Closing Coffee Production Loops With Waste To Ethanol In Matagalpa, Nicaragua

By: **Jeremy C. Ferrell** & **Kristan Cockerill**

Abstract

Wet milling of coffee cherries is an effective process resulting in a high quality, high value product; however, it requires large volumes of fresh water and produces wastewater and pulp byproducts that pose environmental threats if unmitigated. A promising sucrose source is the fermentation sweet water (agua miel in Spanish) that showed an average Brix value of 12 from our sample area. These sugars can be directly fermented with conventional yeast strains, Saccharomyces cerevisiae and Zymomonas mobilis for conversion to ethyl alcohol. These sugars are the primary agent for eutrophication of adjacent water sources. Sweet water effluent samples from our study area in Nicaragua showed a pH of 4.64, ammonia nitrogen at > 10 mg/L, phosphates of 150 mg/L, dissolved oxygen of 0.01 mg/L and BOD > 200 ppm. Upon release into surface water sources, this concentrated effluent impacts aquatic life and creates ideal conditions for bacterial growth. Often, it leaches into the shallow groundwater sources, thus polluting drinking water for local communities. Health effects from consuming contaminated drinking water include skin irritation, stomach problems, nausea, and breathing problems. Surveys conducted in the study area showed a community with limited access to electricity and potable water whose greatest needs include health, education, and cooking fuels. The community was aware of negative environmental effects from wet-milling during the coffee harvest season. The objective of this study is to identify mitigation scenarios that utilize sweet water as a carbohydrate resource for conversion to bioethanol. Size of the byproduct resource base, economics of conversion, and technical and social feasibility for rural coffee producing communities are discussed. The study area for this research is an organic coffee farm (Finca Esperanza Verde, FEV) and surrounding communities in Matagalpa State in the central highlands of Nicaragua.

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J. Ferrell *, K. Cockerill

Energy for Sustainable Development, USA

A B S T R A C T

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Keywords:
Coffee
Sweet water
Wet-milling
Ethanol
Biofuels
Nicaragua

Introduction

The coffee bean has been used for beverages since the 9th century and today coffee is consumed in mass quantities throughout the world. Coffee offers an excellent example of the complex nature of sustainable development as it intertwines issues of economics, social equity, and environmental concerns. The leading coffee producing regions are in the developing world and although growing coffee provides essential income to millions of people, unmanaged wastes from processing the crop threaten the environment and human health in these already impoverished regions.

Using coffee-based communities in Nicaragua as a case study, this paper reports on a project designed to assess the technical, economic and social feasibility for turning coffee waste into a clean burning fuel to replace wood in a closed loop system to address environmental and human health issues. In terms of GDP per capita, Nicaragua is the second poorest country in the Western Hemisphere and coffee is one of its leading exports (IMF, 2009). Farms there produced 1,600,000 bags in 2008, ranking Nicaragua 13th in world coffee production (ICO, 2008). Many people who live and/or work within coffee-based communities have a subsistence existence. They often rely on non-centralized, non-municipal water sources (i.e. wells, springs) that can be contaminated from coffee waste products. Rural Nicaraguans rely on un-vented, indoor wood burning cooking stoves and the World Health Organization has concluded that breathing this smoke can damage lung tissue and contribute to chronic obstructive pulmonary disease, especially in women (WHO, 2006). This also requires that they spend considerable time gathering wood for cooking, which has a negative effect on quality of life and potentially stresses local ecosystems from over harvesting. Additionally, these families rely on the land to cultivate their own food crops and therefore, protecting ecosystem services is essential to maintaining health in these communities.

Depulping and wet milling

The processing method determines the coffee's final taste and there are three typical methods— dry, semi-wet and wet. Because it

* Corresponding author. Tel.: +1 828 773 6124; fax: +1 828 262 6553.
E-mail address: ferrelljc@appstate.edu (J. Ferrell).

produces a higher quality coffee, the wet method is the most common and requires large quantities of clean water, on average using 3000–4000 l of water per 240 kg coffee (Clay, 2004). This water is necessary for 'depulping' the coffee beans. The fruit from the coffee tree is often called a cherry and each cherry typically contains two seeds that once processed, become the coffee beans we recognize. At harvest, the seeds are 'depulped' or mechanically separated from the fruit. As with all agricultural processes, the separation is not perfect; some fruit remains attached to the seed. The depulped seeds then ferment from 24 to 48 h in holding tanks, loosening any remaining fruit and allow the residual fruit juice to drain out. This juice is referred to as **sweet water** or *agua miel* in Spanish.

Next, fresh water is used to wash the seeds and float out the remaining fruit and lower quality beans. In more mechanized wet processing the coffee goes directly from depulping to further water-aided fruit separation. The seeds are still allowed to ferment as fermentation is considered by many to be a crucial step in developing the proper final coffee flavor. After washing, the coffee is dried on-site (often on simple screen racks) to approximately 40% moisture content. While drying, the beans are sorted into three grades based on size, color and uniformity. Upon sufficient drying, the beans are transported to a commercial drying facility where the moisture content is reduced to 10 to 12% (Laube, 2009). In Nicaragua, facilities typically use cement patios or sheets of black plastic to dry the coffee. In addition, the dryers will ensure that the remaining hull or 'parchment' is removed from the coffee. After final drying and shelling, the coffee beans are ready for export, shipment, or roasting. Fig. 1 depicts the process.

Byproducts from this process result in rinse water, pulp, sweet water, and wastewater containing residual mucilage, a thick syrup-like substance found in the cherries. Rinse water is innocuous other than the quantity required, which is approximately equal to the volume of cherries. Sweet water and waste water though produced at different times during processing are typically combined at discharge. While the wastewater contains higher levels of ammonia, phosphates, and carbohydrates relative to the fresh water, it is the sweet water that contains levels of organic matter responsible for polluting surrounding water bodies (Hearne et al., 2006).

Depending on effluent handling, wastewater can leach into the shallow groundwater sources, the drinking water sources for surrounding communities. A 2006 study around the coffee processing plant in Zimma zone of Ethiopia found downstream concentrations of BOD, phosphate, nitrate, and suspended solids from point source discharge to be much higher than permissible limits by the World Health Organization (Haddis & Devi, 2008). People in the communities surrounding this plant reported skin irritation, stomach problems, nausea, and breathing problems from consumption of polluted water (Devi et al., 2008).

Typically, small processing facilities do not have means to treat the waste water before releasing it into the environment. Additionally, there are few environmental regulations applied in many coffee growing regions and those that do exist are not enforced (Clay, 2004). Some mid-to large- scale facilities mitigate environmental contamination by piping processing waste water to underground holding tanks where it is treated similarly to municipal sewage, using settling tanks and anaerobic digestion (Quetzal, 2009). However, at the community-scale, this is not common practice.

Byproduct management and conversion

The good news is that byproducts from coffee wet-milling are high in carbohydrate content, making them suitable feedstocks for the production of feeds, vinegar, biogas, protein, and compost (Rathinavelu and Graziosi, 2005). The concept for a closed loop coffee system is not new. Fritjof Capra included a concept diagram in *The Hidden Connections* illustrating the remediation potential of coffee wastes and conversion to biomaterials in an agricultural context (Capra, 2002). However, the specific details for closing this loop have not been extensively studied. Fig. 2, inspired by *Hidden Connections*, charts the industrial ecology aspects of closed loop coffee production.

Pulp from dehulled cherries is commonly treated as waste, heaped into piles and left to unmanaged decomposition. Trials in India have shown pulp to be an effective livestock feed, direct or ensilage, comprising up to 15% of daily rations in hogs and dairy cows (Rathinavelu and Graziosi, 2005). Ensiled and partially dried pulp has shown potential as a substrate for mushrooms, including high value species such as Shitake, Lin-chi, and Oyster. Pulp also can be composted on-site, mixed with animal manures and dry materials or fed to composting worms, *Eisenia foetida,* in vermiculture systems. These systems are gaining momentum in Nicaragua to produce a liquid fertilizer, condensate or compost tea, and soil amendment that are used for fertilizing the coffee plantation (Quetzal, 2009).

Anaerobic digestion of waste waters and ground pulp can be used to produce biogas. These wastes are usually added to a manure-based digester in a linear plug flow system, where input and output volumes are equal. Thus, introduced waste water with high nutrient load, pushes out effluent with relatively low nutrient load. Hydraulic retention time, or plug time, is critical for efficient conversion of sugars and organic compounds to carbon dioxide and methane (Dinsdale et al., 1996). Low cost bag-style digesters are most common in Latin America utilizing a plastic membrane over a trench or lagoon with earth, concrete, or plastic-lined bottom. The plastic membrane builds positive pressure as it expands with gas which can be used directly in a stove or boiler application. This system, however, has limited gas storage capacity. A private company *Llama Sana* (Healthy Flame) which designs, builds, and provides technical assistance for biodigester development in Nicaragua is actively marketing its products to coffee producers (Chinchilla, 2008). These digesters have been widely implemented in coffee growing regions around the world where coffee wastes are added to seasonal feedstocks (Bombardiere, 2006).

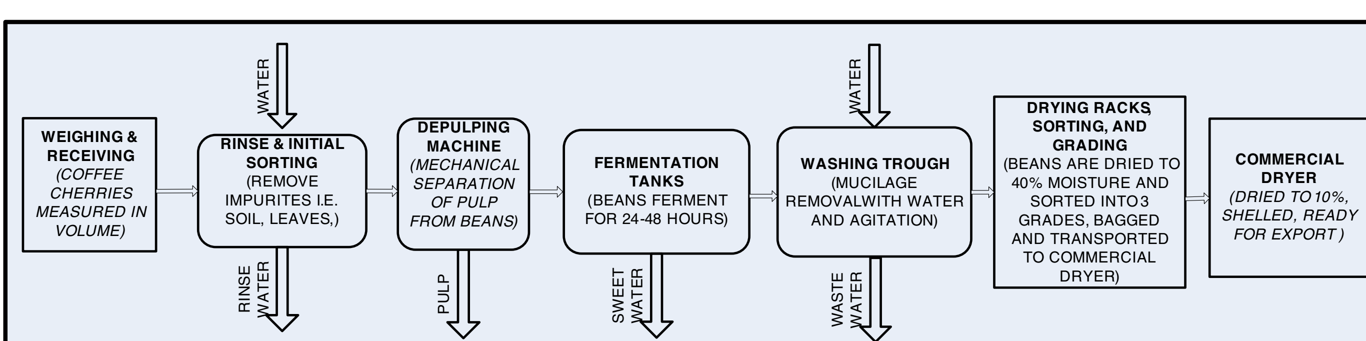

Fig. 1. Wet milling flow chart.

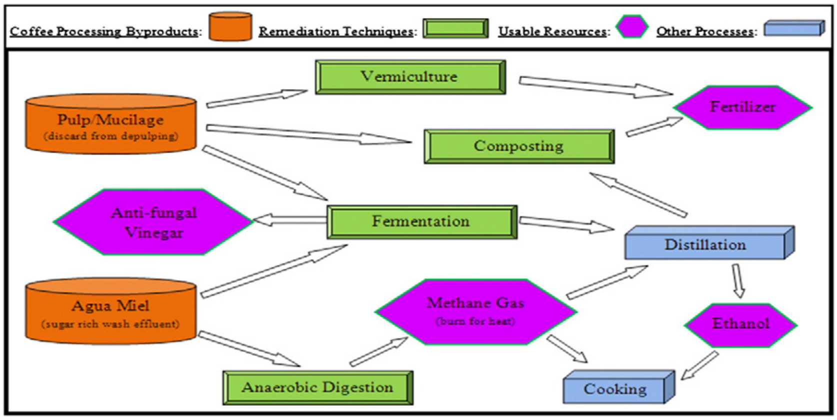

Fig. 2. Potential uses for coffee processing byproducts.

Conversion of coffee byproducts to ethanol has been underdeveloped as a route for energy production and water remediation (Rathinavelu and Graziosi, 2005). This can be attributed to the capital cost for equipment, energy requirements of distillation, and (in India) social issues related to alcohol abuse (Rajvanshi et al., 2007). Additionally, the sweet water resource is seasonal and would need to be augmented by other materials to make for year-round production. One potential alternative is a scenario that marries anaerobic digestion and ethanol fermentation into a single system (Bello-Mendoza and Castillo-Rivera, 1998). Thus, biogas produced during anaerobic digestion can be used as a source of distillation heat during ethanol production, such as depicted in Fig. 2. The fermentation byproducts (wash and yeast) acquired during ethanol fermentation and distillation could be used as feedstock for the anaerobic digester. These technologies work congruently.

Sustainable development considerations

Many proposed coffee remediation techniques have been technically successful, but long-term implementation has been difficult. For example, many composting programs have effectively remediated coffee wastes, but failed over time due to unmet maintenance requirements (Daviron, 2005). Therefore, while considering the best technical approach, the team also recognized that the developing world is littered with well-intentioned advanced technologies that were inappropriately placed. We understood that the potential for transforming coffee producing regions could only be realized by looking at the entire system: the economic and social implications as well as the technical aspects of developing a closed loop process that would improve environmental conditions.

A truth in altruistically minded projects to benefit the developing world is that those helping to implement new technologies and practices are often not the ones to maintain, operate, and/or continue those creations. The research team relied on ideas from other programs like Carnegie Mellon University's TechBridgeWorld, whose Director Bernardine Dias has noted that, “It's about empowerment rather than just dumping technology” (Naone, 2007). We designed the project to focus as much on learning from the Nicaraguan people, as it focused on obtaining the chemical samples and analyses needed to determine the potential of proposed technologies and to understand the true nature of the challenge of effective wastewater remediation.

This research project built on previous work showing that biogas systems have successfully incorporated coffee wastes as a seasonal feedstock (Bello-Mendoza and Castillo-Rivera, 1998; Bombardiere, 2006; BTG, 2010; Chinchilla, 2008; Dinsdale et al., 1996) and then asked the following questions:

- Is it technically feasible to produce biofuel from small-scale coffee processing?
- Is it socially and economically feasible to implement a closed-loop system for converting coffee waste to biofuel on small-scale farms?

Methods

Data for the study was collected over two trips to Nicaragua and fermentation studies performed in a chemistry laboratory at Appalachian State University. Several members of the research team traveled to Nicaragua and visited Finca Esperanza Verde (FEV), an organic farm with average annual production of 5455 kg/season (beans ready to sell) and Estate Quetzal, a large plantation with average annual production of 5,228,000 kg/season. This production range of approximately three orders magnitude is representative of the small and large coffee producers in Nicaragua. Fig. 3 shows a political map of Nicaragua (courtesy US Department of State), and the Matagalpa Region (courtesy Google Maps).

At these farms and in the surrounding communities, team members conducted surveys with workers and residents in May 2008 and January 2009. Water testing was conducted in the coffee processing season during January 2009 and beans were collected to bring back to the laboratory for bench scale tests.

Surveys

In late May 2008 data were gathered from 13 individuals who worked on one of the coffee farms or lived in nearby communities. Respondents were asked about their primary sources for cooking fuel, their access to electricity and access to running water. They were also asked if they knew what biogas and ethanol are. If the respondent did not know, the fuels were described and then respondents were asked for their impression of these energy sources. Finally, respondents were asked what the most immediate needs were in their community.

In January 2009, 18 people not included in the May survey were interviewed. In addition to the questions from the May 2008 interviews, this group was also asked how much time they spend gathering firewood and if they have noticed any changes in their local environment. The interviews were conducted in Spanish by a member of the research team. Respondents were selected at random, though influenced by proximity to the coffee farm and their willingness to be interviewed (Table 1).

Water testing

To assess the water quality in the case study sites and to ascertain the potential for fuel production based on the water chemistry, wet

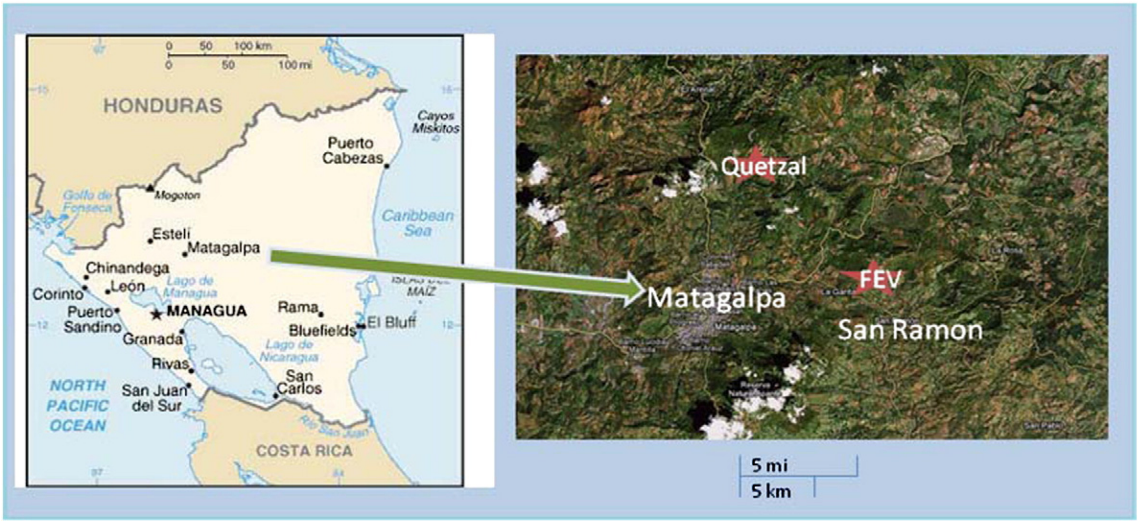

Fig. 3. Map of Nicaragua and Matagalpa Region.

chemistry testing on coffee wastewaters was performed at both farms.

At Finca Esperanza Verde potable, spring, and downstream waters were used as baselines for comparing the coffee wastewaters. Testing occurred on January 4th, 2009 during the peak of the harvest season. This site incorporates a series of three stair-step lagoons to capture effluent and allow soil infiltration. Effluent is piped to the first lagoon, where once full it spills into the next. The effluent from wash one and two are piped to the first lagoon. Wash three is straight piped into an adjacent stream. The lagoons are earth lined and slowly seep effluent. Wash samples (one, two, and three) were taken from the end of pipe before entering the lagoon. Only the first of the stair step lagoons, Lagoon 1, was sampled.

Table 2 shows the results from this testing. Sweet water samples from our study area in Nicaragua showed a pH of 4.64, nitrate >10 mg/L, phosphates 150 mg/L, dissolved oxygen of 0.09 mg/L and a calculated BOD >200 ppm, using the BOD_5 test and dilution method.

Additionally, our study site showed fresh water consumption for processing at 67–87 l per kilogram of dried beans at 10% moisture.

Estate Quetzal also has a lagoon treatment system where effluent accumulates, settles, and begins anoxic decomposition before being discharged into an adjacent river. Waste water passes through a filter system to remove particles before entering the lagoons. Data was taken at several points along the treatment process. Estate Quetzal also incorporates water recycling, a system of re-circulating pumps that reuse water from latter rinses to achieve a high concentration gradient, thereby reducing overall water consumption. This technique is used by depulpers at the largest commercial scale. Waste water is saturated with organic material, sweet water, before being discharged. The depulping process at Quetzal is continuous; therefore, no direct sample of sweet water was taken at Quetzal. In Table 3, downstream refers to the sampling point a distance of 100 m downstream from the lagoons. Upstream refers the sampling point, 100 m measurements upstream from the lagoons.

Table 1
Community survey questions.

1) What do you use for cooking? Do you have electricity/running or potable water? How much time do you spend gathering firewood?
2) Do you know what biogas is?
3) Do you know what ethanol is?
4) What is your opinion of these alternative energy sources?
5) Have you noticed changes in the environment (air, land, water) that affects the health of the people or animals?
6) What do you think are the most pressing needs of your community?

Laboratory

To conduct the bench scale assessment for the feasibility of ethanol production, the research team needed to create its own coffee waste. Therefore, fresh coffee cherries were harvested at Finca Esperanza Verde and sent with a USDA phytosanitary certificate to Appalachian State University for replication studies. The 10 kg of cherries were dehulled manually and coffee beans were allowed to ferment in an open container. After 24 h, approximately 2.1 l of sweet water was collected by straining the beans and collecting the liquid that had accumulated at the bottom of the container. A selected strain of distiller yeast, *Saccharomyces cerevisiae* was added to the liquid, placed in a sterile fermenter, and placed under air lock. The mixture was allowed to ferment for 48 h. The solution was separated using a single pass, column still with bench top equipment, resulting in a 50 mL sample.

Results

Technical feasibility

The dissolved oxygen and Brix values clearly show that the organic material is concentrated in the sweet water (*agua miel*). Brix is a measurement of dissolved sucrose by weight of a solution. The sweet water at 12°Brix translates into roughly 12% dissolved sucrose by volume, hence the English translation. Subsequent rinses show dramatically lower Brix and DO values and indicate the level of dilution. Therefore, it is necessary to isolate the sweet water waste stream before mixing with rinse water to ensure a higher value carbon feedstock. This separation can be achieved through slight modification of the washing procedure and the installation of piping to a receiver vessel below the fermentation tank. Theoretical yield of ethanol conversion is 10.8% sweet water volume, based on a sucrose content of 12% and an efficiency of 90%.

The lab-scale replication produced sweet water with Brix value ranging from 0.6 to 11% which is lower than the highest Brix we measured in Nicaragua (12%). It can be assumed that decomposition occurred in transit. The distillate produced an alcohol with density .87 g/mL, corresponding to a concentration of 62% ethanol, based the density of ethyl alcohol, 0.789 g/mL. The sample proofed an open flame test. The simple distillation unit produces a lower

Table 2
Fresh water and wastewater sampling. Finca Esperanza Verde, 1/4/2009.

	Potable water	Spring water	Fresh "agua miel"	Wash one: 1/4/09	Wash two: 1/4/09	Wash three: 1/04/09	Lagoon 1	Downstream
pH	4.3	4.39	4.64	3.87	4.00	4.45	5.04	5.98
DO (mg/L)	5.1	6.37	0.09	0.01	0.18	6.09	−0.02	5.92
NH_3 (mg/L)	0	0.1	7	>10	Undetermined	1	3	1
PO_4 (mg/L)	<10	<10	110	60	Undetermined	<10	>10	<10
BRIX	0	n/a	12	1.5	0.2	0	.1–.2	0.5
Density g/L	0.98	0.98	1.025	0.98	0.98	0.98	n/a	n/a
Observations	Clear	Clear	Dark brown cloudy	Sus. solids, murky gray	Gray and cloudy	Clear w/sus. particles	Cloudy, foul odor	Clear
Water temp. (°C)	22.2	23.4	21.2	19	18.8	19	19	21.8
Air temp. (°C)	24	22.7	22	22.5	22.5	22.5	24	24

concentration of alcohol, but was chosen because of its ease in operation, low capital cost, and lower energy consumption. Single pass, "pot stills" are sufficient to produce cooking fuel grade alcohol in the range of 50–75% alcohol by volume. This mid-grade alcohol is not suitable for use in internal combustion, however is appropriate for cook stoves and has been successfully deployed in rural India (Rajvanshi et al., 2007).

Resource base

From field measurements and communication with FEV farm manager, conversion factors were determined for the various stages of coffee processing and sweet water produced. Starting with 5.6 kg of coffee cherries yields 2 kg of parchment beans at 40% moisture, which in turn yields 1 kg of green bean stage at 10% moisture (Laube, 2009). Sweet water production was observed in the field at approximately 1 l for every 9.2 kg of coffee cherries, offering a significant amount of sweet water available for fuel production. This rate is used for the economic calculations reported in a subsequent section.

Social feasibility

All of the respondents use wood stoves for some or all of their cooking. The majority use non-vented stoves. Nine survey respondents out of 31 have propane stoves as well. When asked an open-ended question about community needs six (19%) people specifically mentioned a better fuel source for cooking, 11 (35%) mentioned water quality issues and 14 (45%) said they need electricity. A few respondents also mentioned a need for improved health care and lower food prices.

When asked if they had access to running water almost 30% reported having access to municipal water. Several people noted, however, that there was often air in the lines or that the supply was shut off when it rained. About 20% said that they rely on wells and 13% use a spring. Others said that they had access, but did not specify the source. One respondent said she did not have access, one said that the family must boil their water, and one reported that their well had been contaminated and they now use a spring.

Several of the people interviewed were quite vocal about the need to improve environmental conditions in their communities. People we spoke with in the village of Yucul said that they could no longer drink the well water due to contamination from the coffee farms above. People were also aware of the impact on aquatic life, which in turn affects fishing yields. As one woman said "The wastewater washes into rivers and hurts the people and species that depend on that water and it gives rise to famine." Another perspective on how coffee production affects food supply came from one man who said "We know that wastewater from coffee production is polluting the water but people in this area are poor and have to eat, they have to have some income to buy what they need and for most, coffee picking is the only work available."

Of the 31 respondents, 42% knew something about biogas and 32% were familiar with ethanol. After the researchers explained these energy sources they asked for thoughts on applying them in the local communities. The majority of people said that they sounded like good ideas and if they were cheaper than current fuel sources it would be of great benefit. Several respondents recognized the potential for these fuel sources to help their communities become more self sufficient. A few people suggested that the cost of this fuel would be beyond the means for their families and communities. Some noted that these alternative fuels would reduce the negative health issues from inhaling wood smoke and improve environmental conditions, but the success would depend on the scale and how the technology was implemented.

The general sense from the interviews is that the Nicaraguans are well acquainted with the complexity surrounding coffee farming and its impacts on their communities. They fully recognize the negative environmental consequences but need the economic benefits. Therefore, the response is typically positive toward the biogas/ethanol proposals as a potential way to simultaneously provide economic assistance and improve the environment. They are realistic, however, and recognize that how this technology is implemented and what it costs will be the determining factors in whether it can be successful. Given the overall level of positive reaction, with a carefully designed implementation process that included public education, the sweet water to ethanol concept appears to be socially feasible.

Economic feasibility

The economic feasibility of sweet water to ethanol conversion is based on scale and technology required to reach the desired end

Table 3
River water and wastewater sampling. Estate Quetzal 1/6/2009.

	Downstream	Upstream	Discharge	1st filter box	Lagoon-filtered
pH	7.3	7.3	4.75	4.79	4.22
DO (mg/L)	5.69	5.6	1.2	0.19	0.38
NH_3 (mg/L)	0.1	11.1	>10	>10 dark orange	>10 dark orange
PO_4 (mg/L)	<10	<10	30	6	Undetermined*
BRIX	0	0	0	3	0.5
Density g/mL	0.98	0.98	0.98	0.99	0.98
Observations	Slight turbidity w/few floating particles	Slight turbidity suspended particles	Yellow brown cloudy	Very dark brown	Light yellow brown
water temp. (°C)	21.5	20.8	20.5	21.1	21.1
Air Temp. (°C)	21.5	21.5	21.5	21.5	21.5

* Estimate based on propane/biogas infrastructure.

Table 4
Coffee production and resource base by scale.

	Green beans (kg/yr)	Parchment (kg/year)	Cherries (kg/yr)	Sweet water resource (L/yr)	Ethanol potential (L/yr)
1. FEV	4550	9100	25,480	2752	297
2. Cooperative	31,850	63,700	178,360	19,263	2080
3. Quetzal	455,000	910,000	2,548,000	275,184	29,720

fuel. The value for transportation grade ethanol is much higher than cooking fuel, but also has a higher capital and operational cost. The following calculations are based on a cooking fuel grade ethanol. The conversion factor to sweet water is approximately 0.83 l per kilogram of parchment beans. Parchment or *pergamino* refers to the coffee bean once depulped, washed, and dried to approximately 42% moisture content. At this point the beans are bagged and sent to a commercial drier where they will be weighed and further field dried to approximately 10% moisture before crating and shipping.

Presented in Table 4 are three distinct scales in the context of Nicaraguan coffee producers:

1) Finca Esperanza Verde, an organic/specialty coffee farm with annual average production of 9100 kg of parchment beans.
2) Coffee of Cooperative of San Ramon, Matagalpa, a collective of 7 area farms with annual average production of 63,700 kg of parchment beans.
3) El Quetzal, a conventional coffee Estate Farm with annual average production of 910,000 kg of parchment beans.

This scale factor translates to a factor of seven for the cooperative and 100 for the Quetzal Estate from the baseline of the single farm.

This scale represents three points of reference most common in coffee production in Nicaragua from the individual farm to the coffee megafarm. The following economic analysis accounts for estimated capital and operational costs, and value of the ethanol product.

Capital and infrastructure costs

The equipment listed in Table 2 allows for the three phases of batch ethanol production: mashing, fermentation, and distillation. Since our primary waste product/resource is the liquid produced from the draining of recently depulped beans, piping and pumps are necessary to move this liquid to the fermentation tank. In the fermentation tank, samples are taken to determine percent fermentable sugars, and pH. Distillers yeast is added and the liquid is stirred to ensure yeast activation. Distillers yeast with tolerance of 22% alcohol by volume production is adequate to ensure full conversion of sugars to alcohol. The pH will be corrected as necessary.

Once the fermentation phase is complete the mash liquid is transferred to the distillation tank via piping and valves. The distillation tank is outfitted with a packed column to increase ethanol purity.

Table 5
Estimate of infrastructure costs for ethanol distillation.

Item	Cost (US $)		
	Scale 1	Scale 2	Scale 3
Fermentation tank	350	700	1050
Distillation tank	500	1000	1500
Distillation column	400	800	1200
Chiller system	500	1000	1500
Receiver vessel	100	200	300
Piping and valves	250	500	750
Pumps	300	600	900
Protective structure	150	300	450
Heating system hybrid*	150	300	450
Chemistry supplies	100	200	300
Totals	$ 2800.00	$ 5600.00	$ 8400.00

* Estimate based on propane/biogas infrastructure.

Table 6
Operating costs per production year by scale.

Item	Cost (US $)		
	Scale 1	Scale 2	Scale 3
Feedstock	56	390	5573
Heating cost	25	176	2513
Labor	20	141	2016
Expendables	5	35	500
Maintenance	10	70	1000
Total	$ 116	$ 812	$ 11,602

The column is plumbed to a cross flow heat exchanger with chilled water for condensation. A receiver vessel collects the ethanol distillate. The distillation tank is also connected to the hybrid heating system that can utilize multiple fuels including biogas, ethanol, wood, and propane (Table 5).

Operating costs

Operating costs include feedstock (sweet water), process heat, labor for processing, expendables, and maintenance costs for repairs (Table 6). Heating costs are estimated on a cost of $23 per MMBtu with 50% heat transfer efficiency (NPGA, 2010).

Value of ethanol product

Ethanol pricing is quoted at $2.00/gal or $ 0.53/l from Chicago Board of Trade (CBOT, 2010) (Table 7).

Ethanol production from sweet water clearly favors the largest scale available in Nicaragua. The smaller scales show no potential for development based solely on economics. The scenario for scale three demonstrates a modest payback period that may justify the capital expenses. The end use for the fuel, either transportation or low grade cooking fuel, plays a significant role in market and price as there are many alternatives for cook fuel and few alternatives to gasoline (Table 8).

Discussion/conclusion

Turning coffee processing byproducts into a resource can reduce the amount of waste entering the environment and improve the lives of the people living in the coffee growing regions on multiple fronts. Coffee has a tremendous opportunity as a sustainable development tool as demonstrated by the *fair-trade, organic,* and *shade-grown* movements that continue to gain market share. The dramatic use of fresh water, however, during wet-milling and its lack of treatment go largely unnoticed. Remediation systems that incorporate energy production, via conversion to biofuels, stand to address the environmental threat and produce a value added product. The findings from this project are transferable to other coffee producing countries as they also face issues of access to safe drinking water and

Table 7
Value of ethanol in US$.

Sweet water liters/yr	2752	19,264	275,200
Max. EtOh L/yr (12%/volume)	330	2312	33,024
Realized EtOh L/yr (75%)	248	1734	24,768
Value of EtOh	0.53	$/liter	
Total value of ethanol	$131	$919	$13,127

Table 8
Net annual income and simple payback.

	Scale 1	Scale 2	Scale 3
EtOH value − operational costs	$15	$107	$1525
Payback of capital costs in years	181.7	52.4	5.5

deforestation for cooking fuels. Unfortunately, this study suggests that this is only economically viable at the largest scale.

Given our results, it may be possible for a large scale ethanol production system located at a large farm like Quetzal to offer a price per liter of sweet water to encourage nearby farms to separate the resource from the effluent water, containerize it and bring it the central processing location. Sugar content could be accurately monitored with BRIX measurements and payment could be made accordingly. The large farm could then sell the cooking fuel, creating an additional revenue stream. This has the potential to create jobs in the form of "middle men" who collect the sweet water from the smaller farms and deliver the resulting fuel back to the workers on those farms. Additionally, ethanol and anaerobic digestion systems require constructing and fabrication of components. Ideally these would be manufactured in country, utilizing the local trades and encouraging new economic opportunities. In job scarce economies, such as many coffee growing regions, this presents a market based approach to address environmental and health concerns.

It should be carefully noted that any new technology that requires different equipment, e.g. new alcohol stoves, must be adopted slowly and methodically to gain support of the target population. Successful, wide-scale implementation will require outreach to the coffee growing communities. The coffee producers, fuel users and coffee consumers must all understand the implications of continuing the current production methods and recognize the potential value in the closed-loop concept.

Producing ethanol can raise social issues, as ethyl alcohol is the alcohol in beer, wine and spirit and is widely abused in rural communities, with the coffee growing regions of Nicaragua being no exception. It may be desirable or necessary to denature or poison the ethanol by adding 2% gasoline, which would increase the cost of production. There is, however, a successful ethanol economy in Brazil, even without extensive product denaturing. This would require a thorough investigation before an ethanol production system was implemented to prevent introducing a social problem while trying to address an energy/environmental one.

Coffee producers can use the water remediation and waste to fuel concept to further advance their sustainability score and market this to increase sales and visitors. By reducing the demand for wood as a cooking fuel, deforestation can be mitigated, while local environment and water quality can be improved in coffee growing regions.

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