Biofuels In Africa: A Criteria To Choose Crop Models for Food and Fuel

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Abstract

The bioeconomy is based on two components: biomass and bioprocess, which is related to natural resources (energy crop, agro-residue, under-utilised waste, soil fertility, land-water availability) and novel technologies (industrial biotechnology, bio/chemical and/or thermo-chemical technology). The shift from fossil fuels to a bio-based economy is necessary, if the world aspires to a "reduced reliance on fossil fuel, mitigating climate change and benefiting rural community". Biomass to biofuels and bio-materials brings in the paradox of food verses fuel, more so in developing countries, with limited natural resources. Employing micro-agriculture resource in LDC's to meet future food-feed-fuel demands is a challenge. Africa which has the bulk of the LDC's should find a balance to meet the need for food and demand for sustainable fuel, surely not at the cost of the each other. Keeping in mind dry land agriculture, this paper explores a possible criteria to choose a crop-based model, to meet feed-fiber-fuel demands of Africa.

Introduction

Henry Ford designed the famed Model T Ford to run on alcohol, he said it was "the fuel of the future". Similarly Dr. Rudolph Diesel invented his compression ignition engine in the 1890's which ran on peanut oil, the original "diesel fuel". Dr. Diesel believed biomass fuel to be a viable alternative to the resource consuming steam engine. The oil companies thought otherwise. Due to the prevalence and price of petroleum products, diesel fuel soon came to be accepted as a petroleum product as well (1). However the oil crisis of the early 1970s gave ethanol fuel a new lease of life.

In 2003, the biologist Jeffrey Dukes calculated that the fossil fuels we burn in one year were made from organic matter "containing 44×10^{18} grams (44 billion tons) of carbon, which is more than 400 times the net primary productivity of the planet's current biota."(2) This is equivalent to four centuries' worth of plants and animal material.

Bioeconomy can be defined as an economy whose basis is biomass and technology for sustainably meeting societies requirements of energy, fuels and products. Strategically countries across the globe are attracted to this development for several reasons,

1. Reduce dependence on Fossil Fuels
2. Better market values for agricultural produce
3. Adopt climate friendly energy, fuel and industrial feedstocks
4. Diversification and total utilization of agricultural potential; beyond food

However the first two reasons would be stronger attraction for developing & developed countries, while the last two reasons would be additional compulsions or luxury so to say for developed nations. However it is a fact that fossil fuel resources are unevenly distributed across the globe, however with better agricultural technology, production could be evenly distributed, overcoming the uneven distribution of other natural resources supporting agriculture. Industrial Biotechnology is revolutionizing the conversion of biomass (sustainable alternative to fossil fuels) to energy, fuel and industrial feedstocks. Developments in Industrial Biotechnology to make clean

The economy of going green: the science, infrastructure, products and markets

and cost effective processes is the driver for renewed interest in the bioeconomy. The key categories of products, of this bioeconomy are bioenergy, biofuels, biomaterials, bulk and fine chemicals. The bioeconomy is a sector worth over 1.5 trillion euros (European Commission, 2005).

Fuels mainly diesel & petrol can be replaced by similar or actually better chemical quality and eco-friendly products by processing biomass, hence the term biofuels. In general plant & animal fat is used as raw material for the production of biodiesel, however recent developments have also led to the use of lingo-cellulosic biomass for production of biodiesel by gasification (synthesis gas) and Fischer-Tropsch (FT) process. Fats are converted by a process of trans esterfication to make biodiesel and glycerol, shown in Figure 1 (www.utahbiodiesel.org).

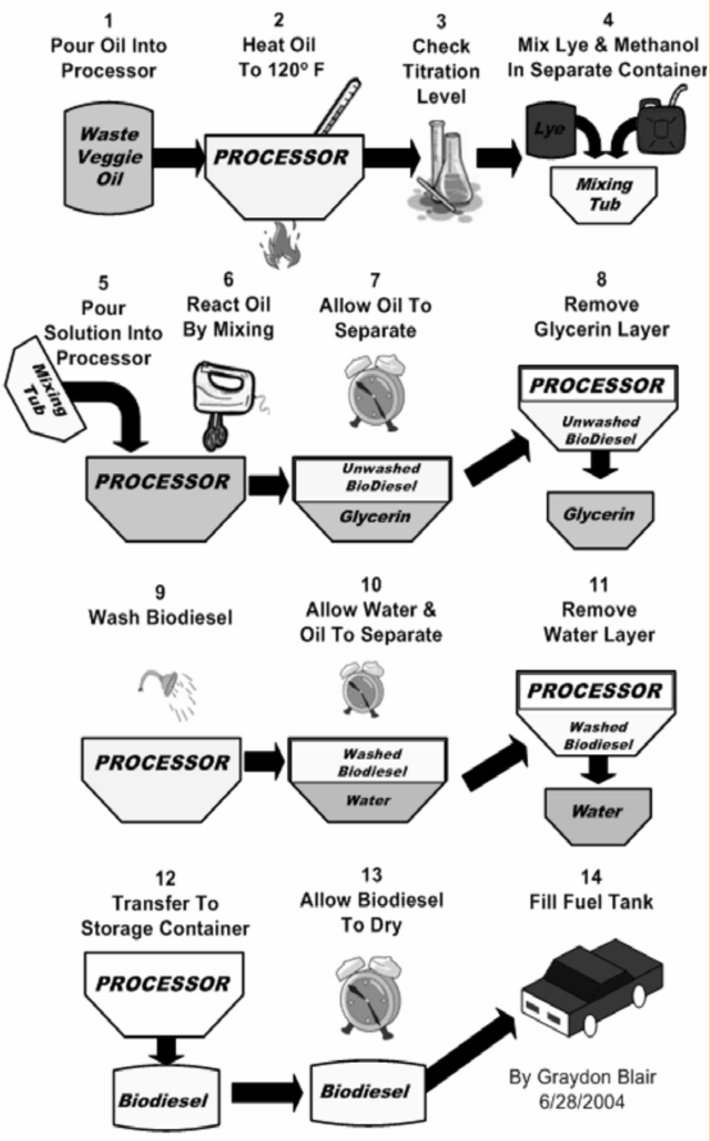
However the production of ethanol from unconventional complex sugar like lignoceullosic biomass (corn stover, straw, sugarcane bagasse, forest residues, municipal solid waste), or through conversion of methane to Ecalene (Gas to liquid, GTL) are recent trends, dynamically evolving. The focus for technology development (Figure 2) has been in the four areas:

-Cellulosic biomass fractionation to its components (cellulose, hemi-cellulose, lignin)

Box 1. Crop wise oil/fuel data per hectare

Crop	kg oil/ha	litres/ha
corn (maize)	145	172
cashew nut	148	176
oats	183	217
lupine	195	232
kenaf	230	273
calendula	256	305
cotton	273	325
hemp	305	363
soybean	375	446
coffee	386	459
linseed (flax)	402	478
hazelnuts	405	482
euphorbia	440	524
pumpkin seed	449	534
coriander	450	536
mustard seed	481	572
camelina	490	583
sesame	585	696
safflower	655	779
rice	696	828
tung oil tree	790	940
sunflowers	800	952
cocoa (cacao)	863	1026
peanuts	890	1059
opium poppy	978	1163
rapeseed	1000	1190
olives	1019	1212
castor beans	1188	1413
pecan nuts	1505	1791
jojoba	1528	1818
jatropha	1590	1892
macadamia	1887	2246
brazil nuts	2010	2392
avocado	2217	2638
coconut	2260	2689
oil palm	5000	5950

Figure 1. A pictorial overview of fats to Biodeisel



-Breakdown to simpler sugars like glucose, fructose, xylose

-Conversion to ethanol and other bioproducts

-GTL: Solids to gas to liquids using FT as an alternative to hydrolysis-fermentation route

Tremendous progress is being made at a rapid rate, on the technology platform front for conversion of biomass to bioproducts. However a similar progress is still to be seen in the development of biomass for bioproducts, or development of energy crops so to say. It remains to be seen, how the era of crop genomics will be able to contribute to the re-design of major crops grown in different parts of the world. If we can double the productivity of rice with one fourth of the current water required and reduce the lignin content in the straw and design it to have more easily fermentable complex sugars, it could make a tremendous impact on the need for food and sustainable fuel.

2 Paradox of Food & Fuel

The world already grows more than enough food & feed for all, but still a billion people don't have enough food to meet basic daily needs. There's more food per capita now than there's ever been before, enough to make everyone fat. People starve because they're victims of an inequitable economic system, not because they're victims of scarcity and overpopulation. Seventy percent of Global food production is in the north, while the bulk of malnutrition, poverty, lowest energy/capita is in the south with only 30% agricultural production, (4). Countries challenged with poverty and malnutrition face the paradox of food vs. fuel as the bioeconomy emerges. If they have not met their food requirements in the past, how will they now cope with the additional stress of having to produce fuel also from agriculture?

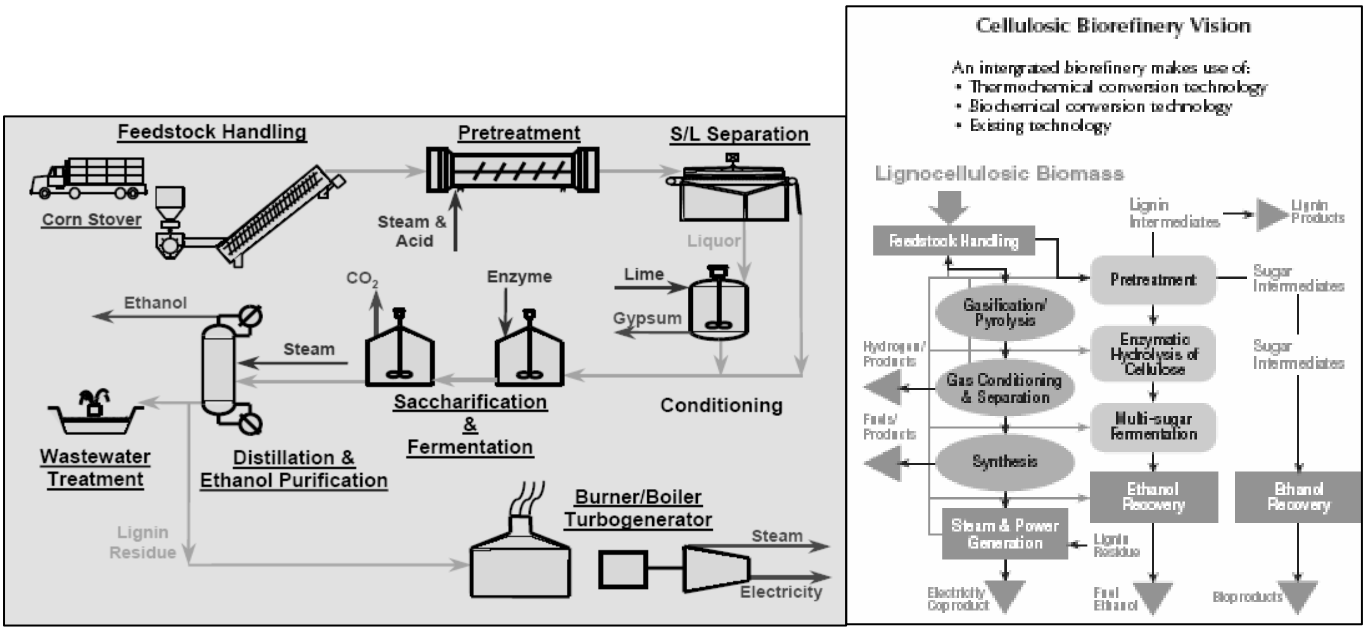
The correct Biomass (S & SF) for production in developing countries can only be decided after looking into a maze of issues like their food-feed-energy requirement, existing malnutrition, potential for irrigated/ dryland production, existing and potential to expand forests, agricultural productivity constraints, underutilised agricultural/ forestry residues, net carbon emission, energy balance etc. With the biomass economy, the paradox of S & SF arises due to the following:

Should a grain crop be distilled to make ethanol fuel or should the villagers eat the grain? If they use the grain for livestock feed, it can be used for ethanol and still feed the livestock: the distillation process to produce ethanol converts the carbohydrates in the grain while leaving the protein (Table 3). The protein residue is excellent stock feed, which can be supplemented by forage crops which humans can't eat. This could mean improved utilization of the available resources.

But what is the net GHG emission and energy balance for grain-ethanol? Is cellulosic a better option? (Figure 4).

Should a crop such as soybeans be used to make methyl esters (biodiesel), or it is better for villagers to live by eating off the bean's products? Or selling them? Or should they press them to make oil, for cooking or for selling (the most efficient would mean hexane extraction in large scale), and feed the high-protein residue "cake"

Figure 2 Sugar/biomass to ethanol via hydrolysis- fermentation- distillation route and *LCB via biorefinery route to ethanol using thermo chemical as add on* (NREL)



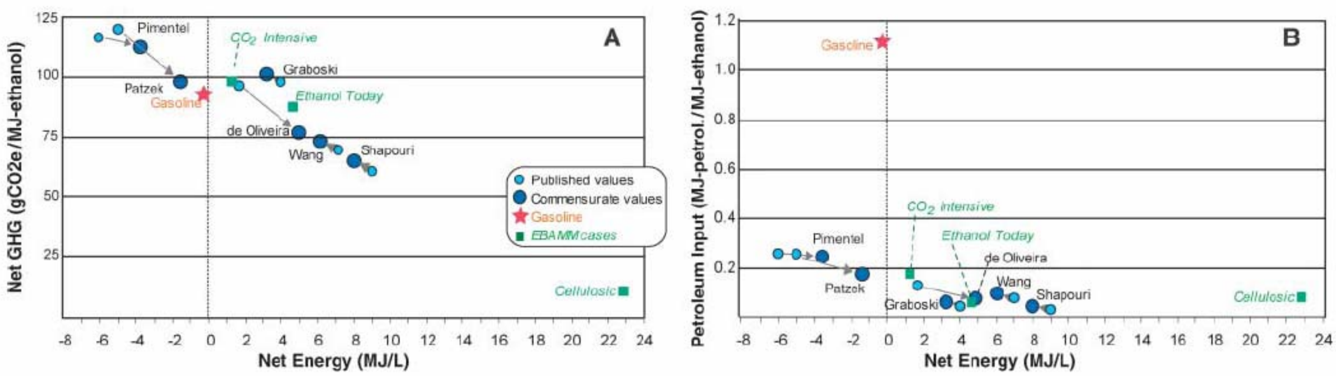


Figure 4 Net energy and net greenhouse gases for gasoline, six studies, and three cases. (**B**) Net energy and petroleum inputs for the same. In these figures, small light blue circles are reported data that include incommensurate assumptions, whereas the large dark blue circles are adjusted values that use identical system boundaries. Conventional gasoline is shown with red stars, and EBAMM scenarios are shown with green squares. Adjusting system boundaries reduces the scatter in the reported results. Moreover, despite large differences in net energy, all studies show similar results in terms of more policy-relevant metrics: GHG emissions from ethanol made from conventionally grown corn can be slightly more or slightly less than from gasoline per unit of energy, but ethanol requires much less petroleum inputs. Ethanol produced from cellulosic material (switchgrass) reduces both GHGs and petroleum inputs substantially.

to livestock (small scale), which in turn they can either eat or sell, while using the livestock wastes (and the crop wastes) to make compost to renew the soil, or to generate biogas for cooking and heating? (The heat generated by the composting process can also be harnessed for heating). Or should they grow a native crop, instead of one imported? (4)

A major criticism often levelled against biomass, particularly against large-scale fuel production, is that it could divert agricultural production away from food crops, especially in developing countries. The basic argument is that energy-crop programmes compete with food crops in a number of ways (agricultural, rural investment, infrastructure, water, fertilizers, skilled labour etc.) and thus cause food shortages and price increases. The subject is far more complex than has generally been presented since agricultural and export policy and the politics of food availability are factors of far greater importance.

Usually the "answer" is in a blend of technologies. Biofuels can be used to power small-scale farm and workshop machinery and electricity generators as well as local vehicles, if you choose the right crop & process technology (Table 3). The question is how do we ensure that available technologies are put to use in the poorest countries, the driver is missing. Capacity building is therefore essential in micro communities to sustainably exploit natural resources like land, water, forest for feed-food-energy needs. The argument should be analysed against the background of the world's real issues like, the use of biomass for food, as animal feed, the under-utilized agricultural potential, the potential for productivity, and the dis/advantages of producing biofuels (4). The rest of the article briefly indicates the potential for biomass production in Latin America, Asia and dwells with African continent in greater detail, in the background of their existing soci-econo-evironmental (triple bottom line of sustainability) conditions, from which arises the paradox of S & SF.

3 Feed-Food-Fuel Security for Africa

South Africa (SA) produces corn among other crops in surplus but there are 10 other nations in the continent on deficit for the same grain, which is one of the problems of the African continent. Should SA focus on production of crops for ethanol, overlooking regional food security? Concentrating more on regional food security on the short-term basis and re-looking at Biofuels with improved technology (lingo-cellulosic biomass to ethanol) may be a justifiable decision due to following reasons. Firstly, SA produces surplus maize/sorghum, which are not the ideal biomass for fuels, as it is competitive to food & feed. Secondly, technology is fast moving to displace corn with lingo-cellulosic feedstocks, due to lower net GHG emission (17) and higher energy balance (18) as indicated in Fig. 6 (17). Thirdly, technology progression should be sector wise, and the full potential of agricultural biotechnology is yet to be diffused into the African continent, as for example only 24% of the corn grown is transgenic. It's optimal to start developing capacities in themes essential for the bioeconomy, ensure Africans truly benefit by green biotechnology, before ushering in white biotechnology, as green drives white biotechnology in a bioeconomy. Biomass is very crucial for ensuring the food-feed-fuel security of Africa, and green biotechnology is yet to make an impact on the African economy. Biotech processes to convert biomass to bioproducts (biofuel, chemicals, materials), varies dependent on the source of biomass and currently most of the biomass is material used in the past for food-feed-energy. Developing biomass specifically for the production of bioproducts is the target for green biotechnology and a lot of information and resource is hidden in the biodiversity of Africa, which should be explored. Bioprospecting for an ideal biofuel crop is a major branch of prospecting, just emerging and we must put in place capacities to benefit from this wave. Bioprospecting for Feed-Food-Fuel Security in Africa is a very interesting theme.

4 Energy Security or Energy Crops?

Contrastingly biofuels in Africa has to be one of the three major produces expected from agriculture in addition to grain and fodder. Two-thirds of the African domestic energy supply currently relies on biomass (19). Therefore, biofuels has to be noncompetitive to feed, food and domestic energy. It directly implies that energy crops like oil palm, jatropha, sugarcane, corn requiring large scales of production with limited sector benefits (Table 3), are not suited to address this unique problem. Therefore Africa needs a crop that addresses all issues, it should be preferable native to Africa, suited for arid agriculture, C4 instead of C3, and a crop already adopted into African food. A crop justifying all needs and promising for African agriculture is "SWEET SORGHUM"(20), and this article christens it as Africa's Millennium crop. This can potential usher in ever green revolution, a terminology recently coined, to ensure sustainable development by Prof. M. S. Swaminathan.

Sweet Sorghum the Saviour of Africa?

Sweet sorghum has many uses, with potential to aid development. Sweet sorghum is a high biomass-yielding crop, grown for grain, feed, sugar and recently as an energy crop for ethanol-electricity and serving human-animal food-feed requirements. (Ecoreport, Imperial College, London). Its excellent growth characteristics (high yield, drought-waterlogging-saline-alkali-resistance, wide adaptability), makes it an ideal choice for Africa. Prof. Li Dajue (Chinese Academy of Sciences) and Peter Griffee (FAO) coined the name "**Four F's Crop**" for sweet sorghum representing Food, Fuel, Fodder (feed), & Fiber (feedstock). Sugarcane is propagated from stem cuttings (4.5 –6 T/ha) while sweet sorghum is sown with just 4.5 kg/ha of seed.

Sweet sorghum is a potential energy crop as it produces up to 7,000 liters of ethanol per ha making it highly attractive for developing countries (FAO). For example Chinese agricultural planners see Sorghum as key for sustainable agricultural development in areas suffering from aridity and saline/alkaline soils. In the Huang Huai Hai region and Northwest China, where the total area of saline-alkaline and salinized land is estimated at more than 170,000 sq km, plants germinate with difficulty, grow slowly, produce poor harvests, if not completely fail.

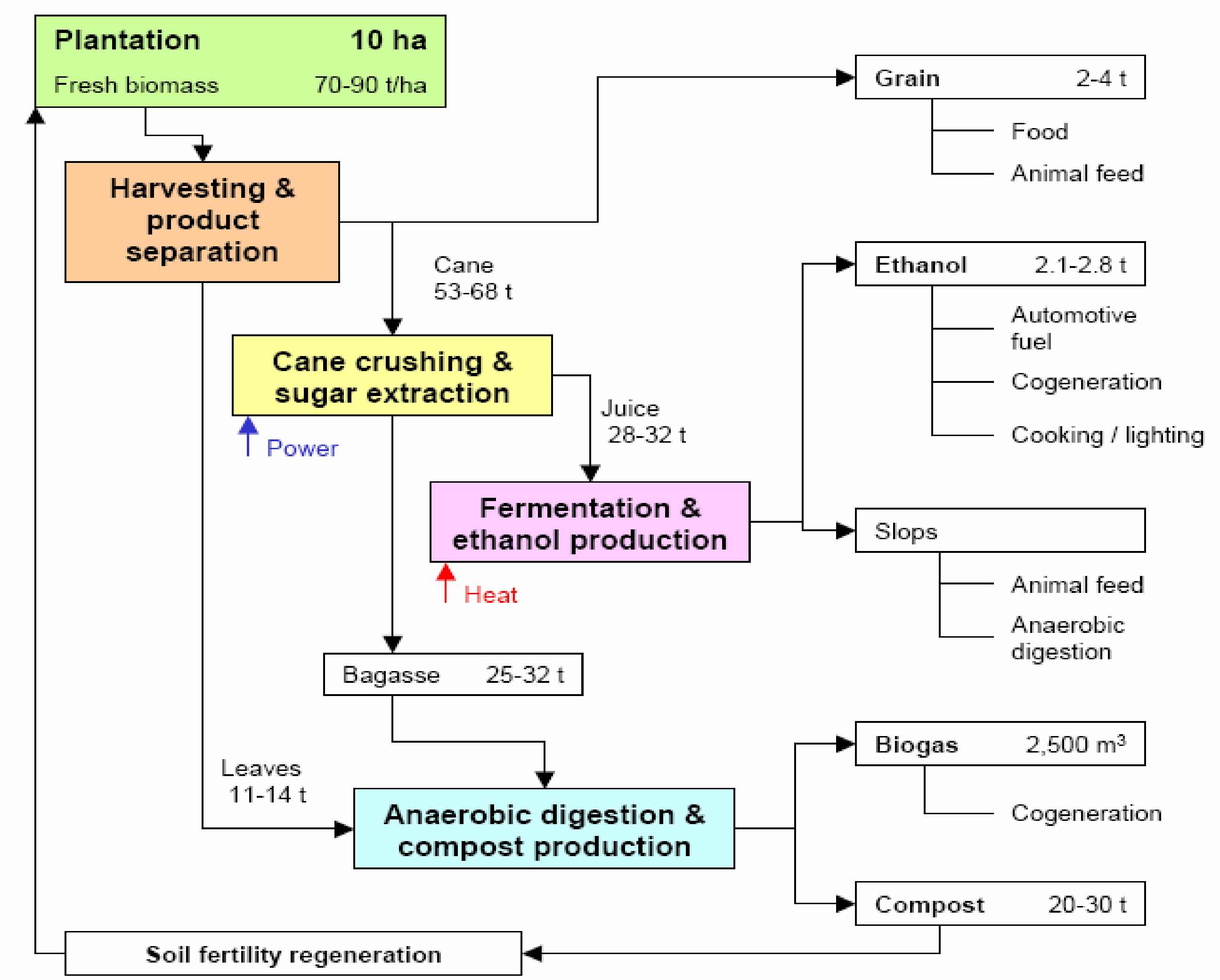
This lack of agricultural development is the cause of poverty in many rural areas and a threat to China's long-term food security (FAO). Chinese since 1970 have developed sweet sorghum varieties yielding 5 T of grain, 7.5 T of sugar and 14.5 dry T of lignocellulosic biomass per ha per crop of 4-5 months duration and currently there are over 7000 varieties/hybrids indicating its importance in China (21). China and Italy are setting up large bioethanol projects with sweet sorghum planted in 21000 and 7000 ha, resulting in 112302 & 42202 T of ethanol/annum respectively (22).

Similarly Nimbkar Agricultural Research Institute, identified sweet sorghum as the ideal crop for feed-food-fuel security of rural India and developed solar distillation of sugar juice to ethanol and used the ethanol for energy efficient stoves (http://nariphaltan.virtualave.net/index.htm, 23, 24). It's demonstrated that sweet sorghum juice can be used as feedstock for the production of hydrogen using thermophilic bacteria (25). Sweet sorghum stalk has 15-18% fermentable sugars and has the potential for cane yield of 40 T/ha or more, but should be crushed within 48 hours of harvest (AICSIP, NRC for Sorghum, Hyderabad, India). ICRISAT India station initiated an identification-development program for sweet sorghum in 2002, and has hybrids for release in India, with industry-incubators for ethanol production trials.

Research on Sorghum and harnessing its prospects would be an excellent program for south-south cooperation for sustainable development. A 8-year agronomic trial and a 2-year industrial trail concluded that 1/3rd of Southern Africa's fuel could be purely met by sweet sorghum grown in only 1% of the total existing cropland. It suggests sweet sorghum future with CDM (http://cdm.unfccc.int/) options is excellent, as an sustainable alternative to the OECD fossil route for development (26). In tropical countries one can easily take two crops of sweet sorghum and produce more ethanol per unit land, in addition to serving food-feed requirements (20). When common African crops corn, sweet sorghum, sugarcane, cassava, sweet potato were compared, for their potential suitability for cultivation with 25% and 50% increase in production, without compromising on food security, next to corn it is sweet sorghum as the second largest crop (27).

However when compared with corn for ethanol production (Fig.6, 15), sweet sorghum is a clear winner due to

Figure 5. Aschematic representation of sweet sorghum based bioenergy Village complex, encompassing microdistillery for ethanol, grain for human consumption and fresh-dried fodder for animal production (20)



yield (28) and lower net GHG emissions (IEA, 17, 18). Sweet Sorghum has shown promising results also in southeastern United states, yielding ethanol (600 gallons/acre) equivalent to sugarcane, and at BECON Iowa state University, it is being studied as a alternative to corn (400 gallons/acre, 28). The seasonality in crop production and instability/difficulty in conversion of some of sweet sorghum sugars have been bottlenecks. The problems of seasonality would be mainly in temperate countries, while difficulties of extraction/ conversion of sorghum is now overcome with thermopermiation technology of Praj, India. These global experiences clearly sends home a strong message to Africa, which suffers from poverty, malnutrition, low energy/capita, desertified landscapes and drought. There is a lot of information on sweet sorghum uses in Africa, role in African bio-energy security etc., however it is not clear, as to why they are no functional sweet sorghum based establishments.

This has to be the focus for change from existing African scenarios. As per FAO 1991, Africa has in total, a potential land for expansion at 752 Mha, next to Latin America is size, of which over 50% is waste lands with the balance divided 20% each of arid, irrigated and 10% of flooded zones.

5 Conclusion

Africa has some of the poorest countries, suffering the most of Aids, with the most severe droughts and cases of malnutrition globally (www.data.org/whyafrica/). 2025-30 global population addition will be 67 million, 2045-50 (943 million), practically all increase in developing countries, and by 2050, every second person added will be in sub-Saharan Africa (43). This in addition to existing malnutrition, signals to concentrate on food security, hence the FEED-FOOD-FUEL strategy; with the 4F crop SWEET SORGHUM for Africa. Almost 1.6

Figure 6. Estimated Ethanol gallons per ton biomass (dry basis, 28)

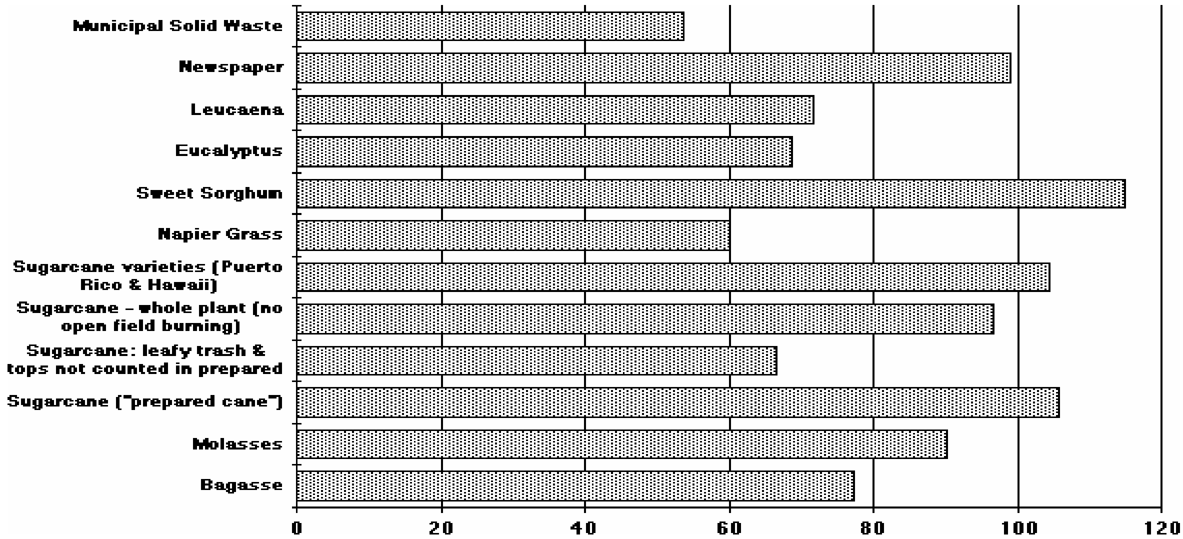


Table 3. A table summarizing salient characteristics of biomass production, processing technology status and potential bioproduct generatability with an LDC's idealistic contrast (sweet sorghum) as the last example in the table. This is a hypothesis based on brief literature search and basic agricultural and environmental science. Conducting a study to validate this hypothesis is worthwhile. Column 11 indicates that resources currently emitting high GHG would be potential candidates for alternate processing and attraction for CDM.

Biomass: Energy Crops	1	2	3	4	5	6	7	8	9	10	11
Arable-land Non-edible oil	++	+++	+	BFI	+++	++	++	++	+	+	+
Corn/Grain	+++	+++	+	BF	+++	+	+++	+	+	+++	+++
Edible oils	+++	+++	+	BFEI	+++	+	+++	++	+++	++	+++
Bamboo/Fibrous	+	+	++	BFI	+++	+++	+	+++	++	+	+
Strach/Tubers	++	++	+	BFEI	++	++	++	+	+++	++	++
Sugarcane/Beet	+++	++	+	BFEI	++	+	+	+	+++	+++	+++
Waste-land Non-edible oil	++	+	++	BFI	+++	+++	+	++	++	+	+
Woody species	+	+	+++	BFI	+++	+++	+	+++	+++	+	+
Biomass: Production Residues											
Agriculture/Industry	+	++	+	BFEI	+	+++	+	+/++	+++	++	+++
Animal Husbandry/Industry	+	+	+	BFEI	+	+++	+	+/++	+++	+++	+++
Aquaculture/Industry	+	++	+	BFEI	+	+++	+	+/++	+++	++	+++
Forestry/Industry	+	+	+	BFI	++	+++	+	+++	++	+	++
Biomass: Waste											
Industrial Waste	+	++	+	BI	++	++	++	+/++	+	++	+++
Municipal Solid Waste	+	+	+	BFI	++	+++	+	+/++	++	+	+++
Municipal Liquid Waste	+	+	+	BFI	+	++	+	+	+	+	++
Oil Waste	+	+	+	BI	+	+++	++	+++	++	+	++
LDC's Ideal Biofuel Biomass	+/++	+	+	BDFEI	+/++	+++	+	+/++	+++	+++	++/+++

Note that:

1: Biomass production Inputs
2: Competition to Land, water, Food, Feed
3: Risk to Biodiversity & Environment
4: B; Biofuel, D: Food, F: Biofertilizer, E: Feed, I: Industrial feedstock
5: Scale
6. Net Energy Balance
7. Net GHG Emission
8. Technology
9. Sectors Benefited
10. Maturity of Technology
11. Current GHG emission

+++ High/Large/Complex , ++ Medium , + Low/small/Simple.

Sectors: Feed-Food-Fuel

billion people in developing countries do not have access to electricity today, representing a little over one-third of world population. Most of the electricity deprived are in Asia and sub-Saharan Africa. By 2030, half the population of sub-Saharan African will still be without electricity; and Africa is the only region where the absolute number of people without access to electricity will increase (44). The proportion of the population using traditional fuels will remain highest in sub-Saharan Africa, where 996 million people will rely on traditional biomass for cooking and heating in 2030 (44). Much of this can change if we address fuel security using Sweet Sorghum, is the authors opinion. This crop can provide energy security at microlevel by the micro energy village complex (20) and considerable percentage of transport biofuels for Africa (26), in addition meting a part of food & feed requirement. Studies indicate the possibility to produce ethanol competitive to Brazilian ethanol or cheaper at 19 US cents per liter (45), promising a biofuel revolution for Africa.

Sweet Sorghums real potential lies in the fact that the crop can establish well in sub-optimal conditions, allowing production of sugar and fiber rich stem, where others struggle. Secondly it consumes one-third the water required by sugarcane, therefore the net water consumption per liter of ethanol is significantly lower (26), which address drought problems of Africa. This feature of sorghum is very important in the background of climate change, which will have more adverse effects in tropical areas than temperate. Developed countries will be beneficiaries with higher productivity in Canada, northern Europe and parts of the former Soviet Union, however poorest developing countries are likely to be negatively affected (46). Here the next 50-100 years will see widespread declines in the extent and potential productivity of cropland (47) particularly in sub-Saharan Africa and southern Europe (48, 49). Some of the severest impacts seem likely to be in the currently food-insecure areas of sub-Saharan Africa with the least ability to adapt to climate change or to compensate for it through greater food imports (43). Growth in the livestock sector has consistently exceeded that of the crop sector. The total demand for animal products in developing countries is expected to more than double by 2030. Livestock production is the world's largest user of land, directly through grazing & indirectly through consumption of fodder/feedgrains (43).

In sub-Saharan Africa, low consumption levels of animal products have changed little over the last 30 years, contributing only 5 percent to per capita calorie consumption, about half the percentage of the developing countries as a whole and a fifth of that of the industrial countries (43). The situation clearly indicates the need to also address feed security in Africa.

Sweet Sorghum can be used in existing sugarcane based ethanol industries, it's an excellent alternative during sugarcane off-season (26). It's also suited for the introduction of community based bottom up approach for development of Africa and several sorghum models are being tested now (50), based on success stories with sugarcane (51). The need of the hour in Africa is to develop capacities very similar to the ones in Asia. In addition to this, the climate for investment and participation by the private sector in development of the continent, like in Asia is extremely essential for Africa.

Can we replace an economy whose every fibre vibrates with the logic of cheap oil and careless pollution with one which runs on renewable energy, heals our surrounding ecosystems and creates no waste? Can biofuels truly compete with petrol? Is it just replacing Biofuels with fossil fuels the solution, without a introspection of our lifestyles which could be highly energy consuming (each family member driving a car alone to work and back, instead of public transport or car pooling)? Will the future be biofuels with a significantly fuel efficient vehicle or is hydrogen the solution? Recent projections suggest that ethanol could represent up to 5% of the world's transport fuel by 2010. That figure may seem modest at first glance, but it is significant, considering no other alternative fuel has had an equivalent impact on the gasoline market in over 100 years (IEA). However, there is a mismatch between those countries where biofuels can be produced at lowest cost and those where demand is rising most quickly (IEA). Arable land expansion will remain an important factor in crop production growth in many countries of sub-Saharan Africa, Latin America and some countries in East Asia, although much less so than in the past (43), indicating future expansion for biofuels. A key long-term concern is that higher usage of biofuels will lead to land being drawn away from other purposes, including food, feed or fiber production, leading to higher prices (IEA). Developed countries would switch to import of biomass to satisfy local biofuel demand, resulting in further aggravation of the developing countries paradox of sustenance and sustainable biofuels. Export of biomass for biofuels by developing countries can be a serious threat than an opportunity if nations use land-water-labour at the cost of feed-food and environment. Bioeconomy in developing countries therefore must act as a bridge between food & non-food uses for a crop, and not independent of them, thereby ensuring feed-food-fuel security. **Africa** must start developing sweet sorghum based microdistilleries and micro energy village complexes. The South African National Biodiversity Institute suggests that over 1080 Mha of land is suited for Jatropha, which can make a tremendous impact on its energy security. All countries have to seriously address energy, fuel and water efficiency in all sectors of economic activity, and develop capacities for optimal use of natural resources for sustainable biomass (unicellular-energy crops-residues-waste) production to address MDG.

The Author

Dr. Seetharam Annadana is a freelance consultant for agricultural biotechnology in India. He operates through his own firm ASR BIOTEC, whose main focus is on Bio-fertilizers, plant Molecular Biology and Biofuels. Dr. Annadana has been helping agencies to develop a model for sustainable biomass production and keeps himself updated with the evolving technology platforms, which is highly dynamic. He has been consulting for the Indian Industry for over 5 years now and has had close contacts with Dutch Biotech firms and obtained his Masters and PhD education at Wageningen UR in The Netherlands. He has been resource persons to UNEP-GEF and UNIDO on subjects like Biosafety and Biofuels in the past.

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