SUSTAINABLE WATER AND ENERGY RESOURCES AT COLLEGE OF MARSHALL ISLANDS

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ABSTRACT

In 2006 Beca embarked on a 5-year redevelopment project for the College of the Marshall Islands (CMI) campus in the Republic of the Marshall Islands. A feature of the Masterplan was to achieve a water utility infrastructure on campus that was as self-sufficient from the municipal water supply as possible given the island shortage of water and poor reliability of supply. Rainwater collection and treatment, RO desalination and alternative energy options for the campus were implemented.

During the period 2007 – 2011 three new classroom blocks, an administration block, college library and an energy centre were constructed. Innovative use of flexible “bladder” tanks for roofwater and treated water storage were used to provide a secure uncontaminated water supply should the buildings become flooded by adverse weather or storm surge conditions due to climate change. Because the RO plant capacity exceeds the Campus demand and there is secure potable water storage, the College has been designated as a community emergency water source.

Building air conditioning is the highest power demand on Campus. To reduce the energy demand an innovative use of seawater cooled marine chillers was trialled to replace multiple split unit air conditioners. Using the cooler seawater temperature allows the chiller to operate with greater efficiency. There is a saving of up to 20% energy compared with multiple split unit air conditioners of similar cooling capacity. Photovoltaic panels were installed on the completed buildings as part of the overall energy sustainability strategy. An initial installation of 65kW of PV panels provided some 400kWh of grid-connected power daily, which offset the 300kWh power requirements for 12 hours operation of the RO desalination water plant.

A diesel generator was installed to provide back-up power supply to the site in conjunction with the alternative energy systems. CMI intends to research the use of coconut oil as a biodiesel fuel substitute. This research may have spin-offs for other outer atolls in the production of coconut oil to provide a more sustainable income than the current copra based income.

KEYWORDS

Marshall Islands, potable water, reverse osmosis, seawater, rainwater, solar power, climate change

1 INTRODUCTION

The Republic of the Marshall Islands (RMI) is a North Pacific nation state consisting of 29 coral atolls with a total population of 62,000 (2005). Two thirds of the population live on two atolls, Majuro (the capital) and Ebeye. In 2006 the College of the Marshall Islands (CMI) in Majuro commenced a 5-year redevelopment programme of the campus to increase the educational opportunities for students. The building programme was to progressively replace the existing substandard buildings with modern classrooms, laboratories, library and administration facilities that will allow the student population at CMI to increase from 600 students to 1000 students and staff numbers to increase from 100 to 200.

The Campus Facilities Master Plan prepared by Beca in May 2006 reflected the desire by the CMI Planning Committee to achieve a utility infrastructure on campus that was as self-sufficient from the municipal supplies as possible. Alternate energy, rain water collection, water treatment concept options were included in the Master Plan report. Figure 1 shows an artist's perspective view of the completed campus.

Figure 1: Artist's Perspective of CMI Campus Redevelopment

2 WATER UTILITES

The existing CMI water utilities in 2006 consisted of freshwater from the Majuro municipal supply, ad-hoc roofwater collection to provide drinking water to some buildings and seawater flushing of toilets. There was no fire protection in the buildings and the campus relied on fire hydrants connected to the seawater reticulation system.

The utilisation of water on the CMI campus was considered as a single integrated strategy whereby the maximum use would be made of on-site resources. The water infrastructure was required to provide;

- Potable water for drinking, food preparation and personal hygiene,
- Flushing water for toilets,
- Fire protection water,

To develop the water management strategy for the campus improvements it was necessary to consider;

- The available water sources, their capacity and limitations
- The water demands of the campus at full capacity
- The treatment required to provide the quality of water for each use

A water source / water demand mass balance was developed to enable water management strategies to be evaluated. The alternative energy requirements to achieve the above objectives were also evaluated.

3 WATER RESOURCES

3.1 Municipal Supply

On Majuro Atoll the average daily quantity of freshwater available for distribution to the community from the municipal supply is about 3,700 m^3, produced both from rainwater harvested from part of the paved area of the international airport and the Laura groundwater lens. This potentially provides the atoll population of 38,000 with approximately 100L/c/d. Increasing population, unrestricted demand levels, unaccounted water losses and climate variability have reduced water availability, such that about 65L/c/d is supplied to the population and water restrictions are in place. The water supply is now (in 2011) restricted to 3 hours in the morning and evening on 2 days per week.

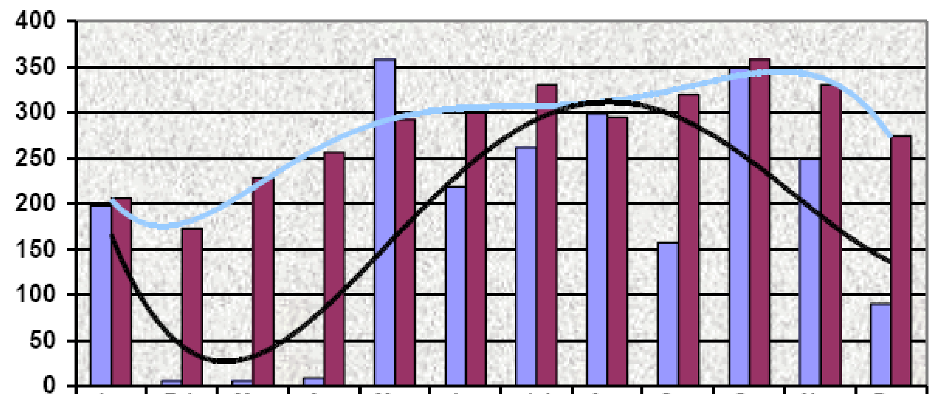
The water receives treatment by coagulation and filtration before distribution, however, the operation of the plant and the frequent periods when the water reticulation is not pressurized leads to potential for contamination. The supply fails to meet potable standards.

The intermittent availability and variable quality makes reliance on the municipal supply for the primary source of water for the CMI campus untenable. It is intended to remain as a backup source only.

3.2 Rainwater

Rainwater is the only natural freshwater resource and collection of roofwater was considered the primary water source for the campus. The Majuro Atoll receives usually about 3300 mm of rain per year. Rainfall is generally highest in October and lower in February. Extended droughts throughout the period from February to April are well known on Majuro and occurred in 1970, 1982, 1992 and more recently in 2008. Figure 2 shows rainfall data for an average year and a typical drought year with their respective trendlines.

Figure 2: Average rainfall (mm) for Majuro Atoll, RMI (SOPAC 1998)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Typical Drought Year	198.12	5.08	5.08	8.89	358.14	218.44	261.62	298.45	157.48	349.25	248.92	90.17
Average Rainfall	205.74	172.72	228.6	256.54	292.1	299.72	330.2	294.64	320.04	358.14	330.2	274.32

The "dependable" annual rainfall is estimated as 2540mm, (defined as the 95%ile of the monthly average of 30 years records). The annual rainwater yield from roof collection of all buildings was estimated as 15,900m^3/yr, based on a collection efficiency of 75% assumed to account for water lost through the "first flush" diverters and overflows during periods when intense rainfall occurs when roofwater storage is full. However the monthly rainfall is seasonal and drought conditions have occurred in the past, leading to potentially lower yields.

4 Campus Water Demand

The design daily water demand was based on the ultimate campus population, estimated as 1200, comprising;

- Full time boarding students 70

- Day students 930
- Teaching and administration staff 200

The domicile students are considered to create a water demand of 136 L/c/d of which 105 L/c/d relates to potable consumption, food preparation, laundry and hygiene. Toilet flushing of 30 L/c/d makes up the remaining total. While this per capita demand exceeds the Majuro 65L/c/d average, it is considered that the availability of continuous potable water and the provision of modern facilities in the dormitories will result in increased consumption. The estimated daily demand of the day students and staff is 38 L/c/d. The estimated total demand for the water system with the fully developed campus is $52m^3/d$.

The annualised water balance based on 344 occupancy days is approximately $17,800m^3/yr$. It is evident that insufficient "dependable" roofwater can be collected to make the campus self-sufficient.

4.1 Toilet Flushing Options

A portion of the design water demand is related to toilet flushing. In the urban area of Majuro seawater is used flush toilets. A municipal seawater reticulation is operated from a pumping system in the lagoon. The existing CMI toilet flushing used the seawater from the municipal main so the option to retain saltwater flushing was considered. While it is attractive in terms of reduction of freshwater demand there are also disadvantages. The most serious being the reliability. It is not uncommon for the seawater system to be stopped due to pump maintenance, power failure or problems with the reticulation (blockages, leaks). To maintain a reliable seawater reservoir would require storage on the CMI site or a purpose-built seawater intake on the nearby reef. Corrosion of pipe fittings of sanitary fixtures was an ongoing maintenance issue for CMI.

The decision to opt for freshwater for toilet flushing was made as this was seen as a major benefit in terms of student well-being and hygiene and would positively enhance the learning environment.

4.2 Desalination

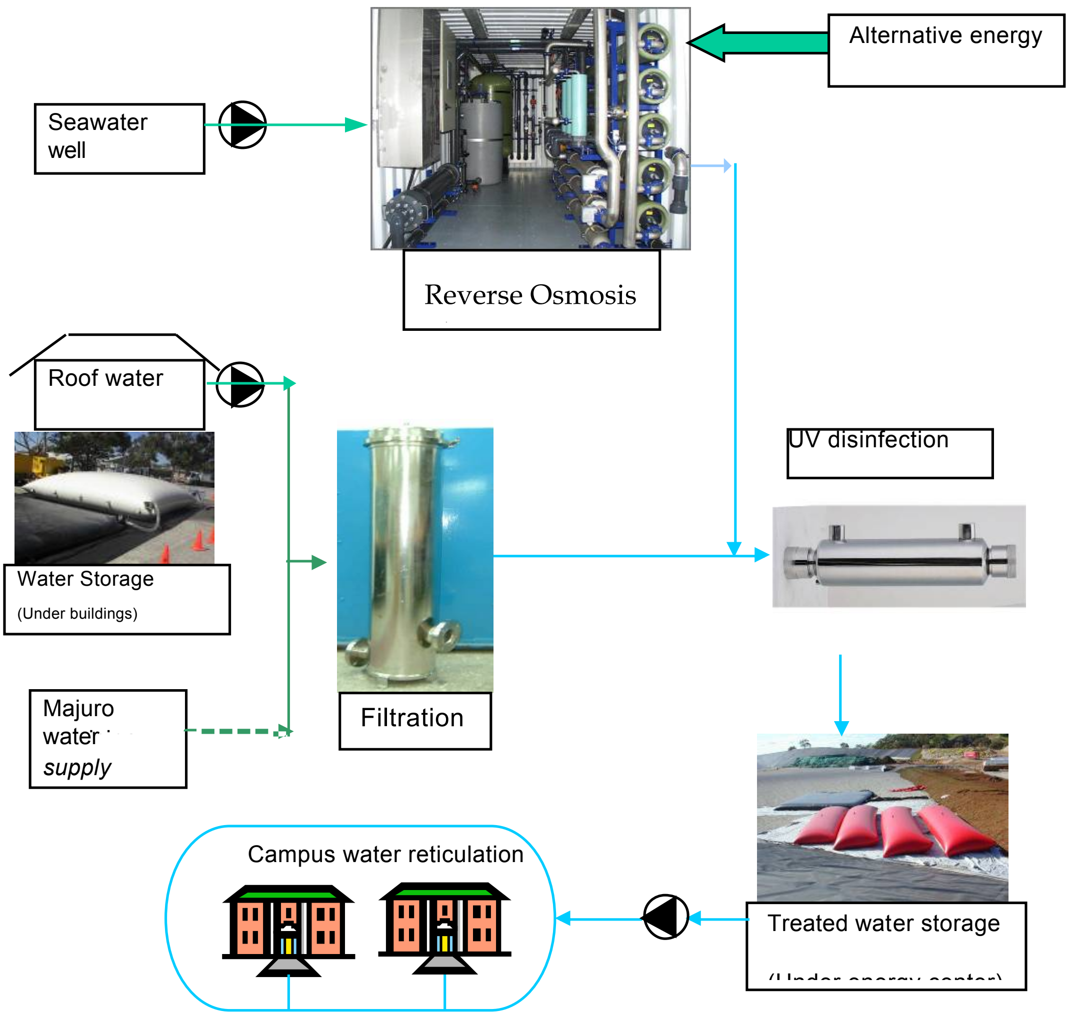
To achieve water self-sufficiency on the campus desalination of seawater by reverse osmosis (RO) was selected to supplement the primary roofwater source when required..

Seawater desalination by RO was one of the components of the freshwater strategy to be installed in the utilities centre. The design capacity of the RO plant was selected as $100m^3/d$, even though $50m^3/d$ is sufficient to meet the maximum campus water demand. The larger capacity allowed the plant to produce the daily demand in 12 hours during daylight, which permitted the use of solar energy to power the plant.

5 INTEGRATED WATER SYSTEM

The objective of the water treatment system is to provide potable water meeting the WHO Drinking Water Standards to the whole of the CMI campus. Figure 3 shows the integrated water system concept that was developed for implementation.

Figure 3: Integrated Water System Concept.



5.1 Roofwater and Potable Water Storage

The utilities centre houses the RO treatment plant, roof water treatment plant, potable water pumps, fire pumps and power generation. The Masterplan concept for storage of both roof and treated water proposed the use of flexible "bladder" tanks in building basements due to the difficulty of constructing leak-proof below ground concrete tanks in a high saline shallow water table environment. Four bladder tanks with a total capacity of 100m^3 were installed in the basement of the utilities centre. Each bladder compartment was prepared with a 100mm layer of sand, overlain with a PVC ground sheet to prevent possible puncture of the tank from sharp protrusions. The tanks were shipped from the supplier folded in a manner that allowed a simple “roll out” onto the pre-prepared bed. Figure 4 shows an installed tank in the utilities centre.

Figure 4: Flexible bladder tank laid out in utilities building basement

Rainwater is collected from the roofs of the main classroom and administration buildings and piped to six rainwater collection bladders with a capacity of 50m^3, installed under a wooden walkway between two of the classroom buildings. With an additional 60m^3 available in an existing concrete tank adjacent to the old dormitory building a total of 110m^3 rainwater storage is provided.

5.2 Water Treatment

Rainwater from the storage bladders and tank is pumped to a 1 micron cartridge filtration unit in the utilities centre and UV disinfected before transfer to the potable water tanks. The treated water from the RO is also discharged through the UV disinfection before entering the potable water storage. As the RO treatment is only a single pass unit the TDS of the permeate water is typically in the 250 -500 mg/L range. While this meets the WHO Drinking Water Standard the water can taste slightly “salty” when compared with low TDS roofwater. Maximising the treatment of roof water and blending with RO water provides acceptable product water.

5.3 Climate Change Design

Climate change and the vulnerability of low-lying Pacific islands to damage from increased sea levels is now a serious design consideration for infrastructure projects. The Marshall Islands are particularly low-lying so recognition of this was incorporated into the campus design. Critical infrastructure such as the power generator and water treatment system were located in the utilities centre building which was built on a raised platform and protected by a seawall. Power transformers, electrical switch boards and the PV inverters were located on the upper floor above flooding level. One of the positive features of using flexible sealed bladder tanks was the ability to provide a secure uncontaminated drinking water supply should the buildings become flooded by adverse weather conditions.

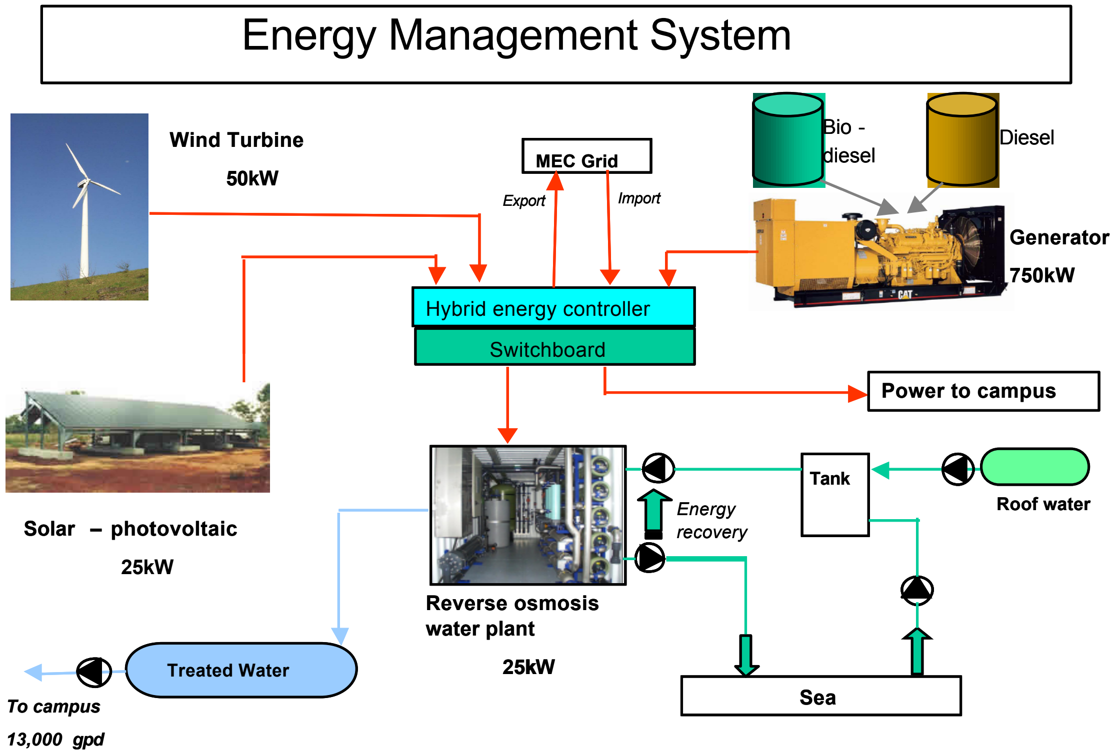
Under public emergency conditions, such as storm surges and extreme drought the College has been designated as a community emergency water source. The design of the water system infrastructure, with secure potable water bladder storage, standby generation and solar power, is able to operate the RO plant to supply up to 100m^3/d of freshwater to meet community needs.

6 ENERGY STRATEGY

The RMI's primary source of energy is based on fossil fuel, with municipal electrical power provided by diesel generators operated by the Majuro Electric Company. A key objective of the campus sustainability strategy was the use of alternative energy sources as far as practical. Maximising energy efficiency and installation of on-site solar photovoltaic, wind and biofuel generation were overarching goals of the strategy. Figure 5 shows the integrated energy and water system.

Three sources of on-site power generation; solar, wind and diesel, were proposed in the Masterplan. Connection to the municipal power grid was retained to provide continuity of supply but with the provision that surplus power from on-site generation could be exported to the local grid. In the 2007 – 2011 construction period the standby diesel generator and Stage 1 of the solar power system were installed.

Figure 5: Integrated Energy and Water System



6.1 Photovoltaic Power

Stage 1 of the energy sustainability programme implemented the installation of photo-voltaic (PV) panels onto the roof of the utilities centre and the adjacent dormitory building. A total of 300x 190W_p PV panels were installed, providing a 57kW_p system. The 3 phase power inverters are grid-connected to the municipal system, allowing for export of surplus power when production is greater than demand. At the time of installation it was the largest grid-connect system in the Pacific, including New Zealand, but excluding Australia. Figures 6 and 7 show the arrangement of panels.

The initial installation of 57kW of PV panels provides some 350kWh of grid-connected power daily, which offsets the 300kWh power requirements for 12 hours operation of the RO desalination water plant. Currently, as the RO plant is not operated every day, the PV system makes a significant contribution to the campus power capacity.

Ultimately all buildings will be fitted with PV panels to provide up to 250kW_p power to the campus, with excess power being exported to the local grid. The PV installation has been trouble free and operated reliably since installation.

Figure 6: PV panels installation

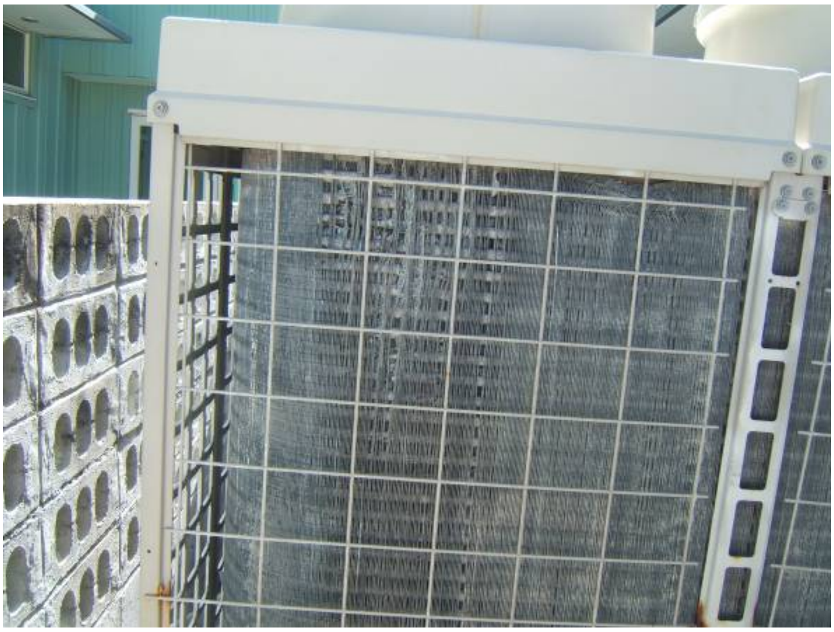
Figure 7: Utilities building showing PV panel installation.

6.2 Air Conditioning

While opportunities existed for design of effective natural ventilation of the teaching buildings in tropical situations, there was a requirement for air-conditioning of tertiary teaching spaces for computers, laboratory and nursing training. This imposed a significant demand on the Campus power system. The total air conditioning power demand was estimated up to 500kW for the whole campus.

The usual approach to air conditioning in Pacific Island states is the installation of multiple split-units serving individual rooms. Generally these are domestic-type air conditioning units. Previously the Campus operated over 96 individual AC units. These units, while cheap, are not designed for the rigors of tropical island conditions where humidity is high and salt-laden air is present. The typical life expectancy of the external compressor/condenser unit in the campus experience is 2 – 3 years, with the internal air handling unit perhaps lasting 5 years. Significant corrosion of the external unit, particularly of pressed aluminium cooling fins on copper tubing, occurs within 12 months. The progressive collapse of the cooling fins (Figure 8) substantially reduces the cooling efficiency, resulting in increased energy consumption. Control electronics housed in the external units are not tropicalised and frequently fail with short circuiting due to salt contamination. Once the electronic control fails the unit is unserviceable, and replacement is cheaper than repair.

Figure 8: Fin corrosion of split unit air-conditioners



To reduce the energy demand an innovative use of seawater cooled chillers designed for marine ship-board installation was trialled on one classroom block (Figure 9). Using the cooler seawater temperature for heat rejection allows the chiller to operate with greater efficiency. There is a saving of up to 20% energy consumption compared with multiple split unit air conditioners of similar cooling capacity. A trial chiller (Aqua-air 480,000 BTU/hr) was installed in the new classroom block 2. The power requirement for the chiller was 39kW compared with an estimated 60kW for split unit air conditioners for the building.

Figure 9: Marine Air Conditioning Chiller

Providing seawater wells in the adjacent reef, with pumping and reticulation for up to 40L/s to service up to four chillers in different buildings was a challenge. The wells required excavation of a hole through the low tide reef platform into permanent seawater and construction of a strong above-water structure to resist wave energy across the reef. Figure 10 shows the finished wells.

Two stainless steel submersible pumps (duty, standby) delivered a continuous seawater flow to the chiller unit. The return flow temperature was raised by approximately 8^{o}C by the reject heat from the chillers. This water was piped to the inlet tanks of the RO unit before overflowing back to the reef. Using the heated seawater for the RO feed increases the capacity of the membranes and lowers the osmotic pressure due to the lower viscosity.

Figure 10: Sea well structures – designed to resist ocean wave impact

6.3 Wind

The wind regime on the Marshall Islands is characterised from the end of December until the end of April by the northeast trade winds which blow quite strongly with an average speed of some 13 miles per hour (21 km/h.). For the rest of the year winds are mainly light and variable, although tropical storms occur during this period. Major storms, such as typhoons, do not often affect the Marshall Islands.

A 50kW wind turbine is proposed for the CMI site in a later development stage. For the expected wind range of 10 – 25km/hr, an efficient turbine will be able to provide 15 – 20kW of energy on a reasonably continuous basis. A daily energy contribution around 360 – 480kWh could be made. Combined with the PV array energy, the wind and solar contribution would exceed the energy requirements of the water system.

6.4 Biofuel

One of the few renewable resources on the Marshall Islands is the production of coconut oil. The Tobolar Copra Processing Authority (TCPA) produces around 60,000 gallons of oil a month for export. According to the report (Zieroth, 2004), Tolobar has carried out trials using coconut oil as a diesel substitute for vehicle use for three years. No obvious technical problems have been reported.

CMI is interested to conduct further research into the use of coconut oil as a biodiesel substitute. The diesel standby generator at CMI is an obvious candidate to explore this use. It is proposed to run this generator on diesel in the beginning. However the College will try to develop a coconut oil industry around the campus curriculum so that the generator could be run on coconut oil base Bio-diesel. This may have spin-offs for other outer atolls in the production of coconut oil to provide a more sustainable income than the current copra based income.

7 Summary

The redevelopment of the College of the Marshall Island campus has come from concept to reality over the last 5 years and will be completed by 2012. The implementation of the integrated water and energy concept has been challenging but will provide the campus with a reliable and energy efficient infrastructure to meet the current and future demands. The educational capacity of the College is enhanced with the opportunity for students to learn first-hand about the modern technologies of solar and wind power, desalination and water resource management.

References

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