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Title: The Potential of Coconut Toddy for use as a Feedstock for Bioethanol Production in Tuvalu (pre-publication DRAFT)

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Abstract

In Tuvalu the sap from the coconut palm (*Cocos nucifera*) is known as "toddy". This paper examines toddy's current use as a foodstuff, the contribution of the sale of toddy products to household incomes and the potential use of sour toddy as a sustainable feedstock for bioethanol production for use as a petroleum substitute in Tuvalu.
The productivity and current uses of coconut woodlands are also assessed. At current levels of production and use, less than 1% of coconut palms are used for toddy production by 1133 producers. Over 5 dam^3 of fresh toddy are produced annually and average toddy production per tree ranges from 1.7 to 4.3 dm^3 d^{-1}.
The sale of toddy products provides 22-24% of annual household income for producers.
The production of bioethanol from toddy has been demonstrated by the NGO Alofa Tuvalu. However, it is not currently cost competitive with petroleum, although in terms of productivity, the current toddy harvest could produce enough bioethanol to replace 31% of the nation's petroleum.
It is evident that there is a large untapped biomass energy potential in Tuvalu which should be utilised if the Government of Tuvalu are going to fulfil their commitment to be carbon neutral by 2020.

1. Introduction

The coconut palm (*C. nucifera*) is known to Tuvaluans and Pacific Island peoples as "the tree of life" since all of its products have a use. The coconut does not just provide food and drink e.g. leaves are woven into blinds, rough mats and thatch for traditional houses; green leaves are made into baskets, hats and trays for everyday use; husks provide fibre for string and cord, as well as soil organic matter when piled on the ground and left to decompose; husks also provide a source of fuelwood and shells are used for fuelwood and charcoal. The contents of the actual nut have a multitude of uses such as medicines, oil production, copra production, etc. Palm trunks and stems are used in traditional house and pig pen construction and the spathe and inflorescence of young palms is "cut" for toddy [Figure 1]. Very little research has been done on toddy production.

Figure 1. Detail of toddy collection – the spathe and inflorescence is sliced and bound with string; the toddy (sap) is collected in the glass bottle. This palm is of the variety "Malayan Dwarf".

Tuvalu is a Small Island Developing State with LDC (less developed country) status in the World Bank Classification. It is located approximately 1000km north of Fiji and is

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geographically isolated. Its total land mass is just 26 km^2, spread across 900,000 km^2 of its exclusive economic zone. It consists of 9 island groups (Funafuti, and the "outer islands" of Vaitupu, Nanumea, Nanumaga, Niutao, Nui, Nukufetau, Nukulaelae, and Niulakita) which are serviced by 2 inter-island boats. Within these groups there are a large number of islands with settlements - the largest covering 520 ha and the smallest 42 ha. There are many smaller uninhabited islets. The total population is around 10,500 people: over 4,800 on Funafuti; around 1,500 on Vaitupu; less than 50 on Niulakita; and between 400 and 700 on the 6 other outer islands. Funafuti contains the capital and administration centres and Vaitupu the main educational and agricultural centres. The nation is regarded as exceptionally vulnerable to rising sea levels and increased storm activity as the maximum height above sea level is a mere 5 m. [1]

The remoteness of these islands has four major effects: 1) A high level of cost for imported goods due to shipping; 2) A lack of exports; 3) A limited potential for tourism development; 4) Supply disruptions of all imported goods. [2]

The country's main food resource is the ocean. Due to lack of productive land and a reliance on imported rice, rather than traditional taro (partially due to recent salt water intrusion and destruction of agricultural land for the construction of air strips during World War II - WWII), agriculture is far from being self-sufficient and consists primarily of coconut and banana trees – there are no forestry products. Subsistence agriculture is the mainstay of families on the outer islands. In addition, pig keeping is very much a part of Tuvaluan culture and a food source for many households.

The currency in Tuvalu is the Australian Dollar (1 AUD = 1.07170 USD). In 2007, imports totalled USD 19,704,389 (25% of all imports were food and beverages) while exports totalled USD 17,276 – imports were around 170 times higher than exports [3]. The Government of Tuvalu has made huge efforts to find non-export related financial resources. Additional sources of revenue for the country include: Duties from fishing boats; employment of seafarers, trained at the Tuvalu Maritime Training Institute, by overseas shipping companies; licensing the ".tv" domain name; interest from the National Trust Fund. However, to complete the national budget, the government of Tuvalu has no choice but to raise funds from international aid (bilateral and multilateral). International donors have provided for Tuvalu's major infrastructure investments such as the hotel, the hospital, the government building and in 2006, a diesel electricity generation plant and an annual USD 1,071,700 fuel subsidy to run the electricity generation plant in Funafuti, without which electricity would be unaffordable for the majority of the Funafuti population. Income from aid is highly unpredictable and any disruption could cause great damage to crucial imports which are vital for daily life such as food and oil. [1]. Tuvalu's economy is small, fragmented and highly vulnerable to external economic influences such as changes in oil price.

Despite the Government of Tuvalu's commitment to 100% renewable energy – "being carbon neutral" - by 2020, Tuvalu is currently dependent on imported oil to provide 82% (159.6 TJ) of its primary energy, the remaining 18% (33.6 TJ) is provided by biomass [2]. There were six oil price increases from mid-2005 – mid-2006; bringing the price of diesel in Tuvalu from USD 0.92 to 1.98 dm^{-3}, and kerosene from USD 1.10 to 1.97 dm^{-3} [2]. High oil prices increase the price of all imported goods. In addition, the country is highly vulnerable to oil supply disruptions and because of the transport distances involved, it is liable to pay a considerable premium over world market rates for its future petroleum resources. The lack of access to adequate, affordable, reliable, safe and environmentally benign energy is a severe

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development constraint. Biomass is a fuel that people are familiar with and currently provides 64% (31.3 TJ) of energy to the domestic sector [2]. Cooking using firewood and coconut husks and shells still represents the majority of the country's domestic energy consumption. However, although continued use of traditional biomass will provide for basic needs, it will not solve the problem of providing the modern energy services required for economic growth and improved living standards. It is likely that the modernisation of biomass energy use, via biogas, biodiesel, gasification, and bioethanol (examined here) will involve some social and cultural changes; in addition further political and techno-economic changes will be required for successful implementation of modern bioenergy initiatives. The successful implementation of sustainable modern bioenergy schemes is certainly a major, but achievable, challenge for Tuvalu.

1.1 Toddy Collection

In Tuvalu, the sap of the coconut palm (*C. nucifera*) is referred to generally as toddy or kaleve and it is both culturally and economically important, especially in the outer islands. In order to collect toddy, the spathe is sliced through or removed with a sharp knife and the inflorescence is bound tightly with string. The spathe is a leaf-like structure that is wrapped around the spadix. The spadix contains the immature polygamomonoecious inflorescences (male and female flowers) - it is essentially the stem that will eventually, once fertilised, develop into coconuts. The cut and bound spadix is referred to as a "tap". A vessel, either a plastic or glass bottle (referred to as a "cup") or a coconut "shell" is placed under the cut surface of the spadix in order to collect the sap – the sap is guided in to the collecting vessel by use of a pinna from a green pinnate coconut leaf. In Tuvalu, the spadix is referred to as the "tusk" or "diari". The knowledge and skills associated with toddy production are such that certain trees, which produce large coconut "shells" are propagated specifically for the purpose of providing collecting vessels for toddy. Toddy "cutting" is almost exclusively a male preserve. Toddy cutting and collecting skills are passed from father to son and knowledge is closely guarded - skills take at least 2 years to master. Toddy "cups" and "shells" are emptied at dawn and dusk. The cut end of the spadix is re-sliced as required. Knives are sharpened and adapted specifically for this purpose. Mythology and folk lore surround the customs and culture of toddy production – some of which comes from Kiribati since much of the associated terminology is from the Gilbertese language. There are 2 types of tusk – the "fat tusk" is known as either "Diari Buni" (after the puffer fish) or "Diari Nei Passia" (Miss fat woman) and immature flowers fill the whole of the spathe; the "thin tusk" is known as "Diari Robono" (after the eel), and the immature flowers are not packed to the end of the spathe. There are different knots and bindings depending on the shape of the tusk – the "neira nuraki" knot can be used on both and has to be tied "in order to take the juice from the elbow to the hand". Coconut string is always the preferred binding and the "tusk" is always bound in the same direction – from the point nearest the trunk (the elbow) to the cut end of the "tusk" (the hand). It is bound this way so that the flow of the sap is not disturbed. [4].

2. Methodology

Primary data was gathered by ground survey (for vegetation), and measurement and questionnaire (for toddy production) (see [5] for details of assessment methodologies). The

field survey of vegetation and natural resources was evaluated and supported using aerial images and vegetation maps (scales 1:10,000 – 1:50,000) [6-11]. Arial images were also used to evaluate area of vegetation cover where ground surveys were not possible - boundaries and densities of vegetation units were distinguished, coconut productivity and planting density was estimated via ground surveys which were undertaken on each of the island groups. Vegetation units were classified according to those used by the Tuvalu Department of Agriculture [7,8]. The vegetation units/classes used and identified in this survey represent the dominant plant communities found throughout Tuvalu. The age of coconut stands was estimated using local knowledge, tree height:crown size and yield of coconuts. The number of palms requiring re-planting was estimated.

2.1 Vegetation Classes

Vegetative cover was classified as follows:

i) Coconut woodland: Cover dominated by *C. nucifera*. Coconut woodland occupies the largest surface area of any vegetation class and is Tuvalu's predominant vegetation type. This class was been subdivided on the basis of palm density - low, medium and high density.

ii) Broadleaf woodland: Vegetative cover dominated by *Pisonia Spp, Cordia Spp, Calophyllum Spp, Ochrosia Spp*, *Guettarda Spp.* and mixed.

iii) Coconut and broadleaf woodland (mixed): Coconut with undifferentiated tree species including banana.

iv) Scrub: Containing or dominated by the following species – *Scaevola Spp*, *Pemphis Spp*, *Messerschmidia Sp, Scaevola Spp/Messerschmidia Sp, Pemphis Spp* & undifferentiated scrub, Scaevola Spp/*Messerschmidia Sp/Pandanus Spp, Scaevola Spp/ Pandanus Spp, Scaevola Spp/ Pandanus Spp*/Coconuts, Mixed scrub and coconuts & banana.

v) Pandanus: *Pandanus Spp*

vi) Low ground cover: grass – usually found around settlement areas and some cultivated plots – sometimes in combination with coconut, breadfruit, banana and pawpaw.

vii) Mangrove – Where larger areas of mangroves were found they were included as a separate vegetation class.

Coconut woodland throughout Tuvalu is dominated by the Tuvaluan variety of *C. nucifera* – the “Tuvalu Tall”, which is very productive. Other varieties, notably the Fijian palm, Malayan dwarf and hybrids from Nauru, Banaba and Fiji are common in the settlement areas.

2.2 Toddy Production

In order to make an accurate assessment of the biomass resource available for use as an energy source it is necessary to assess the amount of biomass produced and consumed – as food & fuel. Since biomass energy consumption has been ignored by official GoT statistics, previous surveys [12-14] detailing domestic and community consumption of coconut products for food, animal feed and fuel were used to estimate sustainability of current and future use of coconut.

Data on production, use and sale of toddy was gathered by measurement and questionnaire (sample size represents 19% of toddy producers) on the following preparations of the sap:

a) Fresh toddy – toddy which is collected from the tree (at dawn and dusk) and drunk directly before it has had time to ferment. It is the basic ingredient in the preparations listed below. Fresh toddy will begin to ferment almost immediately and must be consumed within 6-8 hours.

Tuvaluan name: Kaleve magalo

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b) Boiled toddy – fresh toddy which has been filtered through muslin, brought to the boil and allowed to cool. Boiling toddy in this way improves its shelf life by delaying fermentation and it should be consumed within 12-16 hours.

c) Sour toddy – fresh toddy that has been left in the heat of the sun and allowed to ferment with naturally occurring yeast. Nothing is added to the fresh toddy and the process usually takes around 2-4 days. The resulting alcohol content is between 6 & 9%. It has a characteristic sulphurous smell. Many sour toddy producers reported that the process of making sour toddy is speeded up if a separate container is used to ferment the fresh toddy in without washing the container in-between batches.

d) Toddy syrup – fresh toddy which is boiled and reduced to a syrup. It is usual to boil the toddy that was collected in the morning to make red toddy syrup. Black toddy syrup is made by boiling together in the evening the fresh toddy that was collected in the morning and evening. Toddy syrup can be kept for several years in an air-tight container.

Tuvaluan name: Kaleve kula

2.3 General Assumptions

Average tap yield = 1.3 dm^3 d^{-1}

Average number of taps per tree = 2.4

Average production per tree = 3.1 dm^3 d^{-1}

Alcohol content volume fraction of toddy is 8%

Average household size = 6.2 people [1].

Assumes 1 toe (tonne of oil equivalent) = 42GJ [5]

2 kg fuelwood is required to produce 1 dm^3 of ethanol

1 tonne of fuelwood (coconut husk & shell) HHV = 17GJ [5]

Estimate of total number of coconuts produced annually = 14,100,000 nuts [2].

Estimate of total number of coconuts used as a foodstuff for pigs and humans is annually 6,700,000. The energy available from these coconuts' husks and shells is 52.0 TJ.

From the available husks and shells, the total used as a fuel = 34.2 TJ [2].

Assumptions for Anhydrous Ethanol (C_2H_5OH) [5]:

Net calorific value = 26.8 $MJkg^{-1}$

Water in distilled ethanol H_2O = 6 %

3. Results

Within the different palm density classes [detailed in Table 1] there was also a considerable variation in the sub-canopy and ground cover, especially in the low density woodland. This both reflects and influences utilisation of the coconut palms. For example, in areas where there is regular collection of nuts for domestic purposes, as on Amatuku islet and around settled areas, the woodland is kept relatively clear of undergrowth while elsewhere it is usually overgrown with scrub. The bulk of coconut palms in areas that are furthest away from settlements and are difficult to access consisted mainly of older stands. Breadfruit trees are usually found around settlement areas.

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Table 1: Total replanting area and number of palms for all vegetation classes across Tuvalu

Coconut woodland is by far the dominant vegetation class, covering 57% of the land area [Table 2]. However, much of this coconut woodland appears to be senile, under-managed and under-utilised [Table 1], particularly when away from settled areas.

Table 2: Tuvalu: Land use based on vegetation class

From Table 2 it can be seen that land used for settlement purposes (village/settlement areas, buildings, roads, etc.,) and areas set-aside for community and government use account for 10% of total land area. Bush, scrub and woodlands are generally used for the collection of plant materials for building purposes, firewood, animal feed, garden and pulaka pit mulches, handicrafts, etc., and for hunting birds. Almost all land is divided into privately owned plots, some of which are used for subsistence agricultural activities.

The dominance of coconut woodland [Tables 1 & 2] is because copra production was the predominant economic function of land use on outer islands until 2002, but has been virtually non-existent on Funafuti for the last 30 years. This is despite the fact that Funafuti's coconut resource could sustainably produce 20t of copra per year if harvesting from all islets were to take place [13]. The decline of copra production in Funafuti is due to a variety of reasons which will also affect any planned increase of toddy production for use as a biofuel in Funafuti. These reasons include a more monetary-based economy, high population density leading to more stress on local natural resources, land tenure issues, and collection difficulties due to the wide dispersal of coconut woodland over 33 islets - some of which are only accessible at high tide - for details of the copra market collapse in Tuvalu see [12] and [14]. There has also been no effective formal subsidised coconut replanting schemes on the island (although small plots of private plantings do exist, notably on Fongafale). On Funafuti, the coconut woodland is used as a source for drinking nuts and nuts for other domestic purposes such as pig feed. It is apparent that the coconut resources on outer islands are currently under-utilised.

Table 3: Current fresh toddy production

Table 3 shows that the number of toddy producers across Tuvalu is 1133, utilising 4097 trees for toddy production (less than 1% of total coconut palms from Table 1). Some producers use trees just for cutting toddy, others for both toddy and coconut production. Over 5 million dm^3 of fresh toddy are produced annually, which per person amounts to over 500 $dm^3\ yr^{-1}$.

The majority of toddy production is from trees surrounding settlements. This is because toddy collection is fairly labour intensive as "cutting" takes place at dawn and dusk. With only a relatively small number of trees being used for toddy production, it is not practical for most families to collect toddy from land far from the home.

Average annual household income on outer islands is USD 11,690 [18]. Average annual income on the outer islands from all toddy products is USD 2,655 which represents 22% of total household income.

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Average annual household income in Funafuti is USD 17,272 [18]. Average annual income on the outer islands from all toddy products is USD 4,180 which represents 24% of total household income.

There are large differences in income between Funafuti and the outer islands since the Government of Tuvalu – the nation's major employer - is based in Funafuti. The Government runs the hotel, shops, docks, airport, Electricity Corporation, media centre, fisheries and public works – all of which are based in Funafuti.

Table 4: Fresh toddy production range

From Table 4, average toddy production per tree ranges from 4.3 dm^3 d^{-1} in Vaitupu to 1.7 dm^3 d^{-1} in Niulakita. There are various factors associated with these differences, such as climate (temperature and rainfall), coconut variety, and methods of toddy extraction. The Malayan Dwarf variety is common for toddy production as the "taps" can be reached by using a small step ladder. Average yield per tap ranges from 0.64 dm^3 d^{-1} in Niulakita to 1.96 dm^3 d^{-1} in Vaitupu.

Table 5: Current sour toddy production and household income from sale of sour toddy

From Table 5 shows that household income generated from the sale of sour toddy ranged from USD 0 to 2,805 per year. The people of Nuitao do not sell any toddy products as they operate an informal bartering system. The sale and consumption of alcohol in Niulakita, Nukufetau and Vaitupu is very much a social taboo. In Funafuti and Nukulaelae the sale of sour toddy accounted for 67% of income from all toddy products.

Table 6: Current toddy syrup production and household income from sale of toddy syrup

Table 6 shows that toddy syrup accounts for between USD 0 and 3,058 in Niulakita. Niulakita sells the majority of toddy syrup to Funafuti and these sales account for 100% of household income from toddy products. The Tuvalu Copra Trading Corporation (TCTC) is responsible for organising exports of all coconut products from outer islands to Funafuti.

Toddy products have various markets: The majority of sour toddy is sold privately. Toddy syrup is sold privately by those living on outer islands to friends and family in Funafuti. TCTC also market local produce and will pay between USD 3.22 to 5.36 dm^{-3} for toddy syrup, depending on which outer island it came from – Nukulaelae and Niulakita have reputations for producing the finest quality toddy syrup. TCTC also sell toddy syrup to Tuvaluan communities in New Zealand – around 154-200 dm^3 of toddy syrup per month are sold to New Zealand at USD 7.50 dm^3 and 28-52 dm^3 are sold by TCTC in Funafuti. TCTC buys around 350 dm^3 per month and has a stock of around 420 dm^3. In addition, in Funafuti, the National Women's Group run a cafe that sells diluted toddy syrup. This drink contains 1 dm^3 of toddy syrup to 13 dm^3 of water and is sold at USD 1.07 for 0.5 dm^3. Catering establishments, such as the hotel and restaurants on Funafuti sell "buckets" of diluted toddy syrup for USD 16.08 for a 14 dm^3 "bucket". Fresh and boiled toddy are also sold privately,

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particularly in Funafuti. In Vaitupu, the Kaupule (local council) buys and sells boiled fresh toddy and toddy syrup.

At current levels of production and use, less than 1% of palms are used for toddy production. There are no adverse impacts on the biomass resource from current levels of toddy production. However, biomass resources in both Funafuti and Vaitupu are reaching their limits of sustainability. In Vaitupu, this is due to the prevalence of coconut mite, and in Funafuti it is due to a combination of issues which are all related to the high population density there.

Table 7: Theoretical toddy ethanol production from current sour toddy and fresh toddy production in all islands

It can be seen from Table 7, that if bioethanol were produced from current estimated sour toddy production, it would be enough to replace around 11% of Tuvalu's total petrol consumption of 26.2 TJ in 2004 [15]. If bioethanol were produced from total current fresh toddy production, it would be enough to replace around 31% of Tuvalu's total petrol consumption in 2004 – the coconut palm is very productive, especially when it is taken into account that current fresh toddy production utilizes less than 1% of Tuvalu's total number of coconut palms.

4. Discussion and conclusions

Since the decline of the copra industry [12,14], coconut development for biofuels is appropriate for Tuvalu's future agricultural development. The coconut resource is currently under-utilised and is capable of providing biodiesel [2,12,14] and/or bioethanol sustainably over the short term. However, if long term sustainability is to be achieved, then an appropriate replanting scheme must be implemented immediately.

When the last subsidised replanting scheme finished in 1987 an ongoing replanting regimen of 35 ha per year was recommended [16]. Over the last decade, only around 5 to 7 ha have been replanted annually on a national basis by private land owners [Table 1]. Many of the stands planted after the end of WWII are ending their productive lives and now require replanting – Nukufetau and Nanumea are particularly vulnerable since much of their coconut was planted at the end of WWII. In addition, any future replanting scheme needs to take account of the small plot sizes found throughout Tuvalu. In the last nationwide subsidised replanting scheme, which ended in 1987, only plots larger than 0.47 ha were eligible for subsidy. Any future replanting schemes should also account for traditional multiple uses of small land plots.

One of the most important influences on land use and agriculture development is the system of land ownership. Land use is governed by the 'Native Lands Act' with all land being owned under customary laws. Land cannot be bought or sold, only leased or inherited. The Government leases back land under 'Native Orders' for development purposes. The traditional land-tenure systems, which are based on subdivision and inheritance, have resulted in:

- Fragmentation of land plots – complicating the logistics of maintenance and harvest.
- Disputes over land boundaries.
- Multiple ownership.

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These problems have arisen as a result of a strictly limited land resource and continued population growth [13]. During the replanting scheme in the 1980's there was a qualifying minimum plot size of 0.47 ha. Considering that the average plot size is much less than this, many subsistence farmers were ineligible for the grant.

In order to encourage uptake of future replanting schemes, the costs of replanting and a payment for the 6 years that it takes for a coconut tree to become productive should be covered. Any replanting scheme needs to be carefully managed to ensure that an appropriate age matrix of woodland is achieved to ensure that all the palms do not stop production at the same time – as is the case in Nanumea and Nukufetau. The average palm density across all area under coconut is 211 palms per ha. If just 45 ha per year were to be replanted, then there would be a rough conservative estimate of 12,000 m^3 (around 9,500 t) of timber available for other uses annually. This could be used as fuel for gasifiers – possibly for electricity generation to power an oil mill on each outer island – or for more conventional uses such as construction and making furniture.

The number of coconuts currently used is sustainable (section 3). However, it is essential that an appropriate replanting scheme be implemented alongside any coconut resource based biofuel scheme. This would help ensure that the scheme would be sustainable over the long term. In addition, if such a scheme were implemented, there would be more willingness from landowners to maintain coconut woodland since it would have an economic value. Since the collapse of the copra industry in 2002 [12, 14], there has been little opportunity or incentive for rehabilitating or even maintaining coconut woodlands in the outer islands. The implementation of bioenergy schemes (gasification of coconut husks and shells, coconut oil biodiesel and toddy bioethanol) could provide both economic opportunity and incentive if their introduction is managed sustainably (economically, environmentally and socio-culturally). Biodiesel, gasification, bioethanol and biogas schemes have been demonstrated in Tuvalu by the NGO Alofa Tuvalu and the Tuvalu Maritime Training Institute.

From these pilot schemes, it is evident that these bioenergy technologies are well-suited to Tuvalu as they can be used at small and larger scales in a decentralised manner bringing substantial benefits both to rural and urban areas. Growing biomass is a rural, labour intensive activity and can therefore create jobs and income in the outer islands. Conventional modern agricultural development is difficult since potential agricultural land is unequally divided among the 9 islands, the largest of which (Vaitupu) covers 520 ha and the smallest 40 ha; also, there are 89 islets with less than 5 ha. Maintaining soil organic matter levels and continuing salinisation are also barriers to further agricultural development and diversification. Traditional Tuvaluan agriculture (pulaka pits & pulaka basins) only accounts for around 2% of current land use [Table 2]. Much of this traditional agricultural production has been lost due to disinterest of the younger generation in the outer islands, the migration of people of working age to Funafuti from the outer islands – leaving mostly old people and children on the outer islands, sea water flooding of the pits and the use of coral hardcore for building [1,2,17].

Toddy production and sale has a large impact on the household income of subsistence farmers, particularly those in the outer islands as there are very few income generating opportunities. Mode and average income per day ranges from USD 1.93 to 4.29. 53% of the total population of approximately 10,500 lives on the outer islands and 76% of these households are in the bottom fifth of the income scale [18]. The other quarter of the poorest households are on the island of Funafuti and are often worse off in the more monetary-

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based economy. Throughout Tuvalu there is a pervasive poverty of opportunity - an unacceptable quality of life with insufficient access to education, health care, basic energy services, and economic opportunities [19]. Reviving the economic development of coconut woodlands by developing biofuel schemes will also provide convenient energy carriers which can promote other rural industries. The production of bioethanol from toddy has been demonstrated by the NGO Alofa Tuvalu, but it is not currently cost competitive with petroleum. At current market prices the fresh toddy required to make 1 dm^3 of ethanol would cost around USD 21.43. However, petroleum is not always available on outer islands and it is also too expensive for many families to purchase so the use of toddy ethanol to fuel small fishing boats could provide a viable role for small scale production. Since fossil fuel prices have increased (section 1) there has been a subsequent reduction in the use of small (up to 50hp) 2-stroke engine powered fishing boats and a return to traditional fishing canoes. Production of toddy ethanol by burning coconut husks and shells to distil sour toddy (in a similar way to toddy syrup production) could fill this fuel gap for subsistence farmers and fishermen. However, there are many social and ethical considerations concerning the production of strong alcohol that need to be taken into account before such production is introduced. In addition, the energy balance of producing toddy ethanol in this way is essentially negative – more energy is required to make the toddy ethanol (approximately 34 MJ dm^{-3}) than would be contained in the fuel itself (approximately 20 MJ dm^{-3}). If the same methods of production as those used for toddy syrup were applied to toddy ethanol, it would not be sustainable in the long term over a large scale. However, efficiencies and energy balances for toddy ethanol production could be improved by using specific strains of brewer's yeast that will increase the alcohol content of sour toddy, and using modified solar cookers in the distillation process rather than direct burning of husks and shells on an open fire. The energy balance would then be favourable. This requires further investigation.

It is evident that there is a large untapped biomass energy potential in Tuvalu. For example, a conservative estimate for copra production suggests that at least 200-300 t yr^{-1} copra could be sustainably produced from existing coconut stands which could potentially produce 142,000 dm^3 of coconut oil biodiesel or enough to replace 10% of the fuel used by the inter-island boat service which uses a total of 46.4 TJ annually [2,15]. Productivity could be further increased with improved utilisation of existing forest and other land resources, replanting schemes and improved management and collection/drying. Historical data for copra production in Tuvalu indicates that the highest ever production was in 1979 when 808 t was harvested [20]. Therefore much more useful energy could be extracted from existing coconut stands than is being used at present. Biomass from various sources (coconuts, pig manure, organic waste, etc.) can then form part of a matrix of fuel sources offering increased flexibility of fuel supply and energy security. However, none of the benefits of biofuels will be realised unless they can penetrate existing energy markets. All forms of renewable energy compete in markets which are subject to intense regulation, subsidies, legislation, and other distortions such as reliance on aid.

The Government of Tuvalu has made a statement that it wants to become 100% renewable by 2020 and a comprehensive National Energy Policy Framework has been established [21] which emphasises "Renewable and Sustainable Energy Policy, Strategies and Activities". The Framework covers Energy Policy for the next 15 years. It is therefore evident that strategies now need to be put into place to ensure "adequate, secure and cost effective supply", "efficient utilisation of energy", "minimisation of negative impacts of energy

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production, conversion, utilisation and consumption upon the environment", and to "*Promote the use of appropriate, proven, affordable and cost effective renewable energy technologies both for urban and rural applications".*

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Figure 1. Detail of toddy collection – the spathe and inflorescence is sliced and bound with string; the toddy (sap) is collected in the glass bottle. This palm is of the variety “Malayan Dwarf”.

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548 **Table 1: Total replanting area and number of palms for all vegetation classes across**
549 **Tuvalu**
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Total for Tuvalu **Vegetation Class**	**Spacing** (m)	***Total Area*** **(ha)**	**Total num of palms**	**Area to re-plant (ha)**	**Num. palms to re-plant**	**Tot. num. palms after re-planting**
Coconut woodland						
High density	3 to 4	136	86856	44	27445	103359
Medium density	5 to 6	640	216483	148	63540	219643
Low density	6 to 8	707	122586	284	127180	172766
Coconut & broadleaf woodland	9+	106	9463	28	2300	9463
Coconut replanted areas*	6 to 7.5	65	12645	0	0	12645
Scrub & coconuts	12 to 15	405	20565	109	10281	24956
Settlement area (vegetation)	20	178	4310	49	1094	4310
WWII Airstrip	5 to 7	22	3504	10	1800	7000
TOTALS		**2260**	**476412**	**672**	**233641**	**554142**

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554 * Area replanted since 1999-2000
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Table 2: Tuvalu: Land use based on vegetation class

Total for Tuvalu	Survey Results*	
Vegetation cover	**Area (ha)**	**%**
Coconut woodland	1481	57
Broadleaf woodland	110	4
Coconut and broadleaf woodland (mixed)	106	4
Scrub	432	17
Pandanus	40	2
Low ground cover & mangrove	62	2
Pulaka pits	59	2
Settlements, buildings, roads, dumps etc.	252	10
WWII Airstrip	22	1
Borrow Pits	3	0
Fresh Water Lens	2	0
Enclosed lagoon	39	2
Total	**2607**	**100**

* Synthesis of results from each island group

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566 **Table 3: Current fresh toddy production and household income from sale of fresh**
567 **toddy and all toddy products**
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Island	Fresh Toddy						Fresh Toddy as a product			All Toddy products
	Number of producers	Number of trees	Average number of taps per tree	Daily production of fresh toddy dm^3	Average daily per producer dm^3	Total annual production dm^3	Average sale price of fresh toddy USD dm^{-3}	Amount of fresh toddy sold per week (private, Kaupule, TCTC) dm^3	Annual household income from fresh toddy USD	Total household income from all toddy products USD
Funafuti	220	760	2.7	2432	11.05	887680	2.14	1540	780	4180
Nanumea	148	679	2.1	2036	13.8	743237	2.41	1328	1129	3830
Nanumaga	102	467	2.1	1401	13.8	511516	2.41	914	1129	3830
Niutao	140	432	2.5	1403	10	512065	0.00	0	0	0
Nui	94	321	2.5	964	10.2	351759	1.90	1228	1289	4134
Vaitupu	265	840	2.2	3569	13.5	1302576	1.55	2387	2052	2783
Nukufetau	117	398	2.3	1355	11.6	494514	5.27	188	547	1312
Nukulaelae	39	135	2.7	431	11	157154	2.14	273	780	4180
Niulakita	8	65	2.6	109	13.6	39785	0.00	0	0	3058
Totals	**1133**	**4097**	**2.4**	**13700**	**12.1**	**5000286**	**n/a**	**7857**	**n/a**	**-**

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573 **Table 4: Fresh toddy production range**

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Island	Fresh Toddy: Production range					
	Average daily production per tree dm^3	Highest daily yield from a single tree dm^3	Lowest daily yield from a single tree dm^3	Highest number of taps per tree	Lowest number of taps per tree	Average daily yield per tap dm^3
Funafuti	3.2	14	0.5	6	1	1.19
Nanumea.	3	7	0.5	7	1	1.43
Nanumaga	3	7	0.5	7	1	1.43
Niutao	3.3	15	0.5	8	1	1.32
Nui	3	5	1	4	2	1.2
Vaitupu	4.3	6	0.25	3	2	1.96
Nukufetau	3.4	15	0.5	6	1	1.45
Nukulaelae	3.2	14	0.5	6	1	1.19
Niulakita	1.7	11	1	6	1	0.64

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579 **Table 5: Current sour toddy production and household income from sale of sour**
580 **toddy**
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Island	Sour Toddy					
	Amount of fresh toddy used daily in production dm^3	Amount of fresh toddy used in production %	Amount of sour toddy produced annually dm^3	Sale price of sour toddy USD dm^{-3}	Amount of sour toddy sold per week (private & Kaupule) dm^3	Annual household income from sour toddy USD
Funafuti	1430	59	521950	5.89	2013	2805
Nanumea	1088	53	397201	4.02	1383	1959
Nanumaga	749	53	273365	4.02	952	1959
Niutao	490	35	178850	0.00	0	0
Nui	361	37	131737	6.30	756	2621
Vaitupu	424	12	154857	2.14	308	130
Nukufetau	23	2	8556	7.50	19	62
Nukulaelae	254	59	92528	5.89	357	2805
Niulakita	0	0	0	0.00	0	0
Total	4819	35	1759043	**n/a**	**5787**	**n/a**

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Table 6: Current toddy syrup production and household income from sale of toddy syrup

Island	Toddy Syrup						
	Amount of fresh toddy used daily in production dm^3	Amount of fresh toddy used in production %	Amount of toddy syrup produced annually dm^3	Litres of fresh toddy needed for 1 litre of toddy syrup dm^3	Average sale price of toddy syrup USD dm^{-3}	Amount of toddy syrup sold per week (private, Kaupule, TCTC) dm^3	Annual household income from toddy syrup USD
Funafuti	581	24	129	4.5	4.64	543	595
Nanumea	679	33	126	5.4	5.36	393	743
Nanumaga	467	33	87	5.4	5.36	271	743
Niutao	571	41	112	5.1	0.00	0	0
Nui	546	57	119	4.6	3.57	113	223
Vaitupu	1753	49	351	5	3.22	955	602
Nukufetau	921	68	174	5.3	7.50	211	702
Nukulaelae	103	24	23	4.5	4.64	96	595
Niulakita	92	84	15	6	5.35	88	3058
Total	**5713**	**42**	**1135**	**5.1**	**n/a**	**2670**	**n/a**

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Table 7: Theoretical toddy ethanol production from current sour toddy and fresh toddy production in all islands

Island	Theoretical production of ethanol from current sour toddy prod. dm^3	Energy content of ethanol GJ	Theoretical production of ethanol from current toddy prod. dm^3	Energy content of ethanol GJ
Funafuti	41756	663	71014	1128
Nanumea	31776	505	59459	945
Nanumaga	21869	347	40921	650
Niutao	14308	227	40965	651
Nui	10539	167	28141	447
Vaitupu	12389	197	104206	1656
Nukufetau	684	11	39561	629
Nukulaelae	7402	118	12572	200
Niulakita	0	0	3183	51
Total	**140723**	**2236**	**400023**	**6356**