrations sections are the highest, 92% of the total (Table 6).

The energy balance (i.e. energy content/energy consumptions) is counted including the energy content of by-products for the rate with which they cover the internal energy consumption.

The values for the energy balance depend on the size of the biorefinery: in the model 1 the ratio energy content/energy consumptions is 1.92, in the model 2 it is 1.70.

	Machinery MJ/ha	Fuels and lubricant MJ/ha	Other* MJ/ha
Agricultural phase			
Soil preparation	316	3,302	-
Herbicide application	60	455	714
Fertilisation	101	682	6,111
Sowing	75	455	305
Harvesting	154	2,314	-
Transportation	170	1,337	-
Ensiling phase			
Compressing and application of addictives	136	1,007	6,240
Total	**1,012**	**9,552**	**13,370**
TOTAL ENERGY CONSUMPTION			**23,934**
* fertilisers, herbicides, seeds, addictives (i.e. formic acid)			

Table 5: energy consumptions for the agricultural and ensiling phases related to the use of sweet sorghum as bioethanol crop[56]

Processing phase	Heat GJ/t	Electricity GJ/t	Total consumptions GJ/t
Extraction of sugar juice	-	0,70	0,70
Fermentation	0,04	0,11	0,15
Distillation	6,94	0,37	7,31
Dehydration	2,20	0,12	2,32
TOTAL ENERGY CONSUMPTION	**9,18**	**1,30**	**10,48**

Table 6: energy consumptions of the processing phase related to the bioethanol production from sweet sorghum[57]

9.6 Economic evaluation

In the economic evaluation the main items for the costs and incomes are considered and analysed in the hypothesis that the maximum distance among the fields and the plant is 20 km.

In the costs the main analysed items are:

- agricultural phase: soil preparation (i.e. ploughing and harrowing), herbicide application, fertilisation, sowing, irrigation, harvesting, transportation of the chopped feedstock to the ensiling sites;
- ensiling phase: compressing and application of the addictives (i.e. formic acid); purchase of the addictives;
- processing phase: the investment cost (i.e. building, equipment, overheads, technical costs such as feasibility study and designing, unforeseen expenses), operating costs (i.e. purchase of the raw materials, O&M, consumables, amortisation, interest expenses); the energy consumptions are not included, because in the models they are covered through the exploitation of the by-products.

The agricultural and ensiling phases require approximately 1,000-1,500 €/ha. The wideness of the range is due, most of all, to the agricultural phase. Since sweet sorghum can be cultivated in different soils and climate conditions, the main variables are the requirements of fertilisers and irrigation and the weight of these parameters is significant. Consequently, the costs are higher in the poor soils of the semi-arid areas because fertilisation and emergency sprinkler irrigation likely are required. Then the actual cost must be estimated for the specific cultivation area.

Another important factor, that determines the wideness of the range, is the weight of the addictives cost (i.e. formic acid) which depends significantly on the bought quantity and finally on the logistic of the ensiling. If the ensiling is carried out at each farm the price is high, whereas if the ensiling phase is centralised in one site it is possible to buy a substantial amount of addictive obtaining a lower price and reducing the weight of this cost.

The settlement of the indicated range is a discussion subject of the model for the EU.

Concerning the processing phase, the investment costs depend on the size of the plant and they benefit from the economy of scale; consequently, the smaller plants are significantly more expensive than the bigger ones.

In the estimation, the purchase of the land, the obtaining of the licences and eventually required patents and extraordinary maintenance are not included.

The investment cost of 10,000 t/year biorefinery is approximately 22-25 million €. In proportion the smaller biorefinery of 3,200 t/year has a higher investment cost, 13-15 million €. The wideness of the ranges is due to the chosen technological solutions: in particular, significant differences are ascribable to the crusher systems, that are very different in their capacity and automation level, to the distillation plants (e.g. three-five times effect) and to the energetic exploitation of by-products (e.g. characteristics of the anaerobic digestor, CHP plant).

Likewise, the operating costs depend on the plant size: in the model 1 (10,000 t/year) the annual operating costs are 150-200 €/ton of produced bioethanol, whereas in the model 2 (3,200 t/year) they are higher, 300-350 €/t.

Concerning the incomes, the following items are important for the economic evaluation: the sale of bioethanol, the sale of electric power, the sale of the Green Certificates and the sale of the heat through a district heating network.

At this level, the values of these items are not quantified because they vary significantly among the different Member States, basing on the national markets of the primary energy (i.e. electricity and natural gas) and on the instruments of government incentives for the RES.

Consequently the settlement of the economic analysis is a basic subject of the discussion of the EU model, where all the variables will be fixed for each State of the consortium and the different conclusions of the economic evaluation will be compared among Italy, Spain and Greece.

TOPIC FOR THE DISCUSSION: ANALYSIS OF COSTS AND INCOMES

The values for the costs and incomes vary significantly for each Member State because the incentives and the bioethanol and energy market are different.

Consequently all the items require a specific analysis with the chain actors.

CHAIN ACTORS FOR THE DISCUSSION OF THIS TOPIC

Farmers, agricultural association, seed and agricultural companies, fuel processors and SMEs, energy agency representatives, policy authorities, policy makers, investors.

9.7 Sustainability of the bioethanol production in Europe

In accordance with the Directives of 2009, the sustainability of bioethanol is a basic requirement in order to actually reduce the GHGs emissions from the transport sector.

Consequently the GHGs saving for the bioethanol obtained from sweet sorghum in the considered models have been estimated basing on the methodology indicated in the RES Directive (Annex V, part C).

The GHGs saving depends on the size of the biorefinery: in the model 1 it is 71%, in the model 2 it is 70%.

Both models guarantee the full compliance of the RES Directive, in which nowadays the minimal GHGs saving for the bioethanol is 35% and it will increase in the next years (i.e. 50% in 2017 and 60% in 2018).

The values given to each parameter for the calculation are reported in the Table 7.

GHGs emission items	**Model 1** gCO_2/MJ	**Model 2** gCO_2/MJ
Agricultural and ensiling phases (e_{ec})	11.2	12.2
Change of the land use (e_l) *	0	0
Processing phase (e_p)	11.4	12.5
Transportation and distribution of bioethanol (e_{td}) **	2	2
Utilisation of the bioethanol (e_u)	0	0
TOTAL	**24.6**	**24.7**
* In the hypothesis to convert the cultivations of corn in sweet sorghum, where the irrigation is unsustainable ** Part D of the RES Directive		

Table 7: values for the calculation of the GHGs saving in accordance with the methodology of the RES Directive[58]

The optimisation of these calculations is an important subject of discussion, when also the opportunity to cultivate sweet sorghum on marginal lands or polluted sites will be evaluated. In this case, the obtained bioethanol can benefit from the further GHGs saving of 29 gCO_2/MJ, at the moment not included in the hypothesis.

TOPIC FOR THE DISCUSSION: GHGS SAVING IN ACCORDANCE WITH THE RES DIRECTIVE

The GHGs saving of 35% is an essential requirement to obtain the tax incentives and to count the produced bioethanol in the amount required at 2020; consequently in the next years the demand of this "sustainable bioethanol" will increase.

For each variable considered in the model (e.g. ways to preserve sugars or to exploit by-products) the GHGs savings of the correspondent produced bioethanol will be calculated, basing on the methodology of the RES Directive (Annex V, parts C and D), updated with the results of the BIOGRACE project supported by the Intelligent Energy Europe programme.

In the discussion of the EU model this topic will be treated with the chain actors, analysing in depth all the elements of the calculation.

CHAIN ACTORS FOR THE DISCUSSION OF THIS TOPIC

Fuel processors and SMEs, energy agency representatives.

Apart from the actual GHGs saving of bioethanol, another important criticism of the 1st generation biofuels is the competition for the destination of the agricultural products and, consequently, for the agricultural lands. In fact the food and biofuel industries are using the same parts of plants as raw material, entering the biofuels production in competition with the use of crop for human food.

This problem has been known by the media as "Food *versus* Fuel".

The impact of biofuels on global food prices has been the subject of considerable discussion and attention of the media since 2008.

Even though many reasons determined the price increase of the agricultural products in 2008 (e.g. the speculation of the commodities, a long period of drought in some countries around the world, the changes in the eating habits in the developing countries, the use of corn to produce bioethanol in the US), the problem "Food *versus* Fuel" was presented as the main problem, and the public opinion was convinced that biofuels starve out the world. That is not completely true at this time.

The solution must be searched in an arrangement aimed to reconcile the requirement of food by an increasing population with the energetic demand for the economic development and for the improvement of the life quality for all populations.

This arrangement can be found in different ways, starting from the use of marginal and polluted lands, where food crops cannot be cultivated, benefiting moreover from the phytoremediation process to decontaminate these lands; moreover, the utilisation of crops that at the same time can give feedstock for food and fuel should be considered; finally, at least the development of new technologies for the 2nd and 3rd generation bioethanol must be evaluated, because it is possible in this way to use as raw material residual biomass and other non food resources.

Sweet sorghum acknowledges both opportunities and consequently it contributes to reconcile these important human requirements.

Firstly sweet sorghum can be cultivated in poor soils, characteristic of the marginal lands.

In the second place at the current time important scientific researches are aimed to study some varieties of sweet sorghum which can give food and biofuels, because they present a high yield of grain and at the same time a high sugar concentration in the stalks. In the traditional varieties, indeed, sugars are moved from the stalks and polymerised in starch during the formation of panicles. Furthermore, in the future the use of bagasse for the 2nd generation biofuel production has to be considered an opportunity.

The critical aspects about the introduction of these varieties in the EU agricultural practices (e.g. the machinery applicable in the harvesting to obtain grain and stalks) are an important subject for the discussion of the use of sweet sorghum as bioethanol crop in the EU.

10. EXPERIENCES OF THE TRAVELS

In order to refine the know-how about the sweet sorghum processing in bioethanol, some travels were planned. The destinations were chosen to visit some agricultural institutes, where germplasms are studied and bred, and some plants, where sweet sorghum is processed in bioethanol at the pilot and industrial scales.

Since this chain is not developed in the EU because of important non-technological barriers, some destinations were outside the EU.

The travels were carried out in October and November 2010.

The obtained knowledge, concisely reported in the following paragraphs, is the background for the discussion of the EU model, aimed to import the know-how and to start new entrepreneurships in this sector.

10.1 Experiences of the travel in India

India was selected for the visits because it is one of the few existing countries around the world where sweet sorghum is being used for the ethanol production. In November 2007 the Rusni Distilleries Pvt Ltd at Hyderabad, Andhra Pradesh, started to produce ethanol by processing sweet sorghum. One year later, on December 2008, TATA Chemical Ltd created a bioethanol plant in Nanded, Maharashtra, using sweet sorghum as feedstock too. Food security is a national priority for India due to the fact that about one-fourth of the population is below the poverty line, so India's biofuels strategy focuses on the use of non-food sources. Sweet sorghum allies to this policy because it does not compromise food security for the ethanol production since the farmers can continue to use the grain for food. Sweet sorghum which contains 10-12% sugar content can be crushed and processed like sugarcane and has the added advantages of reaching maturity within a period of 110 days and requires only one-third quantity of water for cultivation.

The Indian Ministry of Petroleum launched a program that imposed blending of 5% ethanol in petrol in 2003. The implementation of the program in many States was delayed because the high State taxes, excise duties and levies made the ethanol supply for blending commercially unviable. It is estimated that about 540 million litres of ethanol have been supplied for the program by the end of April 2009. The Government does not provide any direct financial assistance or tax incentive for the production or marketing of ethanol or ethanol-blended petrol; however, offers subsidised loans (2% below market rate) from the national–held Sugarcane Development Fund for up to a maximum of 40% of the project cost to sugar mills for setting up an ethanol production unit. More than 115 out of the 320 alcohol distilleries modified their distillation facilities to produce ethanol with total ethanol production capacity of 1.5 billion litres per year. In India the production of ethanol is derived mainly from sugar by-products while the use of other feed stocks like sweet sorghum, sugar beet, etc. are at a preliminary stage.

The Government supports research for identifying sweet sorghum cultivations suitable for the local climate and supports also some public research organizations such as ICRISAT. ICRISAT is headquartered in Hyderabad, Andhra Pradesh, and its mission is to *"help empower 600 million poor people to overcome hunger, poverty and a degraded environment in the dry tropics through better agriculture"*. The institute focuses on five crops: groundnut, pigeon pea, sorghum, chickpea and millet. ICRISAT carries out an extended research on genetic enhancement of sweet sorghum for sugar yield. Research on the development of sweet sorghum cultivars was initiated in 1980 with the evaluation of 70 germplasm accessions and was renewed in 2002 to meet the increased demand for ethanol, driven by government policies to blend ethanol with petrol. The wide variability in germplasm and hybrid parents for the traits related to ethanol production, such as sugar content and high stalk yield, offers bright scope for the development of high stalk yielding sugar-rich varieties and hybrids. The Sweet Sorghum Breeding Program aims to improve the sugars content, the juice content and the plant biomass apart from sugar yield. Hybrids are superior for sugar yield (t/ha) and are less thermo and photoperiod insensitive.

ICRISAT established in 2003 the ASP to promote public-private partnerships that will commercialise science-generated technologies. So far more than 20 technologies have been marketed through the private sector, thus creating employment opportunities and industrialisation. A key success story has been the commercialisation of ethanol from sweet sorghum when ICRISAT developed hybrids that yielded high juice and sugar content for industrial production of ethanol, and the technology was successfully commercialized by M/s. Rusni Distilleries Ltd. ICRISAT has created also two platforms: the ICRISAT – Private Sector Sweet Sorghum Ethanol Research Consortium has been established to meet current and future demands of the sweet sorghum-based ethanol distillery units, and this is being facilitated by ABI of ICRISAT. The ICRISAT – Private Seed Sector Sorghum Hybrid Parents Research Consortium operates with 22 members at present and aims to strengthen sweet sorghum hybrid plants research at ICRISAT and shares the products of this research with the seed industry, which in turn provides sweet sorghum hybrids to the farmers.

Sweet sorghum supply chain involves centralised and decentralised models. Under centralised model, farmers supply the sweet sorghum stalks directly to the distillery whereas in decentralised model farmers supply stalks to DCU which act as cluster centres. To enable farmers who are located away from the distilleries to participate in the sweet sorghum to ethanol value chain, a decentralised crushing and syrup making unit is proposed involving farmers from a cluster of three to four villages. ICRISAT's strategy is to examine the feasibility of applying one or more of these measures to mitigate the yield losses and help supply raw materials (stalks or syrup) to the distillery over an extended period in a year. In the DCU units, stalks are crushed and the sweet juice is boiled to produce concentrated syrup (> 60 °Brix) that can be stored for more than 9 months and can be used in ethanol production, particularly in off-season, increasing the feedstock supply to the distillery. The DCU of ICRISAT processes the sweet sorghum crops of 70 farmers, with the supply from about 30 hectares. The unit has 3 crusher machines two of which have a capacity of crushing 2 tons of stalks/hour while the other has a capacity of 1 t/h. In the 2009 rainy season, a total of 560 tons of green stalks were crushed to realize 29 tons of syrup (approximately 60 °Brix).

Rusni Distilleries is the world's first sweet sorghum based ethanol plant. It's a mid-sized plant with a capacity of 40,000 litres of ethanol per day (in full operation). Rusni has 30 crushing units of 1 t/h capacity each, and 6 tanks for the fermentation phase and the syrup production. Rusni, apart from the sweet sorghum syrup supplied by the cluster centre (DCU), buys sweet sorghum stalk for 9-10 € per ton from other farmers near the area. The ethanol plant process 870 tons of sweet sorghum stalks. All the stalks passed in a series of two rollers and they are so crushed twice; the juice yield corresponds to an extent of 40% of stalk yield on weight basis. Juice is pasteurized at 100 °C for 30 minutes; yeast is added and fermented for 34 to 45 hours. The production cost of bioethanol is approx 0.30 €/litre, while the public outlet pays 0.40 €/litre and the private outlet pays 0.46€/litre of ethanol. The cost of the plant was about 7 million €.

The second bioethanol plant in India which uses sweet sorghum as feedstock is a centralised plant in Nanded, Maharashtra, property of the TATA Chemical Ltd. The plant has a capacity of 30,000 litres of ethanol per day and uses also sweet sorghum bagasse as fuel for generating power. Sweet sorghum stalks are transported to TATA Chemicals bioethanol plant unloaded on the feeder carrier to be discharged to the fibrizer. The raw material pass through 4 power operated hammer mills of 3-roller mill (TRPF milling system) to collect the juice. The extracted juice is then carried to the furnace for syrup production and evaporation. If the syrup must be carried directly for fermentation, sugar is concentrated about 40-50% (semi-syrup) and then diluted to 18%. The syrup of 85 °Brix, conserved for about one year, is also diluted before the fermentation. The juice is then inoculated with yeast and run in fermenter for a period of 72 hours at 30-32 °C. Finally, after the fermentation, the distillation phase takes place for the production of bioethanol.

Figure 9: crushing unit at ICRISAT, Hyderabad, Andhra Pradesh (India)[59]

Figure 10: DCU in Medak district, Andhra Pradesh (India)[60]

Figure 11: juice concentration unit at the DCU in Medak district, Andhra Pradesh (India)[61]

10.2 Experiences of the travel in Spain

In Spain during the month of October 2010 there were different visits, one to the bioethanol plant of Abengoa in Babilafuente, Salamanca, and another to the ACOR Cooperative in Olmedo to visit its sugar production plant from beet and biodiesel from sunflower and rapeseed. Spain, given its cerealistic tradition, has based its bioethanol production on cereals like wheat. The process is based on the dry milling and enzymatic hydrolysis of starch. In Spain, despite being a producer of cereals which could be used for bioethanol production, most of the raw materials used for this production are imported from other producing countries, where the cost per kilogram of raw material is lower and therefore allows obtaining a final tighter cost per litre of bioethanol. Thus, the percentage of cereals used for industrial destinations for bioethanol production in Spain, is less than 7%.

Abengoa – Bioenergy Group has three bioethanol plants in Spain:

- Biocarburantes Castilla y León (located in Babilafuente, Salamanca);
- Bioetanol Galicia (located in A Coruña, Galicia);
- Spanish Ecocarburantes (located in Cartagena, Murcia).

In the case of the plant located in Babilafuente, cereals, especially wheat and barley, are the selected raw materials for the bioethanol production. In any case, it should be noted that the distribution in Spain has followed a defined pattern for the three industrial operating plants. For the first two cases, both located in Cartagena and in A Coruña, the main product was anhydrous bioethanol for ETBE production, so its location has been decided considering the proximity to a port for the introduction of raw materials and close to a refinery for further processing of bioethanol into ETBE. This change in the type of final product, and in the trend of use, originated the selection of the third production plant in Spain, located in Babilafuente, in the middle of a cereal-producing area, such as Castile and Lion region and close to a temporary storage area of petrol, which would facilitate the blending or direct mixing, during loading of tankers, for subsequent distribution to the national stations. The only difference between the three production plants that Abengoa has in Spain is that in the case of the Cartagena plant, the fermentation is carried out in continuous process, whereas in the cases of Salamanca (Babilafuente) and A Coruña, the fermentation stage is carried out in batch. Abengoa is a company for bioethanol production and not an agricultural company and, therefore, it does not control neither production nor the price of raw materials. Consequently, the company cannot consider the development of small and medium scale plants as an alternative, like the main objective of the SWEETHANOL Project. This aim could be achieved if the model varies, involving producers of raw materials in the same production process. This alternative sought model, in which SWEETHANOL Project intends to base, is that ACOR Cooperative shows in its sugar production plant from beet and biodiesel from sunflower and rapeseed.

10.3 Experiences of the travel in Peru

Peru is a country in which the incipient development of bioethanol production and use is having a particular impact on industrial, agronomic and social development. Its history in the biofuel sector began a few years ago, following the footsteps of other nearby countries such as Brazil, Colombia or the US. In this case, the development of bioethanol production in Peru has had an economic and environmental justification. This last justification is due to the high level of pollution that can be found in cities like Lima, mainly due to the traffic.

Considering all these factors referred to Peru, the European SWEETHANOL project has selected this country to evaluate the reality of a new situation referred to the bioethanol production, promotion and application.

Figure 12: fields of sugarcane in Paramonga (Peru)[62]

Figure 13: harvesting of sugarcane in Sullana (Peru)[63]

Peru has a large tradition on the sugar production from sugarcane. Now, this raw material is used for producing bioethanol, applying high level technologies to increase the productivity and quality of the sugarcane in semi-desert areas or areas with a low productivity.

The production of bioethanol from sugarcane is the most extended system to produce this biofuel. This affirmation is based on the production of bioethanol in Brazil, which is the country with the largest production of bioethanol followed by the US. Both countries have applied important politics to promote the production and application of the bioethanol as biofuel. At this moment, sugarcane is one of the most important raw materials used all around the world to produce bioethanol, mainly due to the high yield of its productivity and to the high production per hectare of bioethanol. Apart from this, the energy balance using sugarcane as raw material is very good, considering that 100% of the energy consumption during the bioethanol production is covered by the same crop (with the bagasse, which is the biomass generated after the extraction as already mentioned above).

The use of sugarcane for bioethanol production in Peru has been made considering the social and the environmental aspects. This aim has taken into account the development of desert and semi-desert areas as a priority. This development fits well with the sustainability required for the production of bioethanol by the RES Directive, as it allows the transformation of desert areas without any kind of productivity into productivity areas with similar yields of high quality areas. Good examples of this transformation are the industrial and agricultural projects developed by Maple and Caña Brava in Piura's region.

Bioethanol production is not still widespread in the country, focusing mainly in the region of Piura by Caña Brava, with its production plant, and the future plant of Maple, both from sugarcane. The rest of the sugar mills in the country are not still producing bioethanol fuel. The development of a new legislation will ensure the blending 7.8% of biofuel (bioethanol) with fuel. This new legislation will promote the development of rural areas and, of course, allow the development of a new type of industry.

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This handbook contains the agricultural, technical, energetic and economic information and data about the current processing into bioethanol, focusing on the use of sweet sorghum and comparing the models to produce bioethanol also from other raw materials which are present in Asia, South America and Europe.

The handbook is mainly targeted at farmers, agricultural associations, fuel processors, SMEs, seeds and agricultural companies, investors, policy makers and public authorities representatives, energy agencies.

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