Ethanol as a Household Fuel in Madagascar
World Bank Final Revisions, June 2011
Project Gaia Responses to Peer Review Questions

Ethanol technology
Submitted by Harry Stokes

1. Low-cost feedstock shows highest return, so why does analysis focus on sugarcane?

Low cost, alternative feedstocks represent a new approach, while sugarcane and other industrial crops, such as corn (U.S.) and to a lesser degree cassava (Indonesia), are much better understood and have extensive track records. Even sweet sorghum, extensively researched and in various stages of development, is less well understood than sugarcane. More attention could be given to alternative feedstocks—with cassava and sweet sorghum the best explored to date.

Fermentation of many alternative feedstocks has to varying degrees been explored in the laboratory and tested in the field, but what is less well understood is the scalability of these feedstocks and the agronomics of these feedstocks as crops—how they would be collected and cultivated on an industrial scale, what their hardiness and disease resistance are, how they would be managed and handled. So there is less mystery about how to make ethanol from them but many unknowns about how they could be grown and handled as feedstocks and scaled up to support larger projects.

The development of smaller scale ethanol plants should encourage the study and testing of alternative crops and feedstocks for commercial use, albeit through production on a smaller scale.

Here is an interesting illustration. The National Biotechnology Development Agency (NABDA) in Nigeria has recently purchased a 1,000 liter/day microdistillery from Brazil with the intent to produce ethanol from cassava pieces left over in the harvest in farming areas in Oyo State, an important cassava producing district. A cassava front end for this plant, with processing and enzyme treatment, is well understood and has been studied and developed by CGIAR and others, in locations as diverse as Brazil, Colombia, Malawi, India, Indonesia and the Philippines. As it happens, Oyo State is a center for cashew (*Anacardium occidentale*) production in Nigeria and the cashew nut is associated with a fruiting body called the cashew apple. This cashew apple is discarded during the harvest of the cashew nut. It is a sugary substrate that can be fermented to produce alcohol and laboratory work has been performed to determine how best to ferment the cashew apple. But it has not yet been done on a production scale. The NABDA project in Oyo State may provide the first opportunity to do this and to study the efficacy of the cashew apple in the commercial production of ethanol. (See: T.

2. Molasses feedstock – why focus on ethanol production direct from sugar-cane, not from molasses (which would provide higher returns)?

Ethanol from sugarcane produces a higher yield of ethanol per land area than ethanol from molasses. Thus, on the basis of the size of the farm and the crop produced from it, taking the direct route from sugarcane to ethanol produces more, indeed much more ethanol per land area than from molasses. This pathway is also more energy efficient. Producing sugar obviously uses energy and takes energy away to for other purposes.

Molasses, however, is an excellent feedstock. Small scale sugar production is possible. Where a small farm or group of farms is making sugar on a small scale, molasses should be available and could be used for ethanol production. The small operator could make ethanol either from sugarcane juice or from molasses, or both.

Where industrial sugar operations are producing large amounts of molasses, this molasses many be available cheaply for purchase. In this case the ability to purchase molasses cheaply and in abundant quantities would create an excellent opportunity for a small ethanol producer. But molasses is heavy and expensive to haul. So the small scale producer would be best positioned near the source of the molasses.

The cost to purchase molasses will represent in all likelihood 60% to 70% of the cost to produce ethanol. Therefore, cheap molasses helps to assure that the ethanol produced will be cheap.

Molasses stores well so permits the production of ethanol in the off season after the sugarcane harvest is over. If the molasses supply is sufficient, a distillery can operate throughout the year.

Sugarcane juice can be boiled into syrup and stored for off season production of ethanol as well.

Some yield relationships:

Ethanol production from sugarcane juice yields a much higher production of ethanol per acre, but ethanol production from molasses produces a higher yield per ton of feedstock.
Horta 2004 gives these equivalencies: One tonne of sugarcane will yield 6 liters of anhydrous ethanol (~7 liters hydrous) through the sugarcane to molasses to ethanol pathway (with sugar as the primary product). One tonne of sugarcane will yield 75 liters of ethanol through the direct sugarcane juice to ethanol pathway. The relationship is therefore about 10 : 1. Ten times the ethanol can be manufactured per hectare by processing ethanol directly from sugarcane.¹

Typical yield per Ha, sugarcane to ethanol: 4,000 to 8,400 liters

Typical yield of ethanol per tonne of sugarcane: 60 to 80 liters

One tonne of sugarcane processed for sugar yields about 130 kilograms of molasses.

Sugar yields 1 to 8 or 9 (sugar produced by weight to weight of cane) (New Africa Securities 2009, for Zimbabwe).²

Thus, one tonne sugarcane may be expected to yield in the range of 125 kg sugar.

90 liters of molasses yield per tonne of sugarcane (Pakistan). (Dufey 2010)³

Typical yield of ethanol per tonne of molasses 5 : 1 (5 tonnes molasses yields 1 tonnes ethanol)

185 gallons of molasses (1 tonne) will yield 72 to 88 gallons of ethanol (depending on molasses sugar content. (Blume 2007) This is a yield of 2.6 to 1 by volume and 1 to 5 by weight (about 335 gallons of ethanol per tonne compared to 185 gallons of molasses per tonne).

Yields per tonne: tonne of molasses yields average 78 gal ethanol (Blume 2007)

Yields per tonne: tonne of sugarcane yields 17 gal ethanol (Blume 2007)

US production rates: Using 2003-05 U.S. average sugar recovery rates, one tonne of sugarcane would be expected to yield 21.5 gallons (81 liters) of ethanol. One tonne of molasses would yield about 76.5 gallons (289 liters) of ethanol. Using raw sugar as a feedstock, one tonne would yield 150 gallons (564 liters) of ethanol. (USDA 2006) (USDA values converted to metric.)

3. Scale – are there economies of scale for large-scale distillation, or for clusters of micro-distilleries? Can single installations of micro-distillation compete?

Single micro distilleries operating as discreet business units can compete in a local or regional stove fuel market if the system is closely tied to a feedstock source that is competitive and if the processing unit is efficient, both energy efficient (economizing on fuel) and process efficient (possessing a distillation unit that efficiently separates ethanol from water). Feedstock represents the largest cost in making ethanol; after feedstock either labor or energy represent the next largest cost. If a micro distillery is able to exploit the opportunities offered by its small size to economize on feedstock, labor and energy, then the potential exists for the micro distillery to produce ethanol at a competitive price.

Large scale distilleries achieve substantial economies as a result of the following:

- Advanced equipment that recovers ethanol efficiently, recycles heat efficiently, and employs energy-saving equipment like efficient boilers and molecular sieves.
- Industrialized operations that produce more sugarcane per hectare. Access to ample inputs (fertilizers, irrigation, etc.)
- High degree of mechanization both in the fields and the factory and thus higher rates of materials handling with much lower labor costs.

Micro distilleries should not necessarily be measured against industrial distilleries to judge their utility or practical efficiency. They may serve an entirely different purpose. They achieve gains in this way:

- They are situated close to or within the resource to be converted (adjacent to fields or in fields)
- They can be sized to cost-effectively use the resource. Small resource supplies cannot support large and expensive plants. Yet small and geographically concentrated resources typify the kind of resource that is available for management and exploitation for biomass fuels in most African economies. Charcoal is manufactured on a very small scale. Both farms and woodlots are generally small scale. In many if not most African settings, crops for bioethanol production can be produced on a small scale when they cannot be produced on a large scale. The benefit of the micro distillery is that it enables ethanol production to be carried out on the same scale in which most other biomass energy is procured—on a very small scale.
- Because the micro distillery can be supplied with small feedstock streams, it can exploit feedstocks which might otherwise be considered to have no value. These include agricultural co-products and residues, market wastes and processing wastes. They may even include unusual feedstocks like poultry

Final 7-12-11
manure or wild, gathered feedstocks like prickly pear cactus and mesquite pods.

- Micro distilleries may use simplified and inexpensive equipment which nevertheless produces ethanol efficiently. Potentially all of this equipment can be locally manufactured. Capital cost per unit output can actually compare favorably with industrial-scale plants.
- Micro distilleries serve a local market. There may be no need for a wholesaler in the fuel supply chain, which can be short and economical.

4. Relate proposed micro-distillery program to tokagasy production system – micro-distillation approach with modern technology would build on traditional tokagasy production, which has distributed sugar-cane cultivation, distillation and delivery systems in place.

Fuel Ethanol Market vs. Beverage Market—a Barrier

A barrier to the adoption of ethanol as a fuel that exists in many countries is the existence of local beverage markets and the uncertainty on the part of government how, or whether, to regulate for a fuel market and/or for a beverage market. The markets are entirely different from one another and both should be regulated. In the case of Madagascar, the beverage market is an illegal market (unlike other settings where the market is legal and regulated—Brazil and cachaca might be the best example). This poses its own uncertainties.

An aspect of the beverage market barrier is that distilled spirits (usually at about 45%) may be sold for beverage at prices higher than the fuel ethanol market can bear.

The fuel market is potentially very large while the beverage market is small and constrained, so only a certain amount of distilled spirits can be sold into the beverage market. A fuel market will quickly surpass the beverage market in size and importance. Without the beverage and fuel markets being regulated, there is a risk that the beverage market could be undercut by the fuel market, with artisanal distillers put out of business. There is also the risk that the beverage market could remain a barrier to the early development of the fuel market if ethanol fuel, which should be regulated from point of production, is black marketed into the toaka gasy market. A few million liters of annual production of fuel grade ethanol, if inappropriately diverted, would entirely displace the toaka gasy market.

Industrial ethanol is made today in Madagascar’s sugar factories and has been for several decades. It is not difficult to regulate industrial production of ethanol for fuels and chemicals, and to keep this production separate from production for beverage use. Obviously producing fuel ethanol on a small, distributed basis will require new regulations to be written and implemented. What may be more difficult is to regulate the toaka gasy business, from production to sales. This should be done. Possibly the
introduction of fuel ethanol to the Malagasy economy offers the opportunity to bring the toaka gasy industry into the formal economy.

Outfitting Distillers of Toaka Gasy to Make Fuel Ethanol

For those farmers or artisans who run a distillery and believe that they could increase capacity and sell fuel ethanol, two approaches seem possible:

1. They could sell their ethanol-water mix to a better distillery for further distillation, or
2. They could upgrade their own equipment to produce fuel ethanol cost effectively.

The latter could offer significant environmental gains. The former represents business-as-usual. Artisanal stills require a lot of energy, usually firewood, and the distillation is crude and inefficient. Creating a program to upgrade artisanal stills and bring them into compliance with environmental regulations would offer advantages, both in fuel production and in the reduction in the use of fuelwood. Strengthening the better operators would help to put the less good operators out of business. A schedule of fees and taxes could be put in place to raise money for the new regulatory program.

The two most important improvements for artisanal distilleries would be a distillation column to replace the alembic or pot still and an improved furnace to fire the boiler. Different sizes of distillation columns could be built locally for sale. Instructions and training could be provided to operators on how to build a better furnace. A furnace with a grate and good air circulation could burn bagasse. These furnace designs could come from the same experts who have designed better stoves. Plans already exist that could be adapted to local capacity.

Another important improvement for the artisanal distiller would be to provide a hand operated cane crusher to improve juice extraction from cane.

Yet another opportunity to increase productivity would be provide training and seeds to produce hardier sugarcane and diversify to sweet sorghum where possible.

A substantial improvement over these upgraded artisanal operations would be provided by installing an integrated micro distillery sized to achieve some economy of scale. The examples we have looked at from Brazil (Usinas Sociais Inteligentes) and the U.S. (Blume Distillation) suggest better unit capital cost numbers beginning at 1,000 to 1,500 liters per day. The front end of the micro distillery is sized correctly to provide a steady supply of beer to the distillation column for continuous processing, even in batch mode. If the micro distillery is receiving feedstock from many small farms in its area, presumably the feedstock supply will be adequate and reliable. Possibly the more
successful distillers among the artisanal operations that seek to upgrade would become candidates for operating a more completely engineered distillery.

Supply Lines for Making and Delivery Ethanol Fuel

In any biofuels production and sales, whether solid fuels like wood and charcoal or in this case ethanol, the materials handling and delivery to processing or sale is a major part of the price build-up of the fuel and its life cycle energy efficiency. Producing fuel ethanol in place of toaka gasy and installing local integrated micro distilleries to handle the production of many small farmers in an area, as an alternative to pot stills, changes the way in which feedstock is handled and the product is marketed.

Delivering cane from the fields to the distillery becomes a more extensive operation. Once cut, cane should be processed the same day to assure minimal loss of sugar in the stalk. Therefore, the area from which the distillery can receive feedstock is defined by the delivery times and cost to bring the cane to the distillery.

Delivering fuel ethanol to the market will be different from delivering toaka gasy to market. While a small amount of toaka gasy is consumed locally and much is transported to the city for sale, it is presumed that all of the fuel ethanol would find a market in the surrounding towns. A large enough distillery might find a market for its fuel in a more distant town or city—for example the regional capital—and transport its fuel to the city once per week or several times per month in a tanker truck. A standard kerosene tanker truck can be adapted to haul ethanol fuel.

5. Energy for distillation – clearer statement on energy efficiency of modern micro-distillery technology, and ability to be fueled entirely by bagasse (if using sugar-cane) or other agricultural waste (if using low-cost feedstock).

The energy efficiency of distillation has been thoroughly studied and there is no mystery in how to build an energy efficient distillery. The key points in the process that affect efficiency are as follows:

- Efficient cane crushing to extract the juice from the cane
- Heating the juice to remove contamination and assure successful fermentation
- Good production of alcohol in the beer during fermentation
- Efficient extraction of the alcohol from the beer in the distillation column, with the least amount of reflux required
- Recycling the heat used in the distillation to other parts of the process; heat from the boiler used to preheat the mash; heat from the ethanol vapor used to preheat the mash
- Efficient boiler to heat the beer; efficient firebox or furnace to heat the boiler.
- A furnace or firebox that can burn bagasse and other residues in place of wood.
Various levels of life cycle energy efficiency are reported for ethanol fuel from sugarcane and sweet sorghum ranging upward to a ten-to-one energy gain. Micro distilleries are not likely to be as efficient as industrial distilleries in their process efficiency, but they have the opportunity to make up for this with shorter feedstock supply chains, shorter ethanol fuel delivery chains, and with their ability to process materials that would otherwise be wasted. The energy gain achieved in using a feedstock that would have been wasted represents an absolute gain provided the energy used in converting it to fuel is less than the energy derived from the fuel.

See, next page: Efficiency Indicators of a Modern Micro-distillery.

---

4 A number of studies have been cited in the report. Here is a list of relevant reports.


Macedo, Isaias Carvalho. 1996. Energy Balance of the Sugar Cane and Ethanol Production in the Cooperated Sugar Mills, CT Brasil, Ministério da Ciência e Tecnologia Brasil, UNFCCC.

<table>
<thead>
<tr>
<th>Efficiency Indicators</th>
<th>Benchmark</th>
<th>Additional comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of juice extracted from cane</td>
<td>60%</td>
<td>To increase efficiency, use remaining sugars in co-products or increase sugar extraction: Sugars remaining are ideal for animal feed or methanization. Diffusion extracts more sugar than pressing. If using batch rather than continuous distillation, whole fermentation (solids in mash) plus yeast will produce more alcohol.</td>
</tr>
<tr>
<td>Temperature to which juice is heated to remove contamination</td>
<td>32 to 35 degrees C treated with antibiotics</td>
<td>Cook or no-cook? Additional yeast can avoid the need for cooking. Avoiding cooking saves energy but risks contamination. No-cook enzymes have been developed for starchy feedstocks.</td>
</tr>
<tr>
<td>Percentage alcohol produced in beer during fermentation</td>
<td>Average of 8.0 %</td>
<td>Optimizing Fermentation: Choosing the right feedstocks and yeast are critical. Some yeasts will permit higher ethanol yield (up to 15%). Temperature, pH, nutrition, agitation, yeast dosage, and avoiding contamination all affect the amount of alcohol produced.</td>
</tr>
<tr>
<td>Percentage extraction of alcohol from beer in distillation column*</td>
<td>99.80%</td>
<td>USI value. A well-designed distillation tower assures efficient and complete distillation.</td>
</tr>
<tr>
<td>Percentage of total heat achieved through heat recycling from distillation</td>
<td>80%</td>
<td>USI value.</td>
</tr>
<tr>
<td>Efficiency of boiler</td>
<td>70% -- 3 kg of steam per liter of alcohol to be distilled</td>
<td>USI value.</td>
</tr>
<tr>
<td>Boiler that can burn bagasse and other residues in place of wood</td>
<td>Yes, such a boiler is available</td>
<td>If a boiler that burns bagasse is not available, then wood must be burned efficiently.</td>
</tr>
<tr>
<td>Net energy out of the system. How much more available energy does the ethanol provide than the energy that was required to make the ethanol?</td>
<td>4 to 9 (ethanol + bagasse)</td>
<td></td>
</tr>
</tbody>
</table>


---