The Potential of Bagasse-Based Cogeneration in the US

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Introduction

Public awareness of climate change has risen sharply in response to frequent news articles describing volatile weather patterns, rising sea levels and global warming – the Inconvenient Truth. Spurred by hurricanes and heat waves, people are beginning to demand that companies take responsibility for their pollution. The Kyoto Protocol has gone into effect, and carbon markets such as the Chicago Climate Exchange have been established around the world. Rising oil prices has sparked renewed interest in alternative energies, particularly biofuels.

One viable option for biofuels is sugarcane bagasse. This paper seeks to examine the power generation potential of bagasse within the US, while drawing upon examples of similar bagasse power generation projects implemented in India and Brazil under the Kyoto Protocol's Clean Development Mechanism (CDM).

Bagasse Production

Sugarcane processing is a two-stage process. First, sugarcane mills extract the sugar from the sugarcane plants. This raw sugar can then be sent to refineries for purification.

In a sugarcane mill, freshly harvested sugarcane is shredded, mixed with water, and crushed between heavy rollers to extract the juice, which is high in sucrose (10-15%)[1]. The remaining fibrous material is called bagasse.

[1] Wikipedia (2006). "Sugarcane". http://en.wikipedia.org/wiki/Sugar_cane

Sucrose accounts for about 30% of the chemical energy stored in the mature plant. The leaves and stems account for another 35%, and bagasse accounts for the remaining 35%[2].

US Sugarcane Production

The US is one of the world's largest producers of sugarcane. Table 1 shows the top 20 sugarcane producers in 2005.[3] The US was 10th, producing 25.8 million tons (MT).

Figure 2 shows the US sugarcane production by state from 2002-2004[4]. Note that sugarcane production has fallen from 36.6 MT in 2002 to 33.9 MT in 2003, 29.3 MT in 2004 and 25.8 MT in 2005. The decline is largely due to low prices and structural changes in the industry[5].

Table 1[3]
Top 20 World Sugarcane Producers, 2005

Rank	Commodity	Production (Int $1000)	Production (MT)
1	Brazil	8,725,914	420,121,000
2	India	4,825,286	232,320,000
3	China	1,819,452	88,730,000
4	Thailand	1,029,610	49,572,000
5	Pakistan	981,260	47,244,100
6	Mexico	937,277	45,126,500
7	Colombia	827,669	39,849,240
8	Australia	794,369	38,246,000
9	Philippines	643,870	31,000,000
10	***United States of America***	***535,948***	***25,803,960***
11	Indonesia	529,635	25,500,000
12	South Africa	451,230	21,725,100
13	Argentina	400,861	19,300,000
14	Guatemala	373,860	18,000,000
15	Egypt	339,278	16,335,000
16	Viet Nam	311,550	15,000,000
17	Cuba	259,625	12,500,000

[2] Wikipedia (2006). "Ethanol Fuel in Brazil". http://en.wikipedia.org/wiki/Ethanol_fuel_in_Brazil
[3] Food and Agricultural Organization of the United Nations (FAO). "Major Food and Agricultural Commodities and Producers: Sugar Cane, 2005". http://www.fao.org/es/ess/top/commodity.html
[4] USDA-NASS Agricultural Statistics 2005. "Chapter II: Statistics of Cotton, Tobacco, Sugar Crops, and Honey". http://www.usda.gov/nass/pubs/agr05/05_ch2.PDF
[5] Jacob, James (2006). "Ethanol from Sugar: What are the prospects for U.S. sugar co-ops?" *Rural Cooperatives* 73.5. http://www.rurdev.usda.gov/rbs/pub/sep06/ethanol.htm

18	Venezuela,Bolivar Rep of	182,776	8,800,000
19	Peru	147,467	7,100,000
20	Iran, Islamic Rep of	135,005	6,500,000

Sugarcane is primarily produced in four states in the US – Florida (FL), Hawaii (HI), Louisiana (LA), and Texas (TX). In 2004, these four states combined to produce 29.3 million tons (MT) of sugarcane (Figure 2). FL and LA were the largest producers, accounting for 14.3 MT and 11.2 MT, respectively. However, the yields in HI (91.9 tons/acre) and TX (39.9) were higher than FL (33.9) or LA (24.0). In total, 952,000 acres of land were used for sugarcane plantations.

Figure 2[4]

Table 2-27.—Sugarcane for sugar and seed: Area, yield, and production, by States, 2002–2004

State	Sugarcane for sugar and seed [1]								
	Area harvested			Yield of cane per acre			Cane production		
	2002	2003	2004	2002	2003	2004	2002	2003	2004
	1,000 acres	*1,000 acres*	*1,000 acres*	*Tons*	*Tons*	*Tons*	*1,000 tons*	*1,000 tons*	*1,000 tons*
For sugar:									
FL	442.0	419.0	403.0	38.3	39.3	33.8	16,929	16,467	13,621
HI	21.3	19.9	21.5	99.0	102.0	96.0	2,109	2,030	2,064
LA	465.0	450.0	430.0	28.3	26.2	24.0	13,160	11,790	10,320
TX	43.6	41.7	42.7	39.1	39.7	40.0	1,705	1,655	1,708
US	971.9	930.6	897.2	34.9	34.3	30.9	33,903	31,942	27,713
For seed:									
FL	19.0	19.0	17.0	38.1	40.2	37.3	724	764	634
HI	1.4	1.4	1.6	35.5	37.3	37.0	50	52	59
LA	30.0	40.0	35.0	28.3	26.2	24.0	849	1,048	840
TX	0.9	1.3	1.3	30.0	40.2	38.0	27	52	49
US	51.3	61.7	54.9	32.2	31.1	28.8	1,650	1,916	1,582
For sugar and seed:									
FL	461.0	438.0	420.0	38.3	39.3	33.9	17,653	17,231	14,255
HI	22.7	21.3	23.1	95.1	97.7	91.9	2,159	2,082	2,123
LA	495.0	490.0	465.0	28.3	26.2	24.0	14,009	12,838	11,160
TX	44.5	43.0	44.0	38.9	39.7	39.9	1,732	1,707	1,757
US	1,023.2	992.3	952.1	34.7	34.1	30.8	35,553	33,858	29,295

[1] In Hawaii, harvest continues throughout the year and production statistics are on a calendar year basis. In other states, harvest is seasonal and the production statistics year relates to the year in which the season begins.

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The Clean Development Mechanism: Bagasse Experiences in Brazil and India

The Kyoto Protocol (KP) entered into force on 16 February 2005, the ninetieth day following Russia's ratification of the treaty, which fulfilled the treaty's requirements for enactment. The Protocol mandates strict carbon dioxide (CO_2) emissions reduction requirements for Parties that have ratified the treaty, and provides two flexibility mechanisms – the Clean Development Mechanism (CDM) and the Joint Implementation (JI) – to help Parties meet their emissions reduction requirements. CDM allows countries with Kyoto emissions reduction commitments to acquire offsets from projects located in developing countries. JI allows industrialized countries with reduction commitments to acquire offsets from projects located in other such countries. The two mechanisms are outlined and compared[6].

India and Brazil are the two largest CDM hosts to date, with 125 and 80 projects being implemented, respectively. Of these, there are 21 bagasse-based cogeneration projects in Brazil, and 7 in India[7]. By using waste bagasse as a fuel for electricity generation, the dispatch of the same amount of energy – and hence CO_2 emissions – produced by fossil-fuelled thermal plants is avoided. The CDM mechanism thus awards carbon credits to the host Parties, which they can sell on carbon markets around the world (primarily in the EU).

The projects range widely in scale. The smallest project generates only 2,082 Certified Emissions Reductions (1 CER = 1 ton of CO_2) per year, while the largest earns 85,470 CERs/yr[7]. On average, each bagasse-based cogeneration CDM project earns 23,756 CERs/yr.

This paper shall now examine one small-scale project ("Cruz Alta Bagasse Cogeneration Project (CABCP)", Brazil) and one large-scale project ("Deoband Bagasse based Co-generation Power

[6] Walsh, M., Kanaksabai, M., Ho, K. (2006). "Inclusion of Forest Carbon Sinks in EU ETS: Market Potential and Key Issues"
[7] Clean Development Mechanism, UNFCCC (2006). "Registered Project Activities". 12/1/2006. http://cdm.unfccc.int/Projects/registered.html

Project", India) to form a reference for the possible implementation methodologies and CO_2 emissions reductions from bagasse-based cogeneration projects in the US.

Small-Scale Bagasse: Cruz Alta Bagasse Cogeneration Project (CABCP), Brazil[8]

The Cruz Alta Bagasse Project consists of increasing efficiency in the bagasse cogeneration facility at Cruz Alta sugar mill. With the implementation of this project, the mill is able to sell electricity to the national grid, avoiding the dispatch of the same amount of energy, along with its associated CO_2 emissions, produced by fossil-fuelled thermal plants to that grid.

Using the steam-Rankine cycle as the basic technology of its cogeneration system, for achieving an increasing amount of surplus electricity to be generated, Cruz Alta began its efforts in two phases, which are:

- **Phase 0 (until 2002):** Until 2002, Cruz Alta did not use to commercialize electricity. It had two 4 MW and one 2,4 MW backpressure turbo-generators installed and active, totalling 10,4 MW installed capacity. To supply steam, three 22 bar boilers were used.
- **Phase 1 (2003):** In Phase 1, Guarani installed a 21,8 MW backpressure turbo-generator and a 63 bar boiler in Cruz Alta, while deactivating one 2,4 MW backpressure turbo-generator and putting a 22 bar boiler on stand-by, with total capacity in this phase reaching 29,8 MW.

The efficiency improvements allow the project to deliver at least 51.360 MWh/yr between 2003 and 2012 to Companhia Paulista de Força e Luz, a leading electricity distributor in Brazil. The displacement of this amount of fossil-fuelled electricity will generate 70,427 CERs from 2003-2010, or 10,061 CERs/yr.

Large-Scale Bagasse: Deoband Bagasse based Co-generation Power Project, India[9]

The Deoband Bagasse Cogeneration Power Project utilizes sugar mill generated bagasse to generate steam and electricity for internal use and to export the surplus electricity to the Uttar Pradesh Power Corporation Limited (UPPCL) grid (part of Northern regional grid). By displacing carbon intensive grid energy with a renewable, carbon neutral energy source, the project activity reduces carbon dioxide emissions over the project life.

The plant is designed to operate with boiler outlet steam configuration of 87 kg/cm^2 and 515^oC. The plant is designed to operate at a 120 tons-per-hour (TPH) nominal capacity boiler with the super heater outlet steam parameters of 87 kg/cm2 and 515^oC and a double extraction cum condensing type turbogenerator of 22 MW capacity, using bagasse as the fuel. The project will export 16.17 MW during sugar cane season and 19.16 MW during off-season. A crushing season of 175 days and non-crushing/off-season period of around 95 days is envisaged for project activity operation. Over a period of 10 years, 927.40 million kWh of fossil-fuelled electricity would be displaced, generating 854,695 CERs, or 85,470 CERs/yr.

The bagasse to be used as the feedstock for project activity is supplied by the nearby mills. Considering an average of 30.5% bagasse, and a crushing rate of 350 TPH of sugarcane, the bagasse generated in the TEIL Deoband sugar facility is 106.75 TPH. Out of this, 46.72 TPH would be used in the new cogeneration plant, and 11.04 TPH would be saved for off-season

[8] Clean Development Mechanism, UNFCCC (2006). "Project Design Document: Cruz Alta Bagasse Cogeneration Project (CABCP)". http://cdm.unfccc.int/Projects/DB/TUEV-SUED1135342380.37/view.html
[9] Clean Development Mechanism, UNFCCC (2006). "Project Design Document: Deoband Bagasse based Co-generation Power Project". http://cdm.unfccc.int/Projects/DB/TUEV-SUED1156433275.07/view.html

requirements. It is envisaged that approximately 29,050 tons of bagasse would be purchased every year for off-season operations of the cogeneration plant. In total, about 230,000 tons/yr of bagasse will be used to provide 91.46 million kWh, or 0.396 MWh/ton-bagasse.

US Example: Okeelanta Cogeneration Facility, FL[10]

The Okeelanta Cogeneration Facility (OCF), owned by Florida Crystals, is a bagasse- and wood-fired cogeneration plant located in Palm Beach County, FL, adjacent to the Florida Crystals Okeelanta Sugar Mill and Refinery. The plant delivers 68 MW during the sugarcane milling season, and 80 MW during the rest of the year, and 74.9 MW net. During the milling season, the primary fuel is bagasse; during the rest of the year, the fuel is processed wood waste.

The OCF consists of three stoker-fired boilers and one turbine/generator. Each ABB-CE boiler is capable of producing 440,000 lb/hr of steam at 1,565 psig/955° F. The turbine is an MHI/Westinghouse design 3,600 rpm, extraction condensing, down exhaust steam turbine directly coupled to a two pole synchronous 13.8 kV, 60 Hz generator.

During the milling season, the OCF handles 24,000 tons of sugarcane per day. The average heating value for bagasse fired at the facility is approximately 3,700 Btu/lb, with moisture content of 51% and ash content of 2.4%. The bagasse is obtained from the adjacent Florida Crystals sugar processing facility, which processes sugarcane harvested from 90,000 acres of fields surrounding the plant. Each year, the OCF processes and burns 950,000 tons of bagasse to provide 204.5 million kWh, or 0.215 MWh/tons-bagasse.

US Bagasse Potential

Drawing from the experiences of Brazilian, Indian and Florida projects, it is clear that bagasse-based projects are able to provide sustainable electricity, thereby avoiding the dispatch of fossil-fuelled electricity and its associated CO_2 emissions. It is also clear that high-efficiency steam cycles must be employed to maximize the potential of bagasse-based power.

If we take the aforementioned figure that 35% of harvested sugarcane results in bagasse, then one estimate of the 2005 US production of bagasse is 35% * 25.8 = 9.0 million tons (MT). For simplicity, it is assumed that 9.0 MT/yr of bagasse will be generated in future years.

Assuming the experiences from the Florida Okeelanta Cogeneration Facility (OCF) and the Indian Deoband Cogeneration Project (DCP) can be replicated, between 0.215 and 0.396 MWh of electricity can be generated per ton of bagasse. Using a conservative estimate that only 20% of the 9.0 MT of bagasse each year will be used in cogeneration facilities similar to OCF and DCP, between 388,590 and 714,400 MWh of bagasse-based electricity can be generated each year.

In 2005, the US power sector emitted 2,513,609 thousand tons of CO_2 while producing 4,054,688 thousand MWh of electricity[11], which translates into 0.620 tons-CO_2/MWh. Thus, the displacement of between 388,590 and 714,400 MWh of electricity would reduce CO_2 emissions

[10] Bioenergy Update (2005). "The Florida Crystals' 75 MW Okeelanta Cogeneration Plant". *Bioenergy Update* 7.5 (May 2005). http://www.bioenergyupdate.com/magazine/security/Bioenergy%20Update%2005-05/bioenergy_update_May%202005.htm
[11] Energy Information Administration (2006). "Electric Power Annual". 2006. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html

by 240,900 to 442,880 tons. While this forms only a small percentage of the current emissions, it is a significant, non-zero contribution nonetheless.

Revenue Potential for US Bagasse-Based Projects

US-based bagasse cogeneration projects have two income streams:

- *Sale of wholesale electricity*: The sale of 388,590 – 714,400 MWh of electricity to the national grid is a significant source of income for the bagasse-based power industry. The average price for industrial electricity in 2005 was 5.73 cents/kWh[11]. Thus, potential revenues for the industry could amount to US$22.3 - US$40.9 million.
- *Accreditation and sale of carbon credits*: US-based bagasse cogeneration projects can accumulate carbon credits through certification by either the Kyoto-Protocol-based Joint Implementation (JI), or the Chicago Climate Exchange (CCX).
    - *Joint Implementation*: A foreign sponsor from an Annex I Party must finance or co-finance the project. Carbon credits earned are called Emissions Reductions Units (1 ERU = 1 ton of CO_2), and they can be sold over-the-counter (OTC) or traded on European carbon exchanges, e.g. ECX, Nordpool, Powernext, EEX, or EXAA. Current prices are roughly €8/ton-CO_2.
    - *Chicago Climate Exchange*: For a domestically sponsored project, credits will likely have to be issued by CCX. These credits may then be traded on CCX's carbon exchange. Current prices are roughly US$4.25/ton-$CO_2$.

Thus, depending on the sponsor and the accrediting organization, revenues from the sale of carbon credits may range from US$1.02 million to €3.54 million (US$4.70 million).

Conclusion

Bagasse-based power has been implemented successfully in Brazil and India (under the Kyoto Protocol's Clean Development Mechanism), as well as in Florida. Experiences from these projects indicate that high-efficiency steam cycles need to be employed to take full advantage of bagasse-based power. Florida Crystals' Okeelanta Cogeneration Facility (OCF) and the Indian Deoband Bagasse based Co-generation Power Project (DCP) are able to generate 0.215 and 0.396 MWh/ton-bagasse.

The US was the 10th largest producer of sugarcane in 2005, producing a total of 25.8 million tons (MT). Through the processing of this sugarcane into sugar, 35 wt.-% of the sugarcane plant becomes bagasse. Thus, 9.0 MT of bagasse were generated in 2005.

Applying the power-generating rate of OCF and DCP, along with a conservative 20% estimate for the fraction of bagasse used for power generation, 388,590 – 714,400 MWh of bagasse-based power can be generated each year. The displacement of an equal amount of fossil-fuelled power will reduce carbon dioxide (CO_2) emissions by 240,900 – 442,880 tons.

Revenues for US-based bagasse-based power projects will come from two sources: sale of electricity (US$22.3 – US$40.9 million potential revenues), and the accreditation and sale of carbon credits (US$1.02 – US$4.70 million).

References

1. Wikipedia (2006). "Sugarcane". http://en.wikipedia.org/wiki/Sugar_cane

2. Wikipedia (2006). "Ethanol Fuel in Brazil". http://en.wikipedia.org/wiki/Ethanol_fuel_in_Brazil

3. Food and Agricultural Organization of the United Nations (FAO). "Major Food and Agricultural Commodities and Producers: Sugar Cane, 2005". http://www.fao.org/es/ess/top/commodity.html

4. USDA-NASS Agricultural Statistics 2005. "Chapter II: Statistics of Cotton, Tobacco, Sugar Crops, and Honey". http://www.usda.gov/nass/pubs/agr05/05_ch2.PDF

5. Jacob, James (2006). "Ethanol from Sugar: What are the prospects for U.S. sugar co-ops?" *Rural Cooperatives* 73.5. http://www.rurdev.usda.gov/rbs/pub/sep06/ethanol.htm

6. Walsh, M., Kanaksabai, M., Ho, K. (2006). "Inclusion of Forest Carbon Sinks in EU ETS: Market Potential and Key Issues"

7. Clean Development Mechanism, UNFCCC (2006). "Registered Project Activities". 12/1/2006. http://cdm.unfccc.int/Projects/registered.html

8. Clean Development Mechanism, UNFCCC (2006). "Project Design Document: Cruz Alta Bagasse Cogeneration Project (CABCP)". http://cdm.unfccc.int/Projects/DB/TUEV-SUED1135342380.37/view.html

9. Clean Development Mechanism, UNFCCC (2006). "Project Design Document: Deoband Bagasse based Co-generation Power Project". http://cdm.unfccc.int/Projects/DB/TUEV-SUED1156433275.07/view.html

10. Bioenergy Update (2005). "The Florida Crystals' 75 MW Okeelanta Cogeneration Plant". *Bioenergy Update* 7.5 (May 2005). http://www.bioenergyupdate.com/magazine/security/Bioenergy%20Update%2005-05/bioenergy_update_May%202005.htm

11. Energy Information Administration (2006). "Electric Power Annual". 2006. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html