Barbados Renewable Energy Scenario Current Status and Projections to 2010

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Abstract

Renewable energy has had a long history in Barbados. After sugar was introduced to the island in the middle of the seventeenth century, the windmill soon followed, and at the height of their popularity they were five hundred and fifty five of them at sugar plantations across the island. Sugar cane bagasse was used as the fuel to concentrate the juice and produce sugar. Several hundred multi-bladed windmills, Afanmills@, were used to pump water, but most of these have been dismantled. At the moment, the main renewable energy sources are sugar cane bagasse and solar water heaters which contribute about 15% of the island's primary energy supply. Solar photovoltaic (PV) systems are being set up and currently about 37,000 watts peak (W_p) are in operation. Solar crop dryers and solar stills for producing distilled water are also employed. The government of Barbados would like to have renewable energy contribute 40% of the island's primary energy by 2010. Projects under consideration include a 60 megawatt (MW) cogeneration plant to burn bagasse and fossil fuel, a 10MW waste combustion plant, 16MW in wind farms, 3MW of ocean thermal energy conversion (OTEC) plant, 2MW in distributed photovoltaic systems, and probably 0.5MW in wave power.

Keywords
Bagasse cogeneration, Solar water heating, Solar photovoltaic, Wind power, OTEC.

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1. Solar Water Heating

The solar energy available in the Caribbean is much greater than the energy which we use as imported fossil fuels. Table 1 shows the average solar energy received in $kWh/m^2/day$ at four Caribbean sites. Since each square metre of surface area receives about 7 kWh of solar energy on a clear day during the dry season, a 430 square kilometre island like Barbados receives 3 billion kWh on such a day. This is 1.08×10^{16} joules or the energy equivalent of about **1.87 million barrels of oil.** The Ministry of the Environment, Energy and Natural Resources, Energy Division (2000) reported that the amount of petroleum products imported into Barbados in 1999 was 2,085,937 barrels, so the solar energy received on a hot day is similar to a *year's* petroleum imports. Table 2 shows that renewable energy accounted for about 15% of the primary energy used in Barbados in 1999. Most of this insolation is radiated back into space, since the green plants use a very small fraction of it, although some of it is used to heat water in homes, hotels and other businesses.

The solar water heater industry of Barbados is one of the best known examples of the exploitation of a renewable energy technology in the Caribbean. This was started in the 1970's by Mr James Husbands of Solar Dynamics and Mr Peter Hoyos of SunPower, the two leading local manufacturers. In both cases, the driving force was economic. St John (1993) reports that Mr Hoyos performed the simple experiment of switching off his electric water heater for two months and observed the effect it had on his electricity bill. The industry benefitted from the Fiscal Incentives Act of 1974 which allowed the manufacturers to benefit from import preferences and tax holidays. Husbands (1995) points out that in 1980 when the late Prime Minister Tom Adams introduced the Homeowners Tax Benefit which allowed the homeowner to claim the cost of the solar water heater on his income taxes, the industry received a major boost. This results in a major surge in sales in December as people try to beat the end-of-year deadline in order to qualify for the rebate.

For the year 2000 with about 32,000 solar water heaters installed, if each one saves 4,000kWh per year, the total electricity saving is 128 million kWh. At 154US/kWh, the financial savings to the consumers is $19.2 million US/year. Since most people in the other Caribbean islands use electricity to produce hot water, at 3.6MJ/kWh, 5.8GJ/barrel of oil and an overall efficiency of 35% for the electricity generation, transmission and distribution system, this represents a heating equivalent of 227,000 barrels of oil. In the year 2000, the average price of oil was about $30US per barrel, so the foreign exchange saving to the island was about $6.8 million US. This is for purely financial gains, it does not allow for the environmental advantages of not having to burn fossil fuel fuels to generate the required electricity with the concomitant production of carbon dioxide, sulphur dioxide and the oxides of nitrogen (CO_2, SO_2 and NO_x). The first of these is the dominant greenhouse gas and the others cause acid rain. The Barbados Light and Power (BL&P) Company also benefits by not having to produce the 128 million kWh, which is about 19% of its 1998 production of 658 million kWh. These 32,000 solar water heaters are therefore worth 30 to 35MW of additional electric generating capacity.

This is the saving which the solar water heater industry is achieving for Barbados which has a population of about 260,000. If we extend it to a larger territory such as Jamaica with a population of 2.5 million, then the saving would be about ten times as much. Jamaica now uses about one third of its foreign exchange earnings to pay for imported fuel, so the recent decision of the government of Jamaica to encourage solar water heating, especially in the hotel sector, makes sound economic and environmental sense. Other Caribbean institutions such as the Caribbean Hotel Association and the Caribbean Tourism Organisation are now encouraging hotels in the region to use solar water heating and benefit from using this clean technology. Renewable energy is particularly suited for small islands and Jensen (2000) has reported on the success stories of its applications in these locations.

Even though many people in the Caribbean describe hot water as a marginal luxury, one needs it for the tourist industry which is now the biggest industry in the region, so all of our tourism plant should be heating water with solar energy or by heat exchangers connected to the central air conditioning systems where the heat which is removed from rooms occupied by guests is used to heat their hot water, this system is already employed by hotels in Aruba.

2. Bagasse Cogeneration

The sugar industry in Barbados faces an uncertain future. The current mood in the World Trade Organisation suggests that the preferential rates paid for sugar from the former colonies of member states of the European Union will be phased out by 2007, and given that our costs of production are much higher than the world market price of sugar, we now need to maximize the value which we derive from our sugar cane. Gooding (1988) points out that sugar production is one of the few agricultural processes where the energy output is greater than the input. It should therefore be possible to use the excess energy, most of which is contained in the bagasse, to produce electricity for sale to the national grid. In a traditional sugar factory, there is little attempt to optimise the process, so that the energy contained in the bagasse is transformed into a saleable commodity. Traditionally, the sugar factory burned bagasse and its boilers produced steam for generating electricity used by the factory, and processing the sugar cane into sugar. A large fraction of the energy is used to evaporate water from the juice to concentrate it to the point where sugar crystallizes and since this requires low pressure steam, no serious attempt was made to generate high pressure steam for efficient electricity generation because the price received for electricity by the sugar factories was not high enough to provide an incentive.

In recent years, efficient process engineering developed by the French firm SIDEC separated the generation of electricity and process steam from the other activities of the sugar factory and made them into a separate entity, a co-generation plant. Since bagasse is only available during the crop season for about four months per year, the co-gen plant has to use another fuel for the other eight months. SIDEC was originally setup in the 1980's to improve the utilisation of French coal, hence they use coal as the second fuel in most of their co-gen plants. They have developed these efficient plants where the boilers run at high pressure and temperature to give a good Carnot efficiency in the steam turbines which are the prime movers for the electricity generators. More than 35 of these projects are operating in France, including some at mills that process sugar beet. This technology is used in the overseas departments of Réunion and Guadeloupe, as well as in Mauritius. There are two plants in Réunion, one at Le Gol and the other at Bios Rouge, while the one which the author visited in Guadeloupe is at Le Moule, on the eastern side of Grande Terre. This system has a normal output of 50 megawatts (MW) peaking to 64 MW. Mauritius produces 5.8 million tonnes of cane per year which yields 600,000 tonnes of sugar. Their first bagasse/coal plant was commissioned in 1985 and fed some 90 gigawatt hours (GWh) per year into the grid, about 50% of which was derived from bagasse. With the addition of a new turbo-alternator in 1998, about 20% of their national electrical energy was derived from bagasse in 2000. Of their total installed capacity of 480 MW, 59 MW is hydro and 132 MW is bagasse/coal. After several years of negotiations, their Bagasse Energy Development Programme was initiated in 1991. On Réunion, the total installed capacity is 437 MW, of which 126.6 MW is hydro and 118 MW is bagasse/coal. Réunion produces about 2 million tonnes of sugar cane per year which gives 640,000 tonnes of bagasse/year. With a calorific value of 7700 kilojoules/kg, this is equivalent to about 120,000 tonnes of fuel oil. The Bois Rouge plant was commissioned in 1992 and the Le Gol plant in 1995. Bagasse now accounts for 16.5% of their electricity production. Table 3 summarises the generation of electricity from bagasse/coal in these three islands.

Pickering (2000) reports that the Australian sugar industry, 94% of which is in the state of Queensland, is also looking at cogeneration using bagasse. In 1997, Australia produced 5.74 million tonnes of raw sugar from 41 million tonnes of cane. Stanwell Corporation has started to build a $A40 million co-gen plant at Rocky Point Sugar Mill. Since they are aiming for CO_2 reduction credits, they will not be burning coal but will burn green waste and wood waste during the out-of-crop season. Their projected cost of electricity is $45 to $69 US per megawatt hour (MWh). In Barbados, electricity generation costs are about $55 US/MWh, so the co-gen plant will be economically viable if we can match the projected lower-to-middle range of the Australian cost.

The Barbados sugar industry is now considering setting up one new factory and phasing out the three existing old factories. The Barbados Light and Power (BL&P) company is also looking at their increased electricity demand and ways of meeting it; they have just signed the contract for an additional 20 MW gas turbine and will need to decide within a year whether to go for additional gas turbines, to set up more low speed diesel capacity in 2003, or to join the sugar industry in setting up a 60 MW co-gen plant next door to the new factory. Late in 1999, the sugar industry sent a team to Guadeloupe to see the plant at Le Moule, and at the end of February 2000 Mr Frank McConney managing director of the holding company, and Mr Andrew Gittens, CEO of BL&P, visited it and were impressed with the technology. However, delays with the government making a decision have resulted in BL&P deciding to proceed with a 30MW low speed diesel for 2003. If the government and the sugar industry are persuaded that a new sugar factory should be constructed, then the cogeneration plant should be built next door to it. If the electricity demand continues to grow and enough land is retained to produce about 550,000 tonnes of cane, then a cogeneration plant on the scale of the Guadeloupe installation can be set up between 2005 and 2007.

At the moment, virtually all of the electricity used in Barbados is made in thermal plants burning fossil fuels such as fuel oil or natural gas. The 32,000 solar water heaters which have been installed are saving about 19% of BL&P's production, assuming that electricity would have been used to produce the hot water. In 2000, peak electricity demand in Barbados was 124 MW and we produced 537,000 tonnes of cane and 58,333 tonnes of sugar. The sugarcane figure is similar to that produced by Guadeloupe (563,600 tonnes cane and 56,299 tonnes of sugar). The major differences are that Guadeloupe used one factory while Barbados used three, they kept 4,500 tonnes of sugar for local consumption, their sugar production cost is about $500 US per tonne, and they burned 180,000 tonnes of bagasse in their high pressure boilers to produce steam at 80 bar and 520°C to run two turbo-generators and feed 80 GWh of electricity into the grid which is operated by Electricité de France (EDF). Guadeloupe is a bigger economy than Barbados with 421,000 people, an electricity demand of 1250 GWh per year, and a peak power demand of 200 MW. SIDEC maintains that for reliability, no turbo-generator should be more than 10% of the peak demand, which made the maximum size 40 MW. They therefore used two generator sets, each with a maximum of 32 MW, for the Guadeloupe installation. Even though they now accept bagasse with a moisture content of up to 51% water, they do not dry the bagasse with their flue gases since their boilers are so efficient (90%) that their flue gas temperature is only 140°C. Drying the bagasse would increase its calorific value, but dry bagasse dust is a fire hazard.

At Le Moule, The cogeneration plant is operated by Compagnie Thermique du Moule (CTM) and is situated next door to the Gardel sugar factory. The sugar factory no longer has boilers and generators, they get their low pressure steam from CTM at 130 tonnes per hour, 150°C and 3 bar pressure. About 90% of the steam is returned to CTM as condensate. Mr Eric Bourillon, the manager of the Gardel sugar factory maintains that the factory is much easier to operate without having to worry about furnaces, boilers and generators. He reported that after 23 years in the sugar industry using the old system and two years with the new technology, he has no desire to go back to the old way of doing things. Electricity is fed into the grid by CTM and Gardel take what they need from the grid under terms agreed on between the three parties.

Every effort has been made to make the cogeneration plant quiet and environmentally friendly. When burning bagasse, there is virtually no production of sulphur dioxide (SO_2) since bagasse contains almost no sulphur. A vibrating grate is used for bagasse and most combustion takes place above the grate. There is virtually no bottom ash; large particles in the flue gases are removed by the mechanical de-duster and returned to the furnace, while the fly ash is captured in the electrostatic precipitators. 500,000 tonnes of cane per year yield about 5000 tonnes/year of fly ash; this is sold as a fertilizer since its phosphate content is good and it is in great demand in Basse Terre where the volcanic soils are acid with a low pH and benefit from this treatment. During the combustion of coal, they use a moving grate and the bottom ash falls to the bottom. 160,000 tonnes per year of coal gives about 10,000 tonnes/year of bottom ash which is used as the sub-grade in road making. It is also sold it to a company which makes cement blocks. About 800 tonnes/year of fly ash are also produced, which is now being investigated as a cement additive. A low sulphur coal from Columbia is used to keep down emissions of sulphur dioxide. Emission of nitrogen oxides (NO_x) is low for both types of fuel since this can be controlled by careful choice of combustion conditions. Because the plant is totally automated, this is not a problem. Local environmental regulations require that records be kept of all their emissions and they normally are well under the required maximum values.

3. Photovoltaic Power

By the end of May 2001, Barbados will have about 37 kilowatts peak (kW_p) of PV installed at various sites, making us one of the leading Caribbean countries in the utilisation of this technology; the largest of these systems are listed below:

- 1100W_p at the University of the West Indies (UWI) for solar cooling.
- 17,300W_p at Harrison's Cave for running the lights.
- 3,000W_p at Combermere School for operating a computer laboratory.
- 2,000W_p at a demonstration plant installed on a 20MW BL&P gas turbine generating station at Grantley Adams airport.
- 2,000W_p at Government

Harrison's Cave, St. Thomas, Barbados

Headquarters to operate lights and provide emergency power.

- 11,100W_p at the Skeete's Bay fishing complex powering a one-tonne-per-day solar ice maker for the fisherfolk; [Figure1 shows these PV panels being installed].
- A 300W_p portable PV system is used to demonstrate the flexibility and versatility of the technology to members of the public.


Skeete's Bay Fishing Complex, St. John, Barbados

The systems at Grantley Adams airport and at Harrison's Cave are tied to the grid, while the others are stand-alone systems. The Skeete's Bay system is the largest of these and uses twenty four 200Ah, 12V lead acid batteries for energy storage. This is enough storage to allow the two half-tonne ice machines to continue to run overnight. The details of the components of this system and their costs are given in Table 4. The major reason for using stand alone systems is that this allows electricity to be available in the event that the grid is down, as may be the case after a hurricane. One of our aims is to install stand-alone PV systems at emergency shelters and places which provide other emergency services such as hospitals and fire stations so that the island is better equipped to recover from natural disasters.

With the exception of the 2kW_p system set up by BL&P, these PV systems have been financed by the government of Barbados. The Prime Minister has expressed a desire for the island to have the same image in solar photovoltaic power as it has in solar water heating. PV power is increasing at about 20% per year and the European Photovoltaic Association maintains that if yearly production can be increased from the 200MW shipped in 2000 to about 1000MW, then the economies of scale will result in a 50% reduction in the cost of PV cells. Balance of systems costs are still not coming down as fast as cell prices, but the general shortage of power in California and the Sacramento Municipal Utility District's distributed PV programme have persuaded Trace to start manufacturing inverters in Sacramento. Running a demonstration project and training personnel in PV installation and maintenance is expected to place Barbados in a position to take advantage of the rapid growth in the industry when the prices of PV become competitive with diesel generator sets in the range of 5 to 50kW.

4. Projected Renewable Energy Systems

In its special report on nuclear power, the *Economist* (2001) pointed out that the two fastest growing electricity generation technologies in the period 1990 to 2000 were wind at 25% and solar PV at 20%. In spite of the fact that France obtains about 75% of its electricity from nuclear sources and Belgium about 58%, no new nuclear power plant has been built in the USA since the Three Mile Island disaster of 1979. President George Bush and Vice-President Dick Cheney may be advocating a return to nuclear power, but energy conservation and renewable energy make far more environmental and economic sense. In addition to the renewable energy systems mentioned in Sections 1 - 3, the following are being considered for Barbados:

- 16 MW in wind turbine farms at good wind sites in northern Barbados.
- A 3 MW ocean thermal energy conversion (OTEC) plant.
- A 10 MW waste combustion plant.

- A 2 MW wave power plant. The late Prime Minister Tom Adams was very interested in this technology and we are in contact with Wavegen of the UK who have just installed a 500 kW plant on as island off the west coast of Scotland.

- 2 MW of solar PV distributed around the island. We are now looking into the feasibility of installing 500 kW (0.5 MW) at the Cave Hill Campus of the UWI.

- Setting up manufacturing facilities to produce high purity silicon for the computer chip and solar PV industries. This been discussed this with our Trinidadian and Guyanese colleagues and the possibility of a joint venture is being explored.

- Producing hydrogen from renewable energy and using it to power fuel cell vehicles, e.g. cars and buses. These emit only water and are very environmentally friendly, hence they would enhance the island's image as a green' tourist destination. Buses and cars using this technology are already operating in Germany and Canada; DaimlerChrysler, Ford and Ballard are leaders in this field.

Of these technologies, the wind turbine farms are the most advanced in terms of planning. In fact, the major barrier to their implementation is the establishment of a policy which will determine how independent power producers supply electricity to the consumer and their access to the grid.

The OTEC plant has been evaluated by a Scientific and Technical Advisory Panel of the Global Environmental Facility (GEF) and we are now considering ways of financing the pre-feasibility and feasibility studies. The main barrier here is that this will be the first megawatt sized OTEC plant, hence there are several technical characteristics which need to evaluated in a working plant. They cannot be simulated, hence the plant will have to be built and will incur the high cost associated with being low on the learning curve. Since the technology has the potential to supply terawatts of power at sites between latitudes 30° north and 30° south, these are the unavoidable costs inherent in introducing a new source of base load power, most of whose beneficiaries will be in the third world.

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Table 1: Solar Radiation in kWh/m^2 at four Caribbean Sites.

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adams Airport, Barbados	5.1	5.6	6.0	6.2	6.1	5.9	6.0	6.1	5.7	5.3	5.1	4.8
V.C. Bird Airport, Antigua	4.6	4.9	5.6	5.9	5.9	5.8	5.9	5.9	5.3	5.0	4.5	4.2
Belize City, Belize	3.9	4.9	5.5	5.0	4.9	4.8	4.6	5.1	4.8	4.6	4.5	3.9
San Juan, Puerto Rico	4.3	5.1	5.7	5.9	5.8	5.9	6.0	6.1	5.6	5.1	4.5	4.1

Table 2. Barbados Primary Energy Mix, 1999 (In Barrels of Oil Equivalent - BOE)[a]

Resource	BOE	Percent Share
A. Indigenous Energy 1. Oil 2. Natural Gas 3. Liquefied Petroleum Gas (LPG) 4. Hydro 5. Geothermal 6. Other Renewable Sources: Fuelwood Bagasse Charcoal Agricultural Waste Solar Thermal	707,564[b] 323,570 23,129 --- --- Not Available --- 229,000[c] --- Not Available 227,000[d]	61.9 10.7 0.8 --- --- --- 7.5 --- 7.5
B. Imported Energy	2,085,937	

1. Petroleum Products 2. Orimulsion	148,600	6.7 4.9
Total Energy Used	**3,037,236**	100.0

aSource: Energy Division, Ministry of the Environment, Energy and Natural Resources.

bSince the closure of the local oil refinery, this oil is exported and is not counted in the local energy mix.

cFrom a production of 172,540 tonnes bagasse and a calorific value of 7.7 gigajoules (GJ)/tonne, assuming that oil has a calorific value of 5.8GJ per barrel.

dAssuming 4000kWh per water heater per year and 32,000 solar water heaters, with an efficiency of 35% for generation, transmission and distribution of the electricity replaced.

Table 3. Bagasse/Coal Plants Operating in Tropical Islands

	Mauritius	**Réunion**	**Guadeloupe**
Installed electricity generating capacity, MW	480	437	483
Sugar cane production, tonnes	5,800,000	2,000,000	564,000
Bagasse produced	1,800,000	640,000	180,000
Bagasse/Coal generating capacity, MW	132	118	64
Percentage energy generated from bagasse	20	16.5	7

Table 4: Component, Shipping and Installation Costs for the Solar PV Ice Maker

Component or Service	**Cost ($US)**
11,000 W_p of BP Solar 275F PV cells	44,000
2 Trace SW4048 Inverters	4,800
2 Scotsman 1200AE-32A Ice Machines	10,400
9 Charge Controllers, each of 40A	1,350
24 Lead Acid Batteries, 200Ah, 12V	6,600

Circuit Breaker	550
Lightning Arrester	55
Ground Fault Protector	316
Combiner Boxes	1,000
Parallel Interface	271
Wiring and Installation	7,500
Shipping and Handling	2,000
Design and Management (10%)	7,884
Total	**86,726**