The emerging importance of the new feedstocks for bioethanol production

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Table 1. The main bioethanol producers in world scale (2007-2008) in million tones per year.

World rank	Country/Region	2008	2007
1	U.S.A	34.06	24.60
2	Brazil	24.50	19.00
3	E.U.	2.78	2.16
4	China	1.90	1.84
5	Canada	0.90	0.80
6	Thailand	0.34	0.30
7	Columbia	0.30	0.28
8	India	0.25	0.20
9	Central America	n/a	0.15
10	Australia	0.10	0.10
11	Turkey	n/a	0.06
	World Total	**65.61**	**49.59**

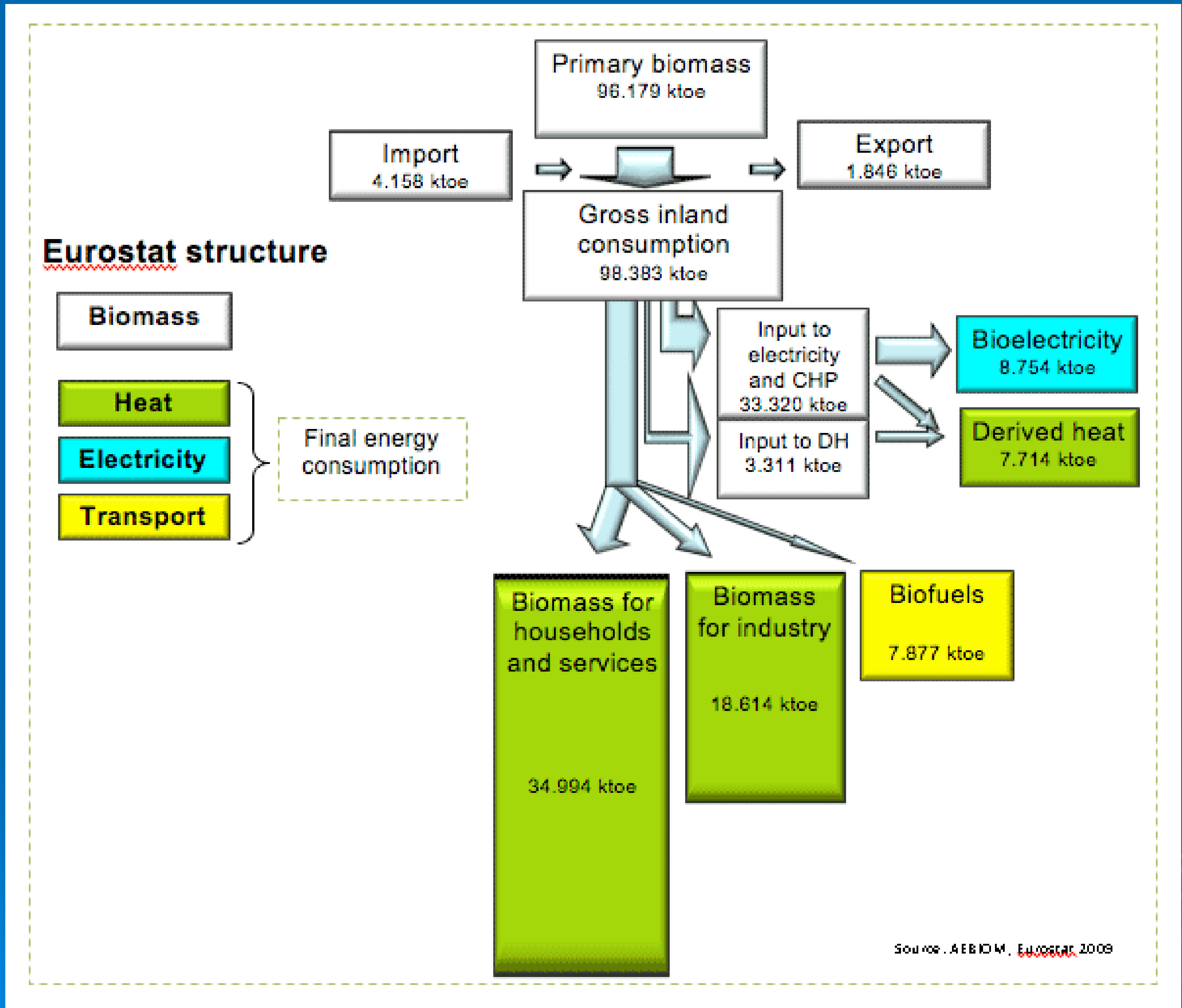
Source: F.O. Licht

Table 2. Comparison of key characteristics between the ethanol industries in the U.S. and Brazil

Characteristic	Brazil	U.S.	Units/comments
Feedstock	Sugar cane	Maize	Main cash crop for ethanol production, the US has less than 2% from other crops.
Total ethanol fuel production (2008)	24.50	34.06	Million m^3
Total arable land	355	270(1)	Million hectares
Total area used for ethanol crop (2006)	3.6 (1%)	10 (3.7%)	Million hectares (% total arable)
Productivity per hectare	6.800-8.000	3.800-4.000	Liters of ethanol per hectare
Energy balance (input energy productivity)	8.3 to 10.2	1.3 to 1.6	Ratio of the energy obtained from ethanol/energy expended in its production
Estimated GHG emissions reduction	86-90%(2)	10-30%(2)	%GHGs avoided by using ethanol instead of gasoline, using existing crop land (No ILUC)
Full life-cycle carbon intensity	73.40	105.10(3)	Grams of CO_2 equivalent released per MJ of energy produced, includes indirect land use changes.
Estimated payback time for GHG emissions	14 years(4)	93 years(4)	Brazilian cerrado for sugarcane and US grassland for corn. Land use change scenarios by Fargione
Cost of production (USD/liter)	0.219	0.301	2006/2007 for Brazil (22 c/liter), 2004 for U.S. 35c/liter)
Government subsidy (in USD)	0(6)	0.119/liter	U.S. since 2009-01-01 as a tax credit. Brazilian ethanol production is no longer subsidized(6)
Import tariffs (in USD)	0	0.1426/lit	As of June 2009, Brazil does not import ethanol, the U.S. does

Notes: *(1) Only contiguous U.S., excludes Alaska. (2) Assuming no land use change. (3) CARB estimate for Midwest corn ethanol. California's gasoline carbon intensity is 95.86 blended with 10% ethanol. (4) Assuming direct land use change. (5) If diesel-powered vehicles are included and due to ethanol's lower energy content by volume, bioethanol represented 16.9% of the road sector energy consumption in 2007. (6) Brazilian ethanol production is no longer subsidized, but gasoline is heavily taxed favoring ethanol fuel consumption (~54% tax). By the end of July 2008, when oil prices were close to its lates peak and the Brazilian Real exchange rate to the U.S. dollar was close to its most recent minimum, the average gasoline retail price at the pump in Barzil was USD 6.00 per gallon, while the average U.S. price was USD 3.98 per gallon. The latest gas retail price increase in Brazil occurred in late 2005, when oil price was at USD 60 per barrel.* ***Source: Wikipedia (http://en.wikipedia-org/wiki/Ethanol_fuel(Modified)***

Fig. 1. E. Union biomass consumption for Energy (2009)



Note: The EREC targets are more optimistic – see fig. 2

Table 3. Production and Consumption of Bioethanol in E.U in Gwh/year

Country	Consumption			Production	
	2005	2006	2007	2005	2006
Germany	1,682	3,544	3,408	978	2,554
France	871	1,719	3,174	853	1,482
Sweden	1,681	1,894	2,113	907	830
Spain	1,314	1,332	1,310	1,796	2,382
Poland	329	611	991	379	711
U.K	502	563	907	n/a	n/a
Bulgaria	0	0	769	n/a	n/a
Austria	0	0	254	n/a	n/a
Hungary	28	136	107	207	201
Italy	n/a	n/a	n/a	47	759
Total in E.U	**6,481**	**10,138**	**13,563**	**5,411**	**9,274**

Source: Biofuel barometer – EurObserv (2007 and 2008)
Le Journal des energies renouvelables No 179 and No 185

Table 4. Expected Results from the Cellulosic Ethanol

Crop	Annual yield (Liters/hectare)	Greenhouse-gas savings (% vs. petrol)(1)	Comments
Miscanthus	7300	37-73	Low-input perennial grass
Switch grass	3100-7600	37-73	Low-input perennial grass.
Eucalyptus	6000-12000(3), (5)	100-200	Plantation needs tropical or sub-tropical conditions. The better results need water. No frost resistant.
Sugar cane	6800-8000(6), (7)	87-96	Long-season annual grass. Only grows in tropical and subtropical climates.
Sweet Sorghum	2500-7000(4), (5)	Same as sugar cane	Low-input annual grass, resistant to dry conditions cultivation from 50º North to 50º South
Corn	3100-4000(6), (7)	10-20	High-input annual crop. Cellulosic technology would allow Stover to be used and increase ethanol yield by 1.100-2.000 liters/ha

Source (except those indicated): Nature 444 (December 7, 2006): 673-676. (1) Savings of GHG emissions assuming no land use change (using existing crop lands). Modified

Table 5. European Efforts for Cellulosic Ethanol

Country	Efforts and Achievements
Sweden	A pilot plan has been realized in SEKAB, in the frame of the E.C. NILE project. The NILE target for enzymatic hydrolysis is to reach a yield of up to 75% of the theoretical max. and they have achieved so far more than 60%[8]
Denmark	In 2009 was opened in Kalundborg a bioethanol plant to produce 5.4 M.liters/year, based on straw as feedstock[12]
Germany	BUTALCO Company cooperates with Hohenheim University to develop yeast strains to process both starch and straw together
Spain	Abengoa Company is building a 19 M.liters of cellulosic ethanol based on new and better enzyme mixtures to be developed by Dyadic International.[14]
U.K	BP, associated with British foods (ABF) and DuPont announced a $400 M. investment to process in late 2009, wheat straw and to produce 420 M.liters of cellulosic ethanol[14]

U.S. Efforts for Advanced Bio-fuels

- **In May 2008 the Food conservation and Energy Act provids:**

  1) grants covering 30% of the cost for Dev. and Installations of Biorefineries to produce "advanced biofuels (all other feedstock except corn).

  2) also loan's guarantees of up to $250 M. for commercial scale installations, gave a serious force to cellulosic ethanol development.

  So, in early 2008. in U.S. were operating plants of 12 M.liters/year and under construction 26 new plants with a capacity of 80 M.liters/year[(14),(17)]

- **In February 2010 the environmental Protection Agency (EPA) finalised a RULE to implement the long-term Renewable Fuels standard of 36 billion gallons (~136 mil.m^3) by 2022 (the target of U.S. Congress) with 21 billion to come from advanced biofuels. The Presidents Biofuels Interagency Working Group supports a strategy to advance sustainable biofuels to exceed the nation's targets**

Table 6. Commercial Cellulosic Ethanol Plants in the U.S.[10],[14] (Operational or under construction)

Company	Location	Feedstock
Abengoa Bioenergy	Hugoton, KS	Wheat straw
BlueFire Ethanol	Irvine, CA	Multiple sources
Colusa Biomass Energy Corporation	Sacramento, CA	Waste rice straw
Fulcrum BioEnergy	Reno, NV	Municipal solid waste
Gulf Coast Energy	Mossy Head, FL	Wood waste
KL Energy Corp.	Upton, WY	Wood
Mascoma	Lansing, MI	Wood
POET LLC	Emmetsburg, IA	Corn cobs
Range Fuels	Treutlen Country, GA	Woos waste
SunOpta	Little Falls, MN	Wood chips
US Envirofuels	Highlands Country, FL	Sweet sorghum
Xethanol	Auburndale, FL	Citrus peels

Source: Wikipedia, Ethanol commercialization

Table 7. Efforts from some countries for Cellulosic Ethanol

Country	Efforts and Achievements
China	Pilot and commercial demo by Sun Opta and China Alcohol Corp.
Japan	➢ Nippon Oil Corporation and Toyota Motor cooperation to produce 250,000 Kilo liter/year of cellulosic ethanol by March 2014 in a price of $0.437/liter. ➢ Honda Motor is building (early 2009) in Kisarazu a new plant with aim to begin operation end of 2009
Canada	➢ Iogen Corp. has a demo – scale plant in Odario targeting to a final process of 40t of wheat/day, already Iogen deliveres cellulosic ethanol to the market ➢ Lignol innovations has a pilot to use wood as feedstock, in Vancouver ➢ KL Energy Corp. has the intention to build a new ethanol plant in Saskatchewan based on wood wastes as feedstock.

Table 8. World land availability and Estimations

Total arable lands:	3,316 billion ha
Present utilized land:	1,300 billion ha
Total irrigated land:	0.70 billion ha
Estimated land needed ~2075	
➢ for 9 billion people:	~1.80 billion ha
➢ surplus land for energy crops:	>750 mio ha

Source: EUBIA Biomass Industry Day, Biomass Conference, Valencia 2008

Besides the today achievements on the feedstocks productivity, on their industrial transformation to ethanol and on the expectations that cellulosic ethanol can reduce greenhouse gas emissions (GHG) by 85% (Argonne Lab. of the University of Chicago) over reformulated gasoline,

there is a growing concern:

1) on how much could be the part of fuels to be produced from biomass to the total fuel demand in the future

2) on the final bioethanol cost for the big petrol consumers as they are U.S. and especially Europe, in comparison with the low cost production of ethanol from sugar can in Brazil and in some other tropical countries

3) on the final environmental impact from the today practice on biomass production and on land and water use.

4) on the growing pressure on food and feed prices.

5) on the mentality of the investors against to poor farmers of the developing countries and to the rural employment.

Fig. 3. The geographical cultivation potential of Sweet Sorghum

(*Source: EUBIA*)

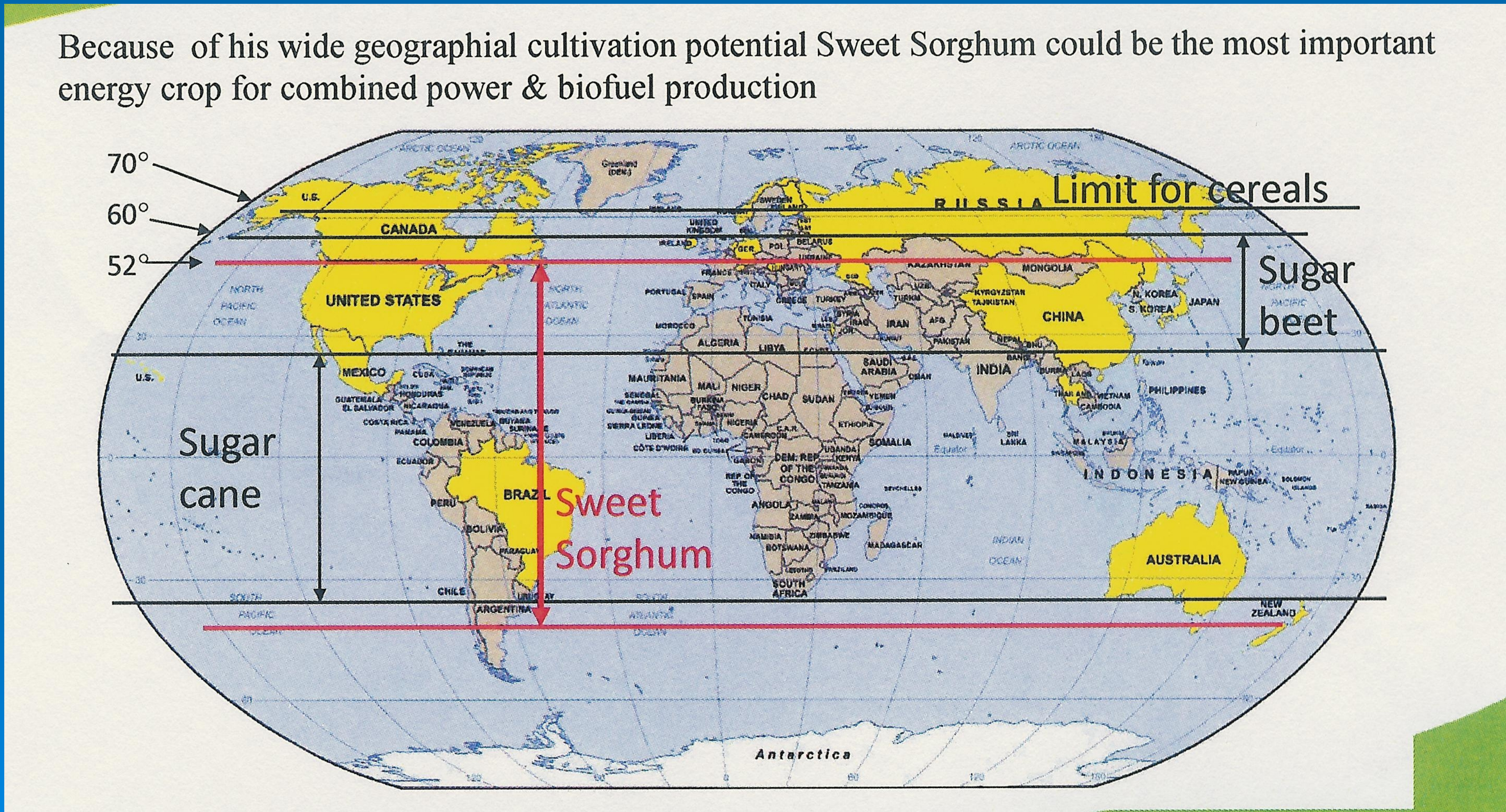
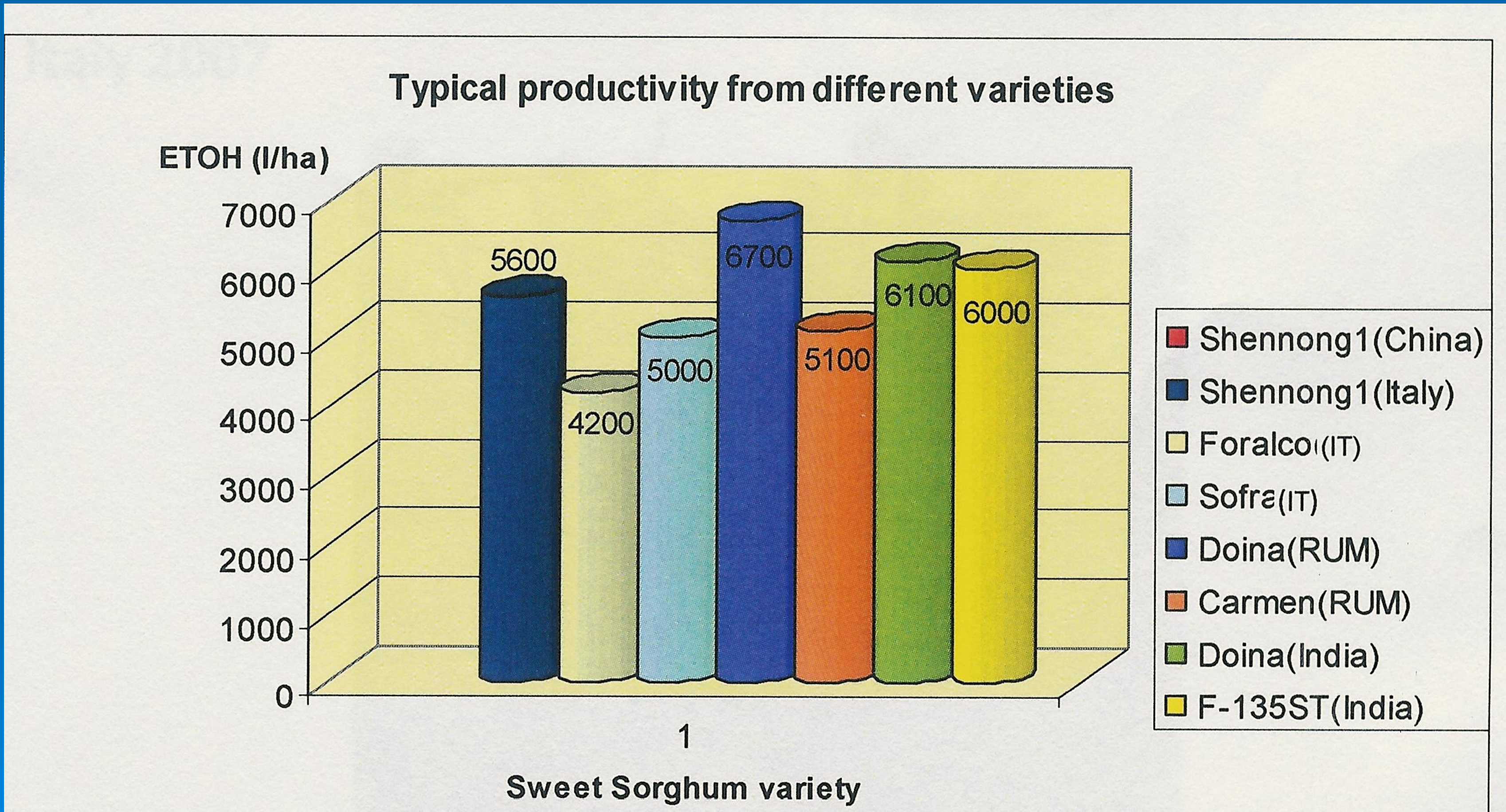


Table 9. Comparison of sugarcane, sugar beet and sweet sorghum in Iran.

	Sugarcane	Sugar beet	Sweet sorghum
Crop duration	About 7 months	About 5 - 6 months	About 4 months.
Growing season	Only one season	Only one season	One season in temperate and two or three seasons in tropical area.
Soil requirement	Grows well in drain soil	Grows well in sandy loam; also tolerates alkalinity	All types of drained soil.
Water management	36000 m^3/h	18000 m^3/h	12000 m^3/h
Crop management	Requires good management	Greater fertilizer requirement; requires moderate management	Little fertilizer required; less pest and disease complex; easy management.
Yield per ha	70 - 80 tons	30 - 40 tons	54 - 69 tons.
Sugar content on weight basis	10 - 12%	15 - 18%	7 - 12%.
Sugar yield	7 - 8 tons/ha	5 - 6 tons/ha	6 - 8 tons/ha.
Ethanol production directly from juice	3000 - 5000 L/ha	5000 - 6000 L/ha	3000 L/ha.
Harvesting	Mechanical harvested	Very simple; normally manual	Very simple; both manual and through mechanical harvested.

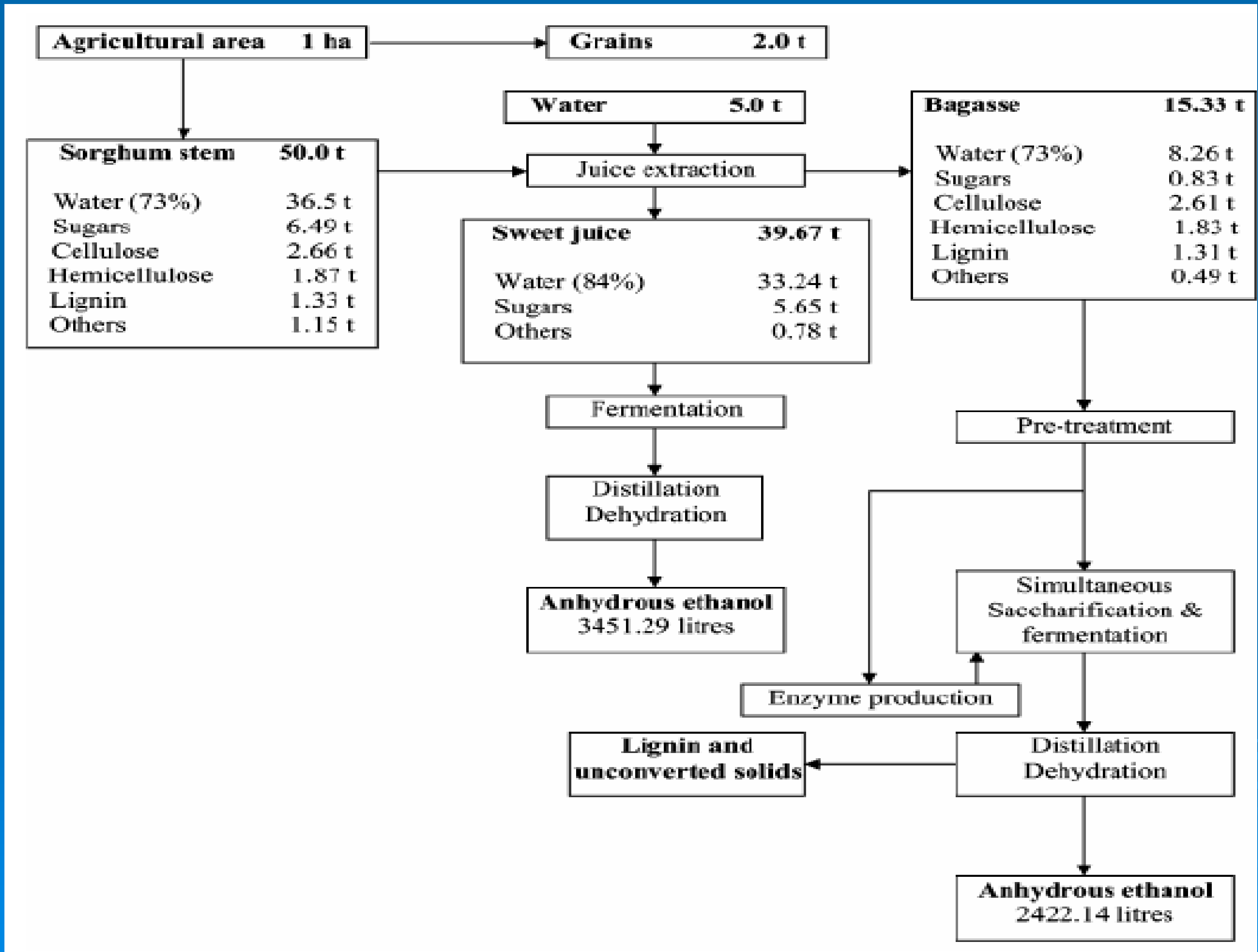
Fig. 4. Sweet Sorghum typical productivity from different varieties
(Source: EUBIA)



Summary of Sweet Sorghum Characteristics

1. It is an efficient convertor of solar energy, as it requires low inputs, and yet a high carbohydrate producer [23]
2. It can be cultivated within a large geographical zone between 52ºN / 52ºS.
3. It requires low water inputs (~200 m3/ton), 1/3 of Sugar cane and ½ of Corn requirements. [25]
4. It requires only 50 Kg of nitrogen per hectare, [20],[31] and can extract residual nitrogen left by previous crops, or from nitrogen fixing plants
5. Its growing period is shorter (3-5 months) [23],[25] than that of sugarcane (10-12 months) or seed-crops (4-5 months).
6. Sweet Sorghum juice doesn't require the long fermentation and cooking time needed from grain ethanol.
7. Big part of bagasse can dried and burned for C.H.P. That residue can also be used for animal feed, for fiber industry or for cellulosic ethanol.
8. The crop gives good results even in poor soil, or even in salty soil.
9. The crop in parallel to juice from stalks, produce also seeds destinated for food, feed or for ethanol

Fig. 6. Mass balance of sweet sorghum ethanol production [27]
(Prasad et al., 2007)



Based on the above characteristics, Sweet Sorghum is the most suitable plant for biofuel production than any other known crop under dry climatic conditions.
Especially for developing countries Sweet Sorghum provides an opportunity to re-direct oil money that used to go-overseas back into their own rural economies (says Dr. William Dar, Director General of the International Crops Institute for the Sami-Arid Tropics – IERISAT). According to Dr Dar, Sweet Sorghum is an ideal “smart crop” because it produces food as well as fuel.

The Sorghum for grain production today is the world’s fifth largest grain crop, with 42 million ha. The leading producers are: U.S., Nigeria, India, China, Mexico, Sudan and Argentina. (28)
According to ICRISAT’s estimations the 50% of the grain Sorghum or 5,1 Million ha in Asia and 12,60 million hectares in Sub-Saharian Africa and many millions hectares in other countries could be replaced by sweet sorghum with the same results in food and feed production, but to produce also ***in parallel ethanol***. Sweet Sorghum gives 23% additional returns to farmers compared to grain sorghum (in India) (29)

Table 10. Earnings from grain sorghum vs. sweet sorghum

	Sweet sorghum		Grain sorghum	
	Rainy	Postrainy	Rainy	Postrainy
Grain yield (t ha^{-1})	1.0	2.0	3.0	2.0
Stalk yield (t ha^{-1})	40	25	10	7
Grain value (US$ $annum^{-1}$)[3]	326		543	
Stalk value (US$ $annum^{-1}$)	707[1]		370[2]	
Total value (US$ $annum^{-1}$)	1033		913	
Leaf stripping (US$ $annum^{-1}$)	40		-	
Net value (US$ $annum^{-1}$)	993		913	

Data based on two crops per annum; on-station performance.
1. Sweet stalk @ US$ 10.87 t^{-1}; 2 Stover @ US$ 22 t^{-1}; 3Grain @US$108.7 t^{-1}

Source: ICRISAT[30]

Table 11. Plant production capacity (Rusni Distilleries)

Plant production capacity (Rusni Distilleries)

Requirements	Units
Ethanol day^{-1} (kl)	35-40
SS stalks required day^{-1} (t)	800-875
Stalks required for 105 days (t) per season	84000-91875
Area required (rainy season) ha	2300-2600
Area required (postrainy season) ha	3700-4200
Total sweet sorghum area required (ha)	6000-6800
No. of small farmers[1] to be involved	3000-3400

1. Small farmers: 2 ha holdings in India. Source: Rusni Distilleries.

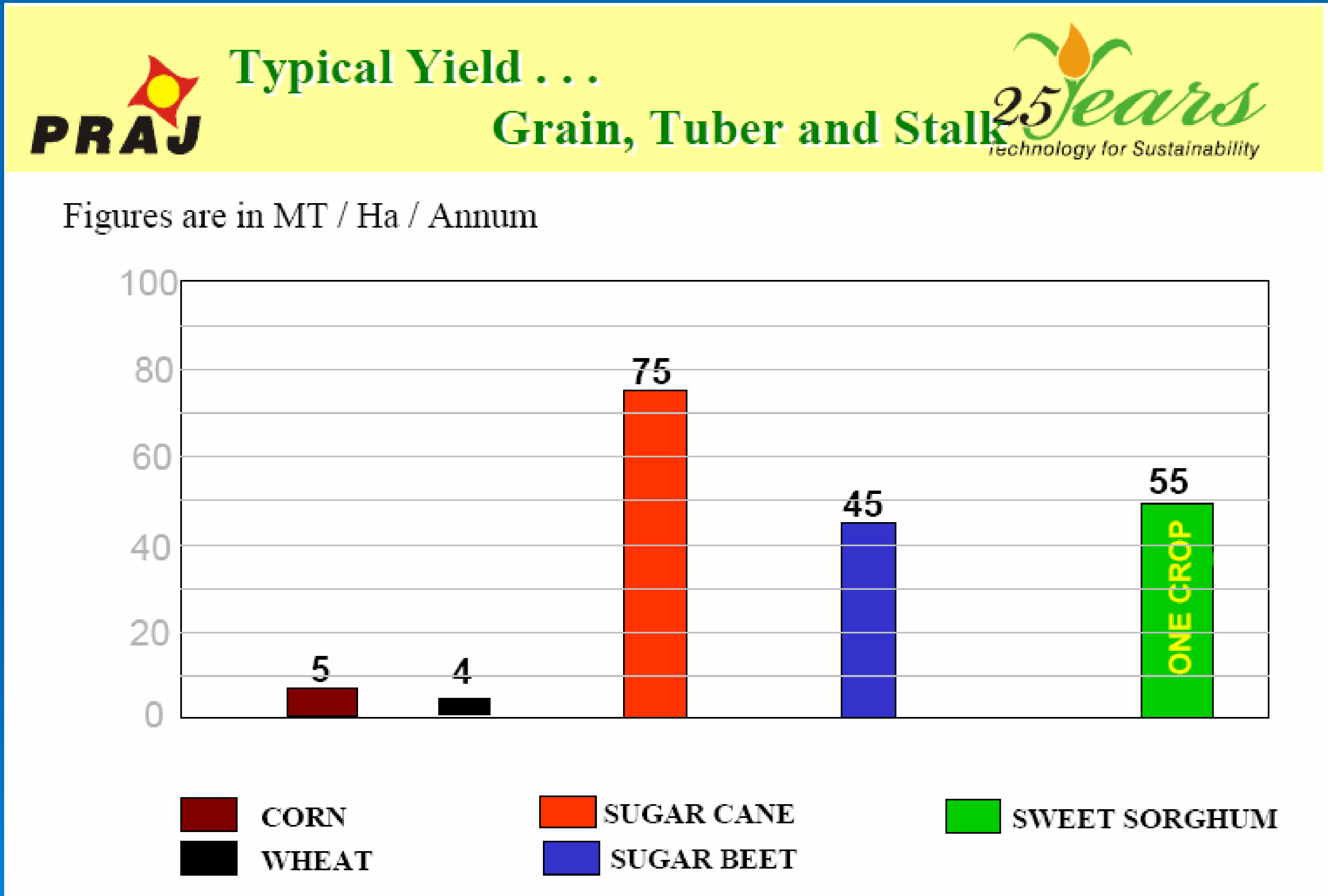
Table 12. Feedstock costs (in India)

Feedstock costs (India)*

	Sweet sorghum	Sugarcane	Maize
Crop duration	4 months	12 months	4.5 months
Water requirement	4000 m^3	36000 m^3	8000 m^3
Ethanol source	Juice Grain Stillage	Juice -- Bagasse	-- Grain Stover
Ethanol yield ($kl\ ha^{-1}$)	3.16	8.90	3.22
Cost of cultivation (US$ ha^{-1})	258	995	287
Feedstock cost (US$ kl^{-1} ethanol)	81.6	111.5	89.2

* Based on bioethanol per hectare.

Fig. 7. Typical Ethanol Yield from: Grain, Tuber and Stalk



Source: PRAJ, Bioethanol Congress &Expo 15-16 April 2009, Moscow - Russia

Table 13. Combined Productivity of Bioethanol and Power & Bio-Heat from different crops (average) [m3 of ETOH + KWhe + KWhth/ha.year]*

Sweet-Sorghum has the potential to provide the highest yield of bioelectricity (especially in tropical areas).

	m^3 BIOETHANOL/ha - KWhe/ha KWhth/ha	R = OUTPUT ENERGY / INPUT ENERGY
Sugar-cane	ETOH : 6,0 m3/ha KWhe : 17 000 Kwhe/ha - KWhth : 34 000 KWhth/ha	~ 4
Corn	ETOH : 3,5 m3/ha KWhe : 8 200 Kwhe/ha - KWhth : 16 400 KWhth/ha	~ 1,4
Sugar beet	ETOH : 5,5 m3/ha KWhe : 11 700 Kwhe/ha - KWhth : 23 400 KWhth/ha	~ 1,7
Sweet sorghum	ETOH : 6,0 m3/ha KWhe : 35 000 Kwhe/ha - KWhth : 40 000 KWhth/ha	~ 6
Jerusalem artichoke	ETOH : 5,5 m3/ha KWhe : 16 000 Kwhe/ha - KWhth : 32 000 KWhth/ha	~ 4
Sweet potatoes	ETOH : 4,3 m3/ha KWhe : 24 000 Kwhe/ha - KWhth : 48 000 KWhth/ha	~ 2
Wheat	ETOH : 2 m3/ha KWhe : 8 200 Kwhe/ha - KWhth : 16 400 KWhth/ha	~ 1,2

*NOTE : Significant part of heat and ~ 15% of the produced electricity will be required for the complex operation.

Intensive plant breeding research in U.S. to replace corn ethanol from S.S. ethanol in Corn Belt

The target is to increase the sugar content of S.S juice to a level needed to produce 1000 gal. of ethanol/acre (9m3/ha) under the Corn Belt conditions. The specific research goals at the University of Nebraska are:

1) Better efficiency on net energy yield for better results on greenhouse gases than corn ethanol.
2) Dual ethanol production (sugar + cellulose) to maximize the conversion. So, **a)** they have transferred genes from low lignin content varieties to S.S. line and hybrids **b)** they have identified genetic variation for cold tolerance in Sorghum, succeeded to improve lines with capacity of germination at 10oC soil temperature (they can plant, in 42o North, the first two weeks of April, instead of the second week of May!!) **c)** they have introduced into S.S. genes that confer stress resistance, as cold, drought and salt stress. **d)** they try to extend the growing season for more total biomass yield. **e)** they try to develop high-water and nitrogen use efficiency through better management practices. A practical achievement is the rotation with Vetch (Vicia villosa Roth) in the same year with a vetch coproduction of 7.5 – 12.5 t/ha.

Sweet sorghum commercial ethanol is already in operation in Texas and Oklahoma, and also in Iowa

Table 14A. Sweet Sorghum activities in other countries

Country or Region	Efforts and Achievements
Asia	*In Iran,* there is a strong scientific team with very significant casuals on S.S. trials on many cultivars lines and hybrids(23)
Africa	*In Kenya*, the company Agrochemical and Food Co (ACFC) is using S.S. stalks for ethanol *In Mozambique* are operating two companies on S.S. ethanol, **1.** ECOEnergia Co, **2.** Mozambique Principle Energy *In Tanzania,*SAKEB Bioenergy International Co is establishing a distillery for S.S. ethanol
Brazil	Among other activities there is also the cooperation of CGIAR centre with scientists from U.S.A to accelerate progress on S.S. ethanol
Japan	The Intern. Research Centre of Agric. Sciences (SIRCAS) is studying NO_2 pollution, the 2001 plant ability and S.S. genotypes

Table 14B. Sweet Sorghum activities in Europe

Europe	*In Greece and Italy* had many years experiments on adaptability and productivity of different S.S. varieties, main results ~ 6m^3/ha of ethanol production/year with limited irrigation (300 mm) and low inputs in fertilizers *In Romania*, they had never stopped to cultivate S.S. local varieties for syrup and animal feed. *In France,* CIRAD coordinate a E.C. project cooperation with other E.U. countries, same under development and ICRISAT. The targets are to study cultivars and hybrids of S.S., under different climatic conditions. *In Hungary,* there is a Norwegian Fund Project of the Institute for Land Utilizations, Technology and Regional Dev/ment, to develop Bioethanol production based on Sweet Sorghum in the North Great Plain Region

Fig. 8. Experimental trials with S.S. varieties in Southern Italy 2007
(Source: Eubia 2009[26])

- **Experimental trials (Sweet-Sorghum) Southern Italy 2007**

Total fresh weight

Australia seeds: NSS. 104 — 170t/ha (28000 ha)

Romania seeds: F135/1143 — 176 t/ha (24000 ha)

Germany seeds: (KWS) — 100 t/ha (21,000 ha)

High S.S. grains productivity: ~ 7.5 t/ha.

In sub-tropical/tropical areas, a good combination for co-production of bioethanol is sugarcane and sweet sorghum plantations (11 months of operation for ETOH).

The leading role of ICRISAT on Research and development in Asia and AFRICA for S.S. ethanol and other products

ICRISAT, operating in Asia (India, China, Philippines, Thailand) in East South Africa (ESA) and in West Central Africa (WCA), has three main research issues, trying to give answers to the following questions:

1) *Food supplies:* do biofuels take land away from growing food, or divert food staff into gas tanks?
2) *Economics:* are biofuels a potential engine for economic development in poor areas, and for energy security in both poor and rich countries?
3) *Environment:* do biofuels truly reduce greenhouse gas emissions, or perhaps inadvertently increase them instead; and do they excessively damage land resources (soil, water, biodiversity)?

Preliminary ex-ante analysis conducted on sweet sorghum cultivation promoted by Rusni Distilleries and ICRISAT in India, showed that S.S. has the potential to become a bioenergy crop of high importance.

Research activities to accelerate the realization of the previous goals

1) Agronomic research to improve yield, quality, nitrogen use efficiency, economic efficiency and greenhouse gas emissions.
2) Plant breeding research to optimize food, fuel and feed yields and quality, especially through hybrids and novel sugar-related genes, and improving plant type for more efficient harvesting,
3) Post-harvest processing research to overcome the harvest-time bottleneck, eg, through decentralized crushing and syrup-making units.
4) Socio-economic research and policy analysis to optimize coordination that engages thousands of smallholder farmers and other poor people with the private sector, accelerating improved technology adoption while monitoring the distribution of benefits to ensure that pro-poor outcomes are realized, and
5) Energy and greenhouse gas lifecycle analysis to quantify greenhouse gas and net energy yields. Analysis is carried out on both decentralized and centralized systems of ethanol production in Asia and Africa (ESA) and (WCA) regions, as LCA varies widely from location to location, as do processing techniques and logistics in each region.

Development activities of ICRISAT

ICRISAT is sharing technology with farmers and private sector, has created two platforms for a **holistic**, pro-poor approach in the sweet sorghum ethanol value.

- *In the first platform* ICRISAT created a Private Sector Sweet Sorghum-Ethanol Research consortium (SSERC), and tryies to meet current and future demands of the S.S based ethanol distillery units. So, the distilleries will not only help widen the marketing opportunities for S.S. farmers to get a higher income, but will also help to generate more employment. Actualy (2009) four companies are partners in this consortium.
- *In the second platform* ICRISAT created the Private Sector Sorghum Hybrid Parents Research Consortium (SHPRC). The overall goal of this consortium is to share the products with the seed industry, which in turn provides sweet sorghum hybrids to farmers.

ICRISAT exchange the materials and technology and test them in collaboration with partners across countries including India, China, Thailand, and the Philippines in Asia and countries in ESA and WCA.

Table 11. **Performance of selected sweet sorghum hybrids during 2006 rainy season at ICRISAT, Patancheru, India**

Hybrid	Days to 50% flowering	Brix	Cane yield (t ha^{-1})	Juice yield (kl ha^{-1})	Sugar (t ha^{-1})	Grain yield (t ha^{-1})	Per day ethanol productivity (l ha^{-1})*
ICSA 749 × SSV 74	85	18.00	57.8	27.2	9.2	3.3	18.5
ICSA 502 × SPV 422	88	20.32	45.1	19.9	8.1	6.2	14.1
ICSA 511 × SSV 74	88	17.97	49.1	22.7	7.8	5.8	15.4
ICSA 474 × SSV 74	82	16.33	52.4	25.4	7.6	7.2	17.1
SSV 84 (control)	94	15.65	35.2	16.8	5.0	2.7	10.5
NSSH 104 (control)	91	15.65	35.2	16.8	5.0	4.1	10.7

*Ethanol productivity estimated at 40 liters per ton of millable cane yield

Source: ICRISAT [(30)]

Table 12. Sweet sorghum scores over sugarcane and maize in India

Parameter	Sweet sorghum[2]	Sugarcane[2]	Maize[3]
Crop duration	4 months	12 months	4 months
Water requirement	4000 m^3	36000 m^3	8000 m^3
Grain yield ($t\ ha^{-1}$)	2.0	-	3.5
Ethanol from grain ($l\ ha^{-1}$)	760	-	1400
Green stalk cane yield ($t\ ha^{-1}$)	35	75	45
Ethanol from stalk cane juice ($l\ ha^{-1}$)	1400	5600	0
Stillage/ stover ($t\ ha^{-1}$)	4	13.3	8
Ethanol from residue ($l\ ha^{-1}$)	1000	3325	1816
Total ethanol ($l\ ha^{-1}$)	3160	8925	3216
Corn oil ($l\ ha^{-1}$)[4]	-	-	140
Income from corn oil (US$ ha^{-1})	-	-	61
Cost of cultivation (US$ ha^{-1})	220	995	272
Cost of cultivation (ha^{-1}) after corn oil profit (US$)	220	-	211
Cost of cultivation with irrigation water cost (US$)[5]	238	995	287
Ethanol cost per kilo liter (US$)[6]	69.6	111.5	65.6
Ethanol cost per kilo liter (US$)[7]	75.3	111.5	89.2

1. Processing costs assumed equal and excluded from the estimates; does not take into account water needs and crop duration
2. Sorghum grain ethanol: 380 $l\ t^{-1}$; sorghum stalk juice ethanol: 40 $l\ t^{-1}$; sorghum or sugarcane stillage ethanol: 250 $l\ t^{-1}$ [Ref. Badger (2002) Trends in New Crops and New Uses];
3. Corn (grain) ethanol: 400 $l\ t^{-1}$; maize stover ethanol: 227 $l\ t^{-1}$ [Ref. Badger (2002) Trends in New Crops and New Uses];
4. Oil produced from corn: 40 $l\ t^{-1}$; oil cost of production: Rs 15 l^{-1}; oil sale price: Rs 35 l^{-1};
5. Sorghum needs two irrigations and maize four each @ the cost US$19 ha^{-1} per irrigation in rainy season
6. Without accounting for water cost; 7. After accounting for water cost

Source: ICRISAT [(30)]

Table 14. Comparing feedstock cost in the Philippines

ICRISAT

Comparing feedstock cost in the Philippines

Feedstock	Price (Php)/MT		liter/ha/year*	Feedstock cost (PhP)/liter	
	Min	Max		Min	Max
Sugarcane	1,000	1,100	6,120	13.89	15.28
Molasses	4,550	5,400	806	19.06	22.62
Cassava	1,500	5,800	5,549	8.38	32.40
Corn	8,500	10,000	5,282	20.92	24.61
Sweet Sorghum			8138[2]	13.98[1]	15.672[2]
- Stalk	550	600	5,625	12.22	13.33
- Grain	6,000	7,000	2,513	17.91	20.90

Sources: GAIN Report on RP sugar industry, GAIN Report on Thai sugar industry, bas.gov.ph, Leyte State University Report on cassava, Biotechnology Coalition of the Philippines Speech, MMSU field tests, FAO & ICRISAT, 2004-2005.

1. Average for stalk and grain; 2. Total for stalk and grain.

* Average ethanol output per hectare.

Table 17. The economics of setting up a distillery…

The economics of setting up a distillery…

Distillery capacity	Cost[1] (US$ million)
40 KLPD	9
100 KLPD	28
200 KLPD	38
[1]Includes civil works and excludes facility for germ separation from maize, November 2006.	

…and the employment generated by a 40 KLPD unit

Country	Beneficiary farmers	Labor (man days)	Direct staff (man days)
India	5000	40000	100000
Philippines	2500	20000	50000
Source: Rusni Distilleries (P) Ltd.			

Fig. 9. EUBIA estimations for the cost of Sweet Sorghum ethanol

Assuming that 60% of the ETOH production cost is due to the feedstock (sugar cost) supply, this value is:

$$\frac{50\ €/t}{0.96_1 * 0.93_2 * 0.5_3 * 0.95_4} = 118\ €/t\ \text{ETOH}$$

1: Sugar extraction efficienc
2. Fermentation efficiency
3. ETOH/sugar conversion
4: Industrial efficiency

Therefore the anticipated cost of bioethanol from sweet sorghum is about 200€/t.

Conservative figure: **250 €/t***

*ICRISAT's culculations based on real figures from a small distillery 40 M3/day give a cost of 278 €/m^3 of ethanol

Summary of Results from Environmental comparison of Sweet Sorghum with other feedstocks and gasoline *(Koppen et all, 2009)[32]*

a. *Energy balance*

- If the crop is used for the production of ethanol (from grain and sugar) and for green electricity (from surplus bagasse), ⇒ **3.5 TOE/ha** can be saved
- If both food from grains and ethanol from the juice are produced, ⇒**2.3TOE/ha** can be saved

b. *Greenhouse gas balance*

The saved gases are depending on yields, production methods, the land cover prior to Sweet Sorghum cultivation, other local conditions, the use of by-products (e.g. bagasse), and the type of fossil energy carriers used.

So the saved gases in CO2 equivalent are : **1.4 - 20 Kg CO_2/ha** *c. Other environmental impact*

- Low water demand in comparison to other bioethanol crops
- Low fertilizer demand reducing the risk of nutrient leaching and thus soil and water pollution
- Short vegetation cycle allowing the double cropping systems reducing fertilizers and pesticides and giving the possibility for a greater agrobiodiversity
- Under intensive practices S.S. risks Similar disadvantages as other intensive monoculture (soil degradation, soil and water pollution).
- Like many other biofuels, S.S. based ethanol has disadvantages to certain emissions compared to its fossil equivalent, like: acidification, eutrophication, photochemical smog and ozone depletion

d. Comparison with other biofuel cros

- The yield stability of S.S. is worst, due to lack of experience.
- S.S. could reduce competition between food and biofuels
- S.S. delivers appreciable yields in soil of restricted suitability for food crops (such as corn)

Fig. 10. EUBIA Estimations on the Energy Ratio of S. S. products

Energy input/output and en. Ratio of Sweet-Sorghum Biorefinery
(Co -Production of Bioethanol+ Agro-Pellets +DDGS)

INPUTS (for 1 ha S.S. plantation)

• Energy consumption for cultivation	~ 0.50 TOE/ha
• Harvesting/grain separation/cane crushing	~ 0.12 TOE/ha
• Agro-pellets processing (pelletisation & transport)	~ 0.69 TOE/ha
•**TOTAL**	**1.31 TOE/ha**

OUTPUTS (Average)

Bioethanol (6m3/ha) =	4,2 TOE/ha
Agro-pellets (21 t/ha) =	8.6 TOE/ha
DDGs (2,25 t/ha) =	0.9 TOE/ha
TOTAL OUTPUT =	**13.7 TOE/ha**

Energy Ratio: $\frac{\text{output}}{\text{input}} = \mathbf{14.4}$

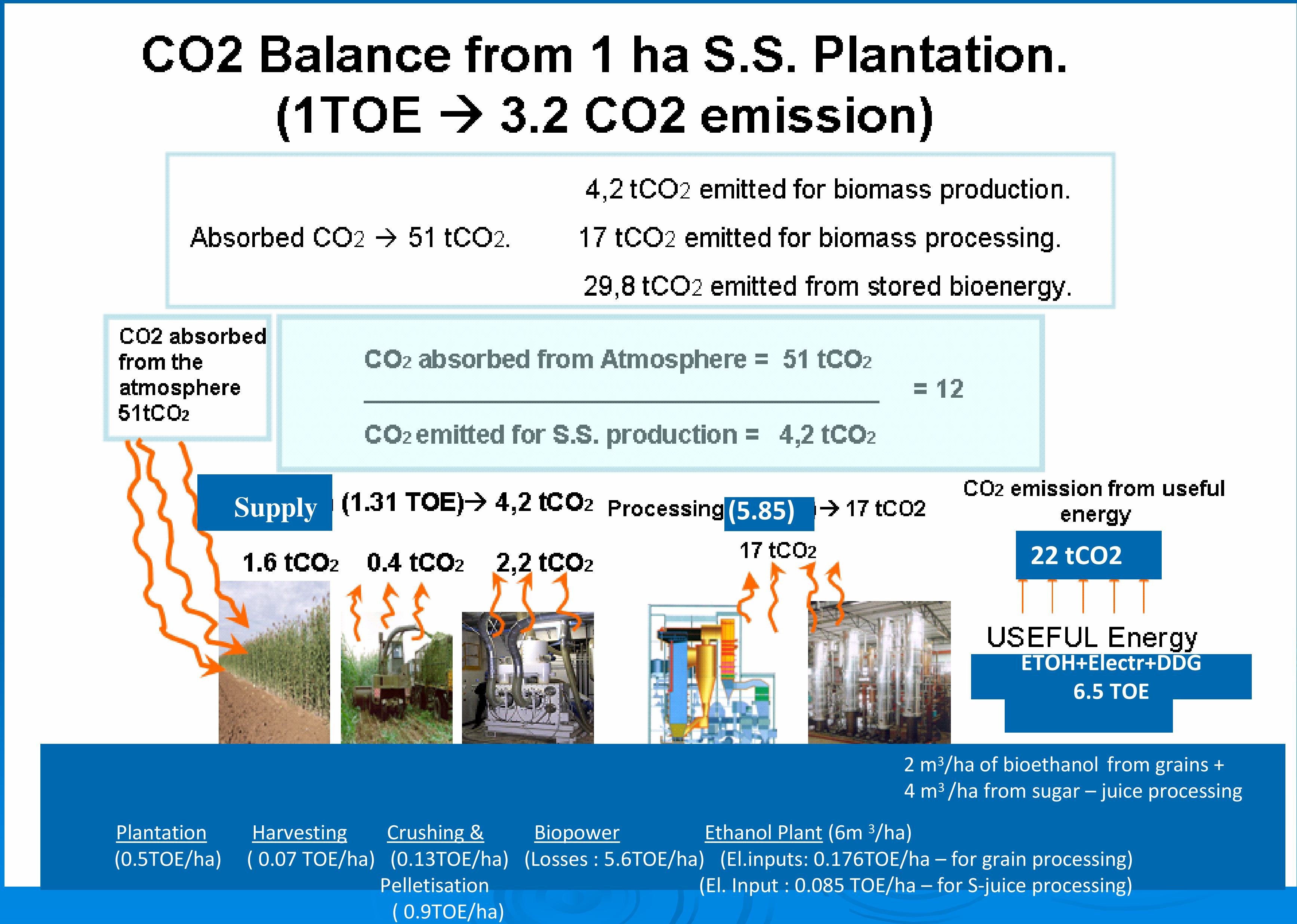
The data are very similar to those obtained in Brasil from sugar – cane however; but must be reminded that :

- Sugar cane can not be grown in temperate areas ;
- Sweet – sorghum,in tropical areas, can produce 2 times more resources (2crops/year) .

IF MAX BIOPOWER PRODUCTION IS ADOPTED, the corresponding Energy Ratio is reduced to

$$R = \frac{8.1}{1.32} = 6.20$$

Fig. 10. EUBIA Calculations on CO_2 balance from 1 ha S.S. plantation



Conclusion

- Bioethanol demand is increasing, worldwide, at a rapid pace.
- Conventional feedstocks have limited supply potential and serious environmental and social problems (food security),
- Cellulosic ethanol technology is in progress especially in the U.S. with the hope to alleviate the disadvantages of the conventional feedstocks, but doubts are about the final cost compared to Brazil and Caribbean cane ethanol.
- The use in the future of the organic part of the M.S.W. is expected to give lower cost.
- Sweet Sorghum even thought a relatively new ethanol crop (1st distillery 2007) is proved that disposes a great potential to save fossil resources, to reduce greenhouse gas emissions, and a promising crop for food and fuel production (in parallel or in rotation), and the creation of new income sources for subsistence farmers.

A better future is coming for S. Sorghum based on the intensive research undertaken in U.S., Asia and Africa by ICRISAT, and also in Europe.