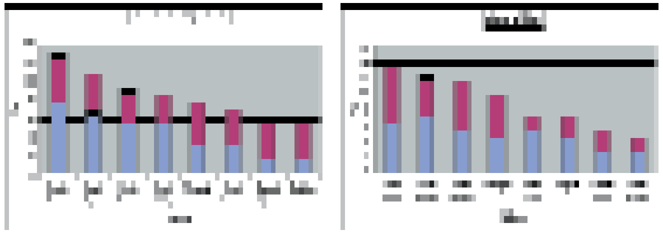
Sweet Sorghum Productivity

The productivity of Sweet Sorghum largely depends on many parameters:
-climatic condition (temperature, precipitation), soil quality, variety of Sweet Sorghum, agronomic practice. Typical values are presented here below (EU Trials):



Stem fresh and dry matter and sugar yields of Sweet Sorghum in various EU regions. Ranges within regions are due to varieties, years and/or treatment effect.

Particularly interesting are varieties developed in China since the year 1970, that show a more equilibrated spread between sugar, starch and lignocellulosics yields:

- Grains ~ 5 t/ha
- Sugar ~ 7,5 t/ha
- Lignocellulosic ~ 14,5 d.t/ha

These data are frequently used as base for an economic evaluation of commercial bioenergy schemes. Of course, for large size projects, the same results can also be obtained by the adoption of two sweet sorghum varieties: one presenting a much higher grain yield (i.e. hybrid Rio & Soave: ~ 8 t/ha) combined with others presenting higher sugar & lignocellulosic yields.

Biomass distribution (typical):

- Cane: up to 75 % of its weight
- Leaves: 10 – 15 % of its weight
- Grains: up to 7 %
- Roots: ~ 10%

For German High Latitude sites (Braunschweig: 52° 17' 35'' North) Sweet Sorghum Korall varieties, developed by KWS Co., since 1982 were able to produce 20 d.t/ha with an accumulated solar radiation of 500 MJ/m^2 (as in Grignon, France). It is estimated that a biomass yield of 80 fresh tons/ha and a sugar production of ~7 ton/ha will be possible in future.
The USA plantations between 21° and 47° latitude yield between 50 to 90 tons (fresh)/ha with sugar yields from 4 to 17 tons/ha.

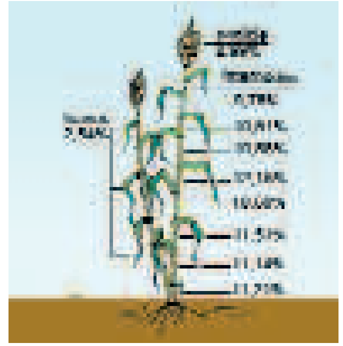


Figure 1: Sugar distribution

Table: high saccharose crop **(377 ZH 101/KWS)**

Saccharose	7,13 %
Glucose	1,74 %
Fructose	1,04 %

Export of Microelements due to Sweet Sorghum Production (yield: 65 fresh t/ha)

- N= 119 kg/ha (~1,8 kg/t)
- P_2O_5 = 24 kg/ha (~ 0,03 kg/t)
- K_2O = 10,8 kg/ha (~ 0,16 kg/t)

Fertilising Value of Sweet Sorghum Bagasse

- N = 0,45 % of humid bagasse weight
- P_2O_5 = 0,22 % of humid bagasse weight
- K_2O = 0,71 % of humid bagasse weight

Fertilising Value of Sweet Sorgum Distillery Stillage

- N = 0,2 % of stillage weight
- P_2O_5= 0,22 % of stillage weight
- K_2O = 0,30 % of stillage weight

Published by

Piazza Savonarola, 10 - 50132 Florence – Italy
Tel. +39 055 5002174 - Fax +39 055 573425
eta.fi@etaflorence.it - www.etaflorence.it

Sylvensteinstr. 2 - 81369 Munich – Germany
Tel. +49 89 720 127 35 - Fax +49 89 720 127 91
wip@wip-munich.de - www.wip-munich.de

Rond Point Schuman, 6 - B 1040 Brussels – Belgium
Tel. +32 2 28 28 420 - Fax +32 2 2828 424
eubia@eubia.org - www.eubia.org

Content elaborated by Dr. G. Grassi, Secretary General EUBIA, Brussels, with the assistance of F. Vivarelli, ETA, Florence

Neither the publishers, nor the European Commission or any person acting on behalf of the Commission is responsible for the use which might be made of the information contained in this publication. Reproduction is authorised provided the source is acknowledged.

LATIN AMERICA THEMATIC NETWORK ON BIOENERGY
LAMNET

SWEET SORGHUM

One of the best world food-feed-energy crop

G. Grassi

Sweet Sorghum is an extraordinarily promising multifunctional crop not only for its high economic value (due to its high sustainable productivity ~20 to 50 dry t/ha and to the wide range of its products: grains, sugar, lignocellulosics) but also for its capacity to provide a very wide range of renewable energy products, industrial commodities, food (grains & sugar) & animal feed products.
Sweet Sorghum can be considered thus a **crop of universal value,** because it can be grown in all continents, in tropical, sub-tropical, temperate regions as well as in poor quality soils and in semi-arid regions. The climatic conditions for successful Sweet Sorghum plantations are: **during the plant cycle (120 – 150 days) the accumulated daily temperatures above 10 °C must be 2600- 4600°C**

In some regions it is therefore possible to obtain two plantations per year reaching full maturity and a large production. Other interesting issues relevant to Sweet Sorghum are:

- Its low water requirements 1/3 of sugar cane, 1/2 of corn, 1/4 of Short Rotation Forestry.
- Its high capacity to absorb CO_2 (~45 t CO_2/ha per cycle), 3 times more than Short Rotation Forestry.

This publication has been realised in the framework of LAMNET, thematic network funded by the European Commission, DG Research, Programme "Confirming the international role of Community Research" (Project no. ICA4-CT-2001-10106)

Cultivation Requirement & Agronomic Practice

- Soil quality: acceptable heavy clay or high % of sand;
- Soil acidity: PH 4,5 to 8,5;
- Soil salinity: better resistance than corn;
- Temperature: total accumulated daily temperature from 2,600 °C up to 4,600°C during the growing cycle with minimum germination temperature of 8°C – 10°C; Sweet Sorghum is a plant for limited daylight hours;
- Water demand is 200 m^3/t with an average rainfall need of 500 to 600 mm.

E.U. Production Cost & Labour for Cultivation of Sweet Sorghum (1 ha)

	Quantity (h/man)
Soil Preparation	3
Fertilization	1
Seeding	2
Weeding	1,5
Pesticides Treatment	1,5
Irrigation	3
Harvesting	2
Transport	1
Total	**15 h/man**
Total Labour Cost (20 euro/h)	**300 euro/ha**
Total Sweet Sorghum Production Cost	**~850 euro/ha**

CO_2 Absorption and Performance of Sweet Sorghum

Due to its high productivity (20 – 40 dry ton/growing cycle) and fast plant cycle (120 – 150 days) sweet sorghum has an impressive capacity to absorb large amounts of CO_2 from the atmosphere during the 4 – 5 months growing cycle, with a small amount of CO_2 (~ 4 % of the total absorbed), emitted for the use of conventional energy during its cultivation. During the following pre-treatment, conversions and utilisation (combustion) further CO_2 emission is produced, but globally Sweet Sorghum closed schemes are CO_2 neutral presenting a **Total CO_2 Balance = 0.** The crop absorption and emission (repartition) levels depend on the local conditions (agronomic practice) and the processing procedures. For Sweet Sorghum closed systems (productivity of 8 tons of sugars/ha + 20 dry ton/ha of solid biomass) the absorption & repartition of the CO_2 emissions during the entire cycle are indicated below:

CO_2 Absorption	CO_2 Emission
By the crop ~ 45 t CO_2/ha during the growing cycle	~ 1,5 t CO_2/ha; (growing cycle)
	~ 8,5 t CO_2/ha: for conversion
	~ 35,0 t CO_2/ha: for utilisation (combustion)
	~ 45 Total t CO_2/ha

One ha of Sweet Sorghum plantation can substitute ~ 11 TOE of net energy without any negative CO_2 emission into the atmosphere

Sweet Sorghum* Potential (medium term: 20 years)

* Assuming a Sweet Sorghum productivity of 8 t sugar/ha and 20 dry ton biomass/ha

	AREA (mio ha)	BIOETHANOL (mio t/y)	PELLETS BIOFUEL (M.TOE/y)
E U –25	25	120	205
Brasil	33	160	270
Africa	12,3	60	50
China	9	45	75
World** (very long term)	900 Sweet Sorghum or Sugar cane	4,300	7,300

** The total world energy supply from high – energy sorghum and sugar cane could in a very long term (2050 and beyond) reach the amount equivalent to the 75% of the present world primary energy consumption.

In some particular areas with scarcity of water and poor quality soil (North of Brasil, some areas of Africa, China, etc.), Sweet Sorghum is an even more promising crop in comparison with sugar cane for Bioethanol production. In summary (Source World Bank) a study on the "Bioethanol prospects and development opportunities in Sub-Saharan Africa", comparing Sweet Sorghum to sugar cane is presented here below:

Summary & Conclusions (Sweet Sorghum-Sugar cane -S.S.Africa)

	Sweet - Sorghum	Sugar – Cane
Total Area (mio ha) (1,9% arable land)	12,3	12,3
Productivity (fresh) t/ha	46	70
Bioethanol Production (billion li/y)	61	43
N. of Distilleries (40 m^3/day)	5,770 -2 crop cycles/y; 330 -day/y operation	4,000
Investments (billion $)	28 (industrial); 47 (agriculture)	19 (industrial) 31 (agriculture)
N. of Jobs (million)	9,9	4,3
Market:		
Gasoline blending	25 % of total consumption	25 % of total consumption
Diesel blending	15 %	15 %
Cooking gel - fuel	100% Kerosene substitution	100% Kerosene substitution

Sub Saharan Africa substituting fossil fuels could have great benefits to contribute towards the reduction of greenhouse annual gas emissions (127 mio t in year 1999). In fact with 1,9% of total arable area, the production of sugar cane or Sweet Sorghum could reduce the CO_2 total annual emissions of ~ 65 – 94 mio or ~300 mio t CO_2/y if solid biomass is also utilised for power generation.

Energy Inputs and Outputs for 1 ha of Sweet Sorghum (Mcal/ha)

Energy Inputs:

Operation of the machines	**1,700**
Ploughing	305,5
Seed bed preparation	37
Fertilization	15,5
Seeding	50
Weeding	129
Pesticides treatment	16
Irrigation	210
Harvesting	937
Fertilizers and pesticides	**1,300**
Fertilizers	1115
Pesticides	185
Seeds, separation and others	**250**
Transport	**1,600**
Total Input for the crop production	**4,850**

Energy Outputs: In case of conversion of sugar into Bioethanol and of lignocellulosics into pellets, the estimated values are as follows:

	Production (t/ha)	Energetic equivalences	Energetic outputs (Mcal/ha)
Sugars	~ 8 (in juice)	3,940 (Mcal/t)	31,500
Bagasse, leaves &grain	~ 20	2,150	43,000
Total Output of the crop production:			**74,500**

Energy Performance per ha of Sweet Sorghum Production

(energy outputs/energy inputs) R= 25,23

Typical Energy Performances (per ha): related to different conversion processes:

For crop production (dry biomass)	25,23
1. For conversion products: Bioethanol and pellets.	15,3
2. Conversion only of sugar to ethanol	6,5
3. For production of pellets from solid biomass	22,4
4. For conversion of Solid Biomass into H_2 and sugar into Bioethanol	10,1

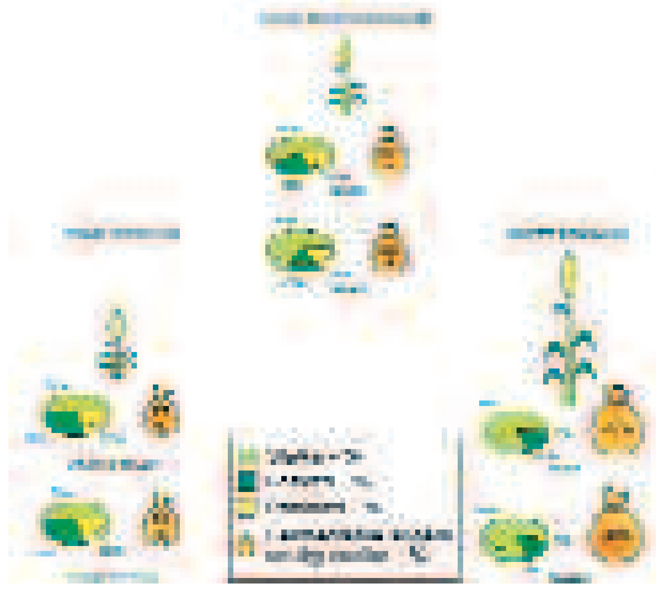
The valorisation of the energy content of the solid component of Sweet Sorghum is very important (3-5 times the energy content of sugar).

Sorghum-Botanic Characteristics

According to a recent study (1997) the origin of Sorghum seems to be located in the dry lands of Sudan, perhaps ~ 6,000 years ago and diffused from here to Korea, Burma, India, China (fossil sorghum grains dated 5,000 years ago have been found). Sweet Sorghum was introduced in the USA around 1850 from China and South Africa and was cultivated for a long time. In 1970 the USA Department of Agriculture developed the method for crystallisation of Sweet Sorghum sugar (Rio Grande Valley, Texas).

A scientific study on sorghum was initiated in 1930. Snowden (1936) identified **31 cultivated** species and **17 wild** species. De Wet (1978) made a more profound classification of the "genre" Sorghum (House 1987): Stiposorghum, Parasorghum, Sorghum, Hetero Sorghum, Chaeto Sorghum. Within the Sorghum, De Wet species grouped the cultivated annual sorghum of Africa and the perennial taxa of South Europe and Asia in three main sections:

- **Sorghum halepense** (Pers); perennial rhizomatic species of South European origin and diffus towards East Europe to India and China;
- **Sorghum propinquum** (Kunth/Hitchc); species of south India, Sri Lanka, Birmania, diffusing towards East Asia;
- **Sorghum bicolor** (Moench); species enclosing all annual taxa (Snowden 1936) (all wild Africa Sorghum sub-species and cultivated sorghum, classified as bicolour sub-species). This species is subdivided in 5 races (House 1987): Guinea, Candatum, Kafir, Dura, Bicolor. Each race presents several varieties and cultivars with different agronomic values and for very different final utilisations (food-animal feed-energy/industrial products).



Morphology of Sweet Sorghum

The root structure is very developed, starting from the first node (two times the number of roots in comparison with corn).

The stalk is constituted by a sequence of cane and nodes, 0,8 - 5,0 m in height, and a diameter of 1 to 5 cm.

Leaves (in general 14 - 17) are dark green and developed at the node level (~1m long/10-15 cm large). Total leave surface is ~1/2 that of corn, with stomates located on both sides of the leaves. This small leave surface, together with the considerable root structure, is at the origin of the great resistance of sorghum to drought. The panicle (inflorescence) can be 70 cm long with a diameter of 30 cm and can produce up to 4,000 grains.

The grains are frequently spheric and of very different colours; 100 seeds contain 342 Cal, 12,0 g of H_2O,10 g of protein and 3,7 g of fat, 72,7 g of total carbohydrate, 2,2 g of fiber, 1,5 g ash, 22 mg Ca, 242 mg P, 3,8 mg Fe, 8 mg Na, 44 mg of K.

Proteins contain no gluten and so the flour does not make good bread unless mixed with other cereals, useful also to alter the taste. Seeds are white, yellow, red, brown (25.000-61.000 seeds/kg). As reported from China, Japan, Hindustani-Mediterranean Centre of Diversity, Sorghum is reported to tolerate alkali, disease, drought, fungus, herbicide, high PH, heat, insect, low PH, poor soil, rust, salt, virus, weeds, water logging (Duke 1978).

The sugar content consists in sucrose, fructose and glucose. Most of the sugar is uniformly distributed in the stalk; only 2% in the leaves and panicle (Figure 1). The typical sugar concentration within a cane cross section is indicated here below (Figure 3 a; b):

Figure 5

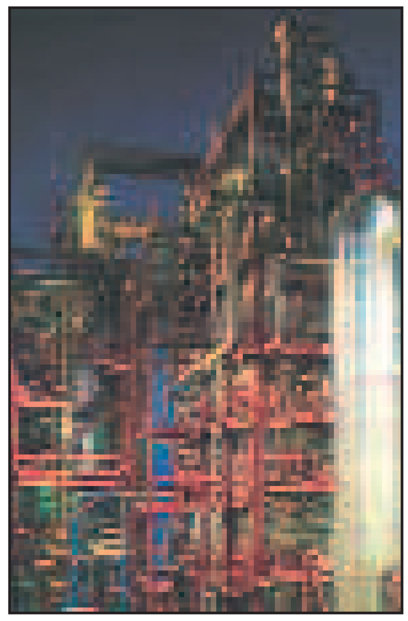
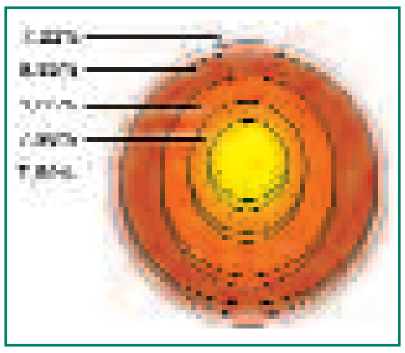


Figure 3 (a; b) *a)*



b)

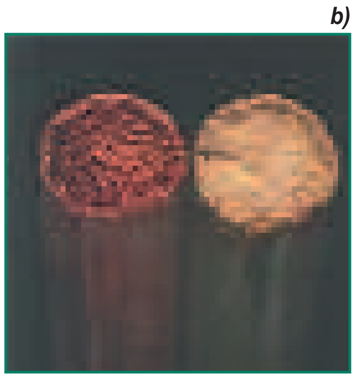


Figure 4

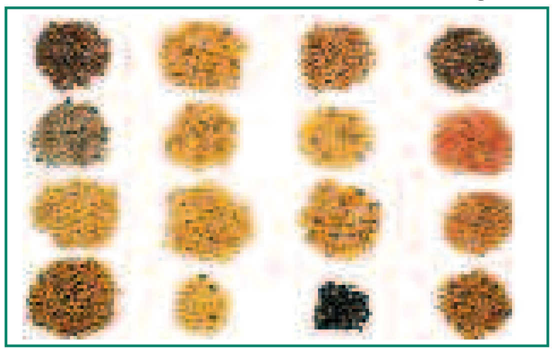
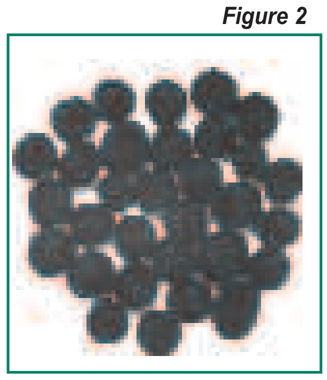


Figure 2



*In future research priority on Sweet Sorghum should be focused on the identification & development of new varieties tolerant to colder and changeable climatic conditions. Of course, in a long term, the in-vitro culture and advanced biotechnology tools may represent a fundamental technique not only for a selection programme but also for the prudent artificial generation of new energy varieties. The production of somatic "embryos" will be of fundamental interest.

Cultivation & Agronomical Practice

In dry land, seeds are normally sown like corn in rows 75-100 cm apart (distance 14-30 cm on the row) at a rate of 3-9 kg per ha; higher seed rate is used for more humid soils. (Figure 4: different kind of seeds). In good rain fall or very humid irrigation conditions, seeds at 20-25 kg/ha can be used to reduce the big stalk size and to increase the number of leaves. Seeding in South Europe happens in March; in the tropics nearly anytime. Seeds are at a 1,5 - 5,0 cm depth depending on soil structure and moisture. Seeds germinate best between 20-30 °C.

Seeding before soil temperature (at 10 cm depth) reaches 12-13 °C can be very deleterious. Sorghum hybrids are rather sensitive to low pH and low P and K fertilisation levels.

In general fertilisers inputs are: 30-60 kg/ha of P, 60-120 kg/ha of K, 150 kg/ha of N.

Sorghum grains is the 4th most important world cereal for human diet (total: 40 mio ha); grains yield may range between 0,2 and 6 t/ha.

Grain Sorghum hybrid are becoming of increased interest for farmers after the discovery (1952) of cytoplasmic male sterility trait with 30-35 % increase of production efficiency. At present 7,3 mio ha of grain sorghum are cultivated in USA (25% for forage and 75% for grain & seeds) with an average yield of 3,3 t/ha; in developing countries the yield is ~ 0,9 t/ha. World record is 21,5 t/ha.

Sweet Sorghum Promising Crop for Energy

Sorghum is on the priority list of potential energy crops. Its photosynthetic efficiency (~ 4 g biomass/MJ of solar radiation) is two times or more efficient in comparison with C3 crops (forest). Besides, **grain sorghum** produces starch efficiently and sweet sorghum (special hybrids) is able to grow anywhere in dry climates with high yields of fermentable sugars, grains and lignocellulosics. One of the most challenging issues and problems to solve for Sweet Sorghum in order to become a very attractive energy crop, is to overcome its seasonability problem and the instable characteristics of its fermentable sugars, that require high investments for a fast Bioethanol (~ 70 to 90 days). Integrated production of several crops (Sweet sorghum/sugar-cane/Sweet sorghum corn/Sweet sorghum/ sweet potatoes, etc...) and simultaneous processing of the full crop components (starch, sugar, lignocellulosic) can improve the global economics of bioenergy schemes considerably in view of a viable production of Bioethanol (now estimated at ~250 euro/t). The innovative "Sinthetic Crystals" technology for sugar-juice concentration and bioethanol distillation seems very promising.

Sorghum Diseases

Major reported diseases include: Carpospores sorghi, Anthracnose of leaves and steams, leaf blight, charcoal rot, rust. Several nematodes have been isolated from Sorghum.

Composition & Characteristics of Bagasse

Cellulose ($C_6H_{10}O_5$): 15 - 25%; Hemicellulose ($C_5H_{10}O_5$): 35 - 50%; Lignin: 20 - 30%; Net Calorific value: 4,125 Kcal/kg (ash free); Bulk volume (20% humidity): ~150 kg/m^3.

Chemical Composition (Source ENEL)

Carbon 52%; H_2: 6,7 %; N_2: 0,98 % ; S: 0,11 %; Clorine: 5400 ppm; Volatile matter: 65,5 %

Direct Jobs Creation for highly mechanised production of Sweet Sorghum and its conversion to bioethanol
(number of jobs for the production of 1 mio t/y of bioethanol)

- Direct jobs for production of Sweet sorghum: 2,950
- Direct jobs for industrial & related activity: 7,000
- Total jobs: 9,950

Employment for the production of ethanol vehicles & Biofuels (Brasil)

- Jobs for 1,000 vehicles production: 541
- Jobs needed for bioethanol fuel production: 1,482
- Total jobs: 1,533

Multifunctional characteristics of Sweet Sorghum

Several products that have been considered for integrated processing of Sweet Sorghum are based on experimental preliminary results as indicated in the following table:

1. Experimental Sweet Sorghum plantation (~100 ha)
2. Experimental Trials of Sweet Sorghum harvesting
3. Sugar juice extraction from Sweet Sorghum cane by a small crushing & decanter unit
4. Bioethanol production from Sweet Sorghum by a small microdistillery (decentralised unit)
5. Bioethanol production trials from Sweet Sorghum in a large plant (centralised unit)
6. Gasification trials of sweet sorghum bagasse (1,000 d. ton) in a large Studvik atmospheric gasifier (20 MWth) (see Figure 5)
7. Production of bio crude oil from Sweet Sorghum bagasse by flash pyrolysis (Ensyn plant) and comparison with flash pyrolysis oil from sugar cane bagasse (Cd+UK)
8. Production of high quality paper from Sweet Sorghum bagasse by the new process ASAM–2 (Kraftanlagen – D)
9. Production of Sweet Sorghum bagasse charcoal pellets (NL + I) for iron and steel use (high quality alloys or for FeO_2 reduction) (see Figure 2)
10. Production of compost from Sweet Sorghum bagasse (Kruger DK, CIEMAT ES)
11. Production (at Lab. scale) of Bio syngas and biohydrogen from Sweet Sorghum bagasse (I)
12. Production (at Lab. scale) of activated coal from Sweet Sorghum bagasse (I)
13. Production of pellets from humid bagasse by the new process of mechanical drying & compactation (low energy consumption) (I and SK)
14. Trials on an innovative technology for Bioethanol distillation & dehydration by synthetic crystal absorption (SE, I and Russia F)

DATA PROVIDED BY:

Rond Point Schuman, 6 B 1040 Brussels – Belgium
Tel. +32 2 28 28 420 - Fax +32 2 2828 424
eubia@eubia.org - www.eubia.org

Published by ETA Florence and WIP-Munich in the framework of LAMNET Thematic Network funded by the European Commission, DG Research, Programme "Confirming the international role of Community Research" (Project no. ICA4-CT-2001-10106).

The activities of LAMNET include the analysis of available bioenergy technologies and systems as well as the development and implementation of policy options for the promotion and deployment of bioenergy. Should you wish to receive more information on this Thematic Network, please contact the project coordinator: Dr. Rainer Janssen, WIP-Munich, tel. +49 89 720 127 43 - fax +49 89 720 127 91 e-mail: rainer.janssen@wip-munich.de