DELIVERABLE III

BIOGAS TECHNOLOGIES AT INDUSTRIAL SCALE

Part I: Feasibility studies on the biogas technologies

Client:

United Nations Industrial Development Organization (UNIDO)
Project: Tonga Circular Economy Project- Biogas Feasibility Study

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AD Solutions UG (haftungsbeschränkt)

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Abbreviations

€	Euro	GCF	Green Climate Fund
AD	Anaerobic Digestion	ha	Hectar
CAPEX	Capital expenditures	HTG	Hybrid Tropical Grass
CE	Circular Economy	kW	Kilowatt
CH_4	Methane	kW_{el}	Kilowatt electrical
CHP	Combined heat and power	kWh	Kilowatt hour
cm	Centimetre	LPG	liquified petroleum gas
CO_2	Carbon dioxide	m^3	Cubic metre
CSIRO	Commonwealth Scientific and Industrial Research Organisation	MAFF	Ministry of Agriculture Food and Forestry
CSTR	Complete stirred tank reactor	MW	Megawatt
DM	Dry matter	MW_{el}	Megawatt electrical
FM	Fresh matter	ODM	Organic Dry Matter
FNR	Agency for renewable resources	OPEX	Operational Expenditures
FOG	Fat, oil and grease	ToCSA	Tonga Climate Service for Agriculture

1 Preamble

Development of a scoring tool based on criterion developed in collaboration with stakeholders

There are no modern, commercial biogas plants serving the people of the Pacific Islands. With no indigenous fossil fuel resources and a crippling reliance on imported liquid fossil fuels that will persist well into the future, the lack of modern, commercial biogas plants is a significant socioeconomic development impediment that has persisted for far too long and must be corrected.

It's therefore crucial that this first modern, commercial biogas plant to be implemented in Tonga showcases the best of what biogas has to offer. The development and implementation of the Tongan biogas plant must be based on proven, mature, world-best-practice biogas technologies, systems, know-how, and experience against a 30-plus year, in-service horizon. This is essential.

The specific lead biogas project that's proposed for Tonga is a 3MWe plus biomethane biogas plant. The reasons why this biogas plant is recommended are summarised as follows:

- ✓ It's large enough and technically interesting enough to attract the best of the European biogas and related sectors. This is critically important.
- ✓ The multifaceted energy deliverables will be profound, enlightening, and socioeconomically impactful. This is particularly the case in relation to the provision of affordable and scalable process energies that are currently completely absent in the Tongan economy.
- ✓ It will enable the development of a new, crop-based agricultural subsector and provide participating farmers with a substantial and highly secure source of income not affected by fluctuating commodity prices.
- ✓ It will enable the complete mechanisation of this new, crop-based agricultural subsector with this same mechanisation available to support the broader development of the Tongan agricultural sector.

- ✓ It will enable the best of what agricultural and agri-industrial aligned circular economy systems have to offer a developing Tropical country.
- ✓ No country has or will develop its way to prosperity with an overreliance on donor funding. This benchmark project uses donor funding strategically and specifically targeted in order to leverage debt financing and equity investment. This results in a financeable, profitable, and attractive commercial project that will in-turn enable many other financeable, profitable, and attractive commercial projects to develop in Tonga based proven circular economy principles and strategies.

This feasibility study will cover:

- ✓ Section1: How to assess the feasibility of a biogas plant
- ✓ Section 2: Scale
- ✓ Section 3: The fundamental feasibility drivers
- ✓ Section 4: Substrate feasibility Part #1 - Long-term circular economy enablers and drivers
- ✓ Section 5: Substrate feasibility Part #2 - Specific substrates in support of the initial 3MWe plus biomethane biogas plant
- ✓ Section 6: Technical feasibility Part#1: High level technical overview
- ✓ Section 7: Technical feasibility Part#2: Specific technical responses in support of the 3MWe plus biomethane biogas plant
- ✓ Section 8: Economic feasibility
- ✓ Section 9: Deliverability

All of these feasibility elements are completely interconnected and whilst this study will look at these elements individually, they must be taken as a whole.

The further development of this project must now progress through three specific phases:

1. Conceptual planning (already partially completed).
2. Detailed planning, engineering, and consent authority approvals.
3. Construction and commissioning.

There are no shortcuts through this methodical step-by-step process.

2 How to assess the feasibility of a biogas plant

The authors experience in Tonga, and the Pacific island more broadly, suggests that the feasibility of this Tongan biogas project is likely to be viewed through the narrow lens of its electricity generation outcomes. This will inevitably lead to comparisons with intermittent renewable electricity generation sources such as solar photovoltaics and wind. Such narrowly focused assessments of the feasibility of this project should be avoided as they are misleading, erroneous, and do not capture the unique circular economy deliverables.

The passive biological process at the heart of a biogas plant is Anaerobic Digestion (AD). The deliverables supported by AD have been eloquently captured in the benchmark 'International Energy Agency' document entitled: **'The role of anaerobic digestion and biogas in the circular economy'.**

'Biogas from Anaerobic Digestion is not merely a concept of production of renewable energy; it cannot be compared to a wind turbine or a photovoltaic array. Nor can anaerobic digestion be bracketed as just a means of waste treatment or as a tool to reduce greenhouse gases in agriculture and in energy. It cannot be pigeonholed as a means of producing biofertilizer through mineralisation of the nutrients in slurry to optimise availability, or as a means of protecting water quality in streams and aquifers. It is all these and more. The multifunctionality of this concept is its clearest strength. Sustainable biogas systems include processes for treatment of waste, for protection of environment, for conversion of low-value material to higher-value material, for the production of electricity, heat and of advanced gaseous biofuel (biomethane). Biogas and anaerobic digestion systems are dispatchable and as such can facilitate intermittent renewable electricity.

And

We are still in the advent of the circular economy. Products from bio-based resources will grow in both absolute and relative terms in the coming years. In the future bioeconomy, wastes will be transformed to high-value products and chemical building blocks, fuels, power and heating; biogas facilities will play a vital role in this development, and in the implementation of the novel production paths that arise in the transition to a bio-economy. The future of the biogas facility is a factory where value is created from previously wasted materials; this ensures sustainability of the environment and potential for financial gain for the local community. The flexibility of the anaerobic digestion system and its ability to digest a multitude of organic feedstocks, while producing a significant range of products ensures the role of anaerobic digestion and biogas in the circular economy'.

The above two paragraphs clearly define how the feasibility of the proposed Tongan biogas plant **must be viewed**. With this in mind, the main takeout for readers is that this benchmark biogas project is feasible, viable, deliverable, and fully financeable with both debt financiers and equity investors expressing an interest in supporting the project. This support is contingent on securing 'Green Climate Fund' CAPEX support for the specific project elements identified in Attachments B and C.

3 Scale

3.1 Size matters

Scale is an important and highly influential feasibility element in the development of a modern, commercial biogas plant. Succinctly stated, the bigger the size of the biogas plant, the lower the cost of energy production (Figure 1).

Additionally, the bigger the size of the biogas plant, the more products, and services the biogas plant is able to deliver and support. I.e., The bigger the size of the biogas plant, the more influential the biogas plant will be in enabling broader, circular economy based socioeconomic development.

Fachagentur Nachwachsende Rohstoffe

(Agency of Renewable Resources)

BIOENERGY IN GERMANY FACTS AND FIGURES 2019

Economic figures	
Specific investment costs	
BGP 75 kW_{el}	approx. 9,000 €/kW_{el}
BGP 150 kW_{el}	approx. 6,500 €/kW_{el}
BGP 250 kW_{el}	approx. 6,000 €/kW_{el}
BGP 500 kW_{el}	approx. 4,600 €/kW_{el}
BGP 750 kW_{el}	approx. 4,000 €/kW_{el}
BGP 1,000 kW_{el}	approx. 3,500 €/kW_{el}

NOTE: The bigger the size of a biogas plant, the lower the cost of the energy production.

Figure 1: The bigger the size of the biogas plant, the lower the cost of energy production

Another important scale related consideration relevant to Tonga is how far Tonga is away from the European epicentre of world-best-practice biogas technologies, systems, know-how, and experience. Therefore, the size of this first biogas plant must be sufficiently enticing to attract the best of the European biogas sector to Tonga. Succinctly stated, this first plant must make a clear statement that Tonga is serious about developing a full-service Tongan biogas sector.

3.2 Two baseline economic models tell the story of scale

Accompanying this document are two baseline economic models covering:

1. A 500kWe biogas plant (Attachment A: Tonga baseline economic model - 500kWe biogas plant for Tonga).
2. A 3MWe (3,000kWe) biogas plus biomethane biogas plant (Attachment B: UNIDO Tonga baseline HTG economic model - with GCF support)

The key takeout from the 500kWe biogas plant model is that this project **is not feasible**. This is because the operational expenses (OPEX) exceed the revenues and this relates directly to scale. It should be noted that even if 100% of the CAPEX for this 500kWe biogas plant was to be covered by grant funding, it is still **not feasible.**

Conversely, the 3MWe plus biomethane biogas plant (equivalent to 4.48MWe and displacing 2,500 tonnes/year imported LPG) is not only viable, but also profitable showing an internal rate of return of 14.02% and a strong positive present value from year one. Additionally, and importantly, as set out in 'Attachment C: Guide and background information in support of the UNIDO Tonga baseline HTG economic model', this project will become more profitable and more socioeconomically influential over time.

It should be clearly noted that both debt financiers and equity investors are ready to support this project. This support is contingent on securing 'Green Climate Fund' CAPEX support for the specific key project elements identified in Attachments B and C.

4 The fundamental feasibility drivers

4.1 Tropical photosynthesis

Next to Tongans, tropical photosynthesis is **inarguably** Tonga's most enabling natural advantage. Tonga's inexhaustible ability to grow prolific amounts of biomass in support of food, feed, fibre, energy, organic fertiliser, and bio-products underpins the ability to transition to an equitable, prosperous, sustainable, and largely self-determined circular economy. However, tropical photosynthesis on its own is only part of the enabling story.

4.2 Enabled by Anaerobic Digestion, biogas and digestate

At the heart of a biogas plant is the passive biological process of 'Anaerobic Digestion' (AD). AD has evolved over billions of years into biological perfection.

The process of AD takes place within the 'digesters' of a biogas plant in the absence of oxygen and light. These are 'anaerobic' conditions.

The organic materials processed within the digesters are called 'substrates'. Through the exquisite, synergistic biological processes of AD, these substrates are deconstructed, repurposed, and value-added.

Substrates are presented in a multitude of forms. However, irrespective of how these substrates are presented, when we retrace the chain of creation of the organic material carried within these substrates we arrive directly, or indirectly, at photosynthesis as the enabling biological process. Therefore, the digesters of a biogas plant are the point of convergence between the products of photosynthesis and AD. What ensues from this point of convergence; from this biological deconstruction, repurposing and value adding, is total resource recovery and zero waste.

Digesters come in many shapes, sizes, and functionalities (Figure 2 and Figure 3). However, they are always this point of convergence between the products of photosynthesis and AD.

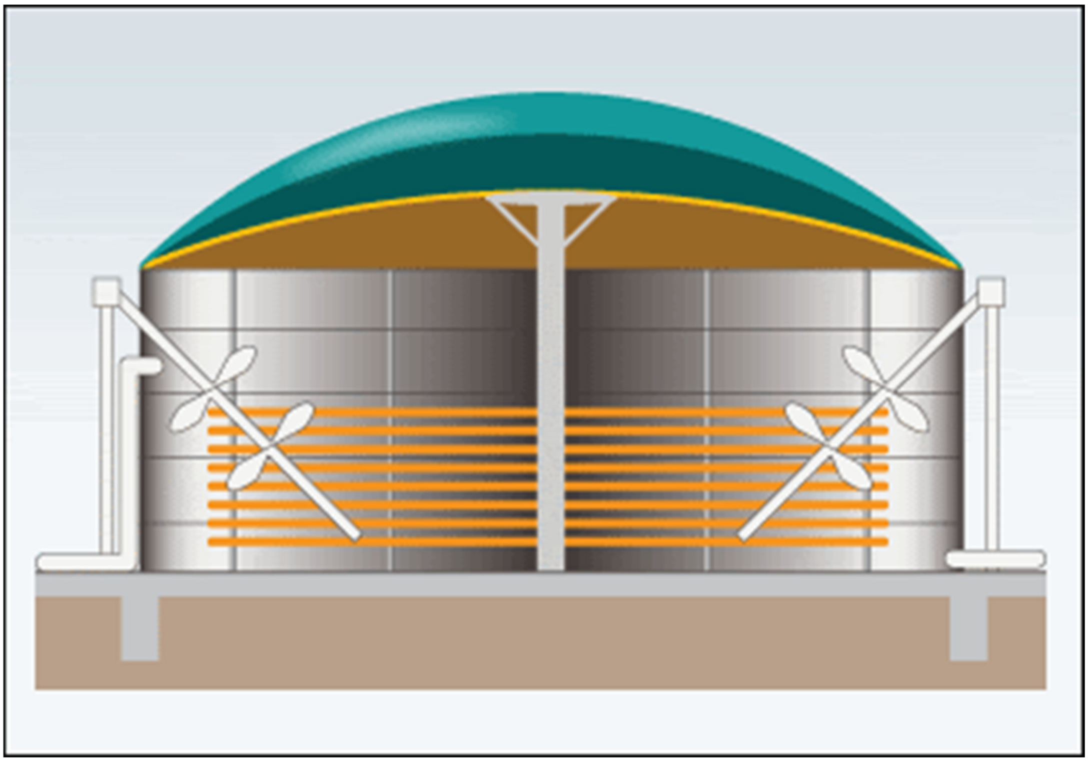

Figure 2: A CSTR digester (Completely Stirred Tank Reactor) where organic material from photosynthesis is presented within a, mixed, homogenous liquid biosuspension (the substrates) for Anaerobic Digestion to produce Biogas and Digestate

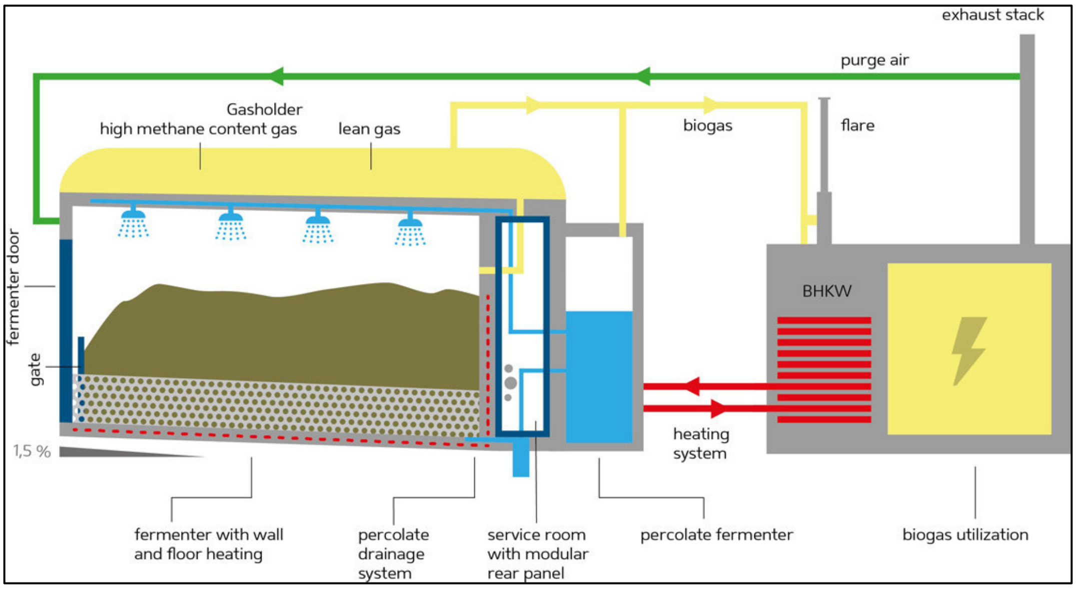

Figure 3: A 'Batch Sequential Dry Digester' (Box Digester) where organic material from photosynthesis is presented as dry, 'stackable' substrates for Anaerobic Digestion to produce Biogas and Digestate

4.3 Based on pillars of sustainable certainty

The two primary products produced by AD are biogas and digestate. Inarguably, two of the most socioeconomically empowering elements that will enable Tonga's ability to transition to an equitable, prosperous, sustainable, and largely self-determined circular economy are biogas and digestate. Therefore, the transition to a Tongan circular economy can be as certain as the photosynthesis that drives it and the AD that enables it.

5 Substrate feasibility Part #1 - Long-term circular economy enablers and drivers

5.1 Enabling and enabled by expansive agricultural and agri-industrial systems

Ultimately, the sustainable supply of substrates in support of a full-service Tongan biogas sector will come from expansive, agricultural, and agri-industrial aligned circular economy systems driven by tropical photosynthesises and enabled by AD, biogas and digestate.

Tonga presents with a completely 'clean sheet' in support of the development of such circular economy systems and this in-fact is a considerable advantage as the design, development, and implementation of such systems can be optimised from the outset.

A number of readily implementable and commercially financeable agricultural and agri-industrial aligned circular economy systems have been investigated in cooperation with the Tongan 'Ministry of Agriculture Food and Forestry' (MAFF). This process included over 40 broad-based community and stakeholder engagements spanning the agricultural sector, the commercial sector, the aid/donor sector, the finance sector, the Government sector, and the broader Tongan society.

A range of implementable and financeable agricultural and agri-industrial circular economy systems discussed were including:

- A complete, vertically integrated poultry meat sector
- The expansion and modernisation of the existing egg sector
- A complete, vertically integrated dairy sector
- A complete, vertically integrated multi-livestock red meat sector
- Grains and feed milling
- A commercial fish processing sector that leverages off Tonga's large Exclusive Economic Zone
- An inshore, high value seaweed sector
- A grass based biorefinery.

All these systems can be enabled by AD, biogas, and digestate and in-turn, all but one of these systems will support the sustainable supply off substrates in support of AD, biogas, and digestate. This is the circular economy at its most enabling.

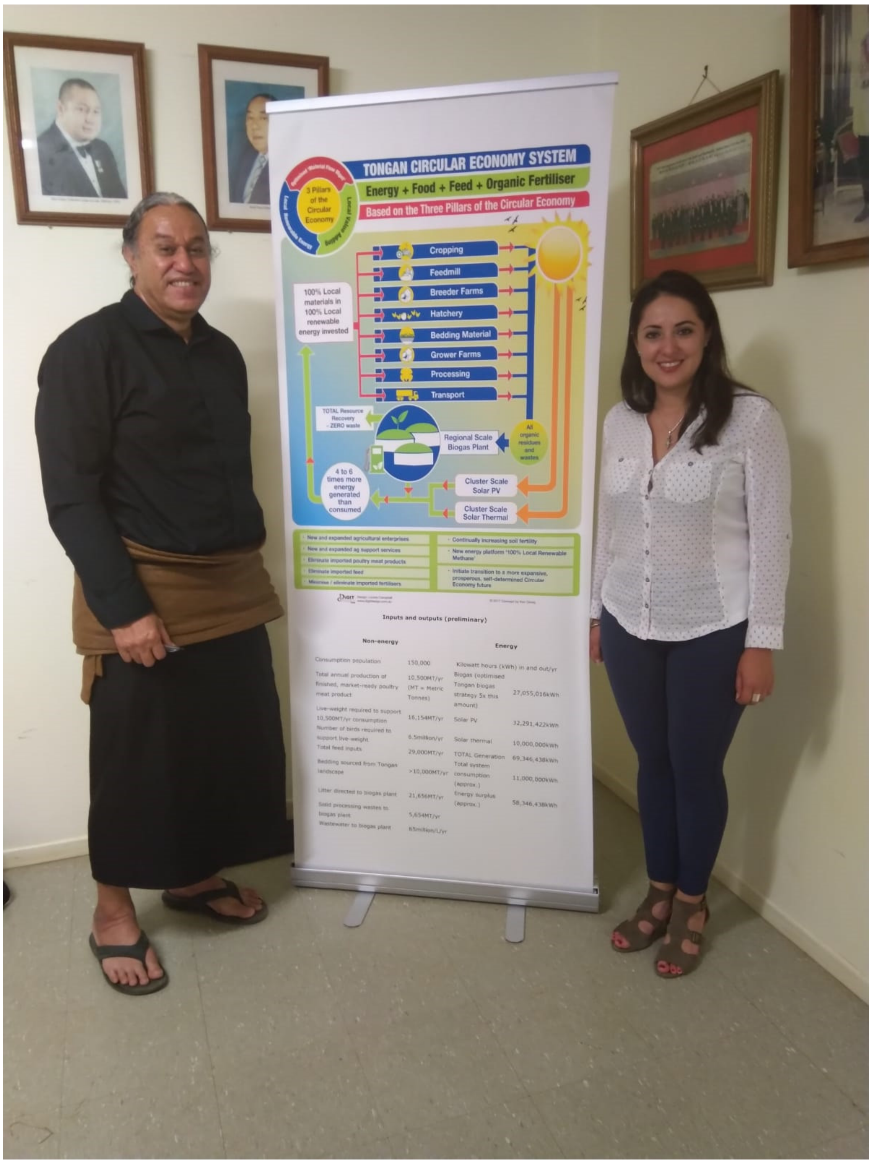

Figure 4: Dr Viliami Toalei Manu: CEO of MAFF and Miss Karen Guerrero with the poultry aligned Tongan Circular Economy System designed by the author

6 Substrate feasibility Part #2 - Specific substrates in support of the initial 3MWe plus biomethane biogas plant

6.1 Developing a sustainable supply of high-security substrates

A commercial/industrial scale biogas plant must be based on a source of high security substrates. These high security substates can support the co-digestion of a wide range of opportunity substrates. However, a source of high security substrates is essential.

The challenges related to opportunity substrates in Tonga have been adequately covered in: DELIVERABLE II BASELINE AND RESOURCE ASSESSMENT TO SUPPORT INDUSTRY SCALE BIOGAS PLANT IN TONGA - Part I: Report on resource availability and sustainability.

What this section covers are two specific, multi-purpose crops that have multiple roles to play in the development of Tongan agricultural and agri-industrial aligned circular economy systems. These same crops have a more immediate role to play as high-security substrates in support of the proposed 3MWe plus biomethane biogas plant. These crops are:

1. Hybrid Tropical Grass
2. Redlands Leucaena

Hybrid Tropical Grass (HTG) is well understood as a biogas plant substrate and the baseline economic analysis that forms part of this report has been based on HTG as a mono-substrate.

Redlands Leucaena is a crop worthy of thorough investigations within the detailed planning, engineering, and consent authority approval phase as an integrated cropping element in support of the HTG.

6.2 About HTG

HTG is a C4, sterile, non-invasive hybrid of Pennisetum purpureum x Pennisetum americanum which can only be propagated from canes. HTG is also known as Hybrid Napier Grass, Super Napier Grass, and Napier Pakchong 1.

HTG was originally developed by the Thai Department of Agriculture in support of their evolving dairy industry. As a general rule, any biomasses that are readily digestible by cows are also digestible within the digesters of a biogas plant.

Viewed strategically, HTG was specifically developed by the Thai Department of Agriculture to leverage off Thailand's prolific and inexhaustible photosynthesis resources. This makes HTG and excellent foundation crop on which to initiate Tonga's biogas sector.

HTG supports a high yielding and relatively low input perennial cropping system (Figure 5) able to deliver yields of over 500 Metric Tonnes (tonnes) of fresh matter/hectare/year through multiple harvests throughout the year.

Figure 5: High yielding HTG supports yields of over 500tonnes of fresh matter/hectare/year via multiple harvests throughout the year

6.3 The history of HTG as a biogas plant substrate

Investigations into the use of HTG as an energy crop based substrate for biogas plants in Thailand began in 2011/2012.

In February 2013, a support programme called 'Distributed Green Generation for Community Enterprises' was passed by the Thai National Energy Policy Council (NEPC) which is an advisory board to the Thai Government. This programme was aimed at the development of energy crop based biogas plants which in-turn formed part of the Thai Government's strategy to enhance the development of distributed and community-based renewable energy systems: particularly for rural areas.

In 2014, specific work was undertaken in support of developing the technical and financial aspects of HTG based biogas plants. This work was led by the 'Energy Research and Development Institute -Nakornping, Chiang Mai University' (ERDI-CMU) and was supported by:

- The Thai Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy
- Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

This early Thai work is captured in the following attachments:

- Attachment D: 'Thailand - New support for community-based biogas: Distributed Green Generation for Community Enterprises'
- Attachment E: 'Napier Grass for Biomass and Biogas Projects: Technical and Financial Aspects for Thailand'.

6.4 Where HTG can be grown in Tonga

In cooperation with Malaysian based HTG experts, BSW Energy Malaysia (BSW), an initial desktop analysis has been undertaken to determine the extent of land on the main Island of Tongatapu that could support HTG. This desktop analysis considered land use maps supplied by MAFF (Figure 6) along with climate and related agricultural information sourced from the 'Tonga Climate Service for Agriculture' (ToCSA).

Based on this desktop analysis, BSW concluded that some 21,921.45ha of Tongatapu could support the production of HTG with average as-harvested fresh matter yields of up to 500tonnes/ha/year. This 21,921.45ha is equivalent to 84.15% of the total Tongatapu land area of 26,050ha.

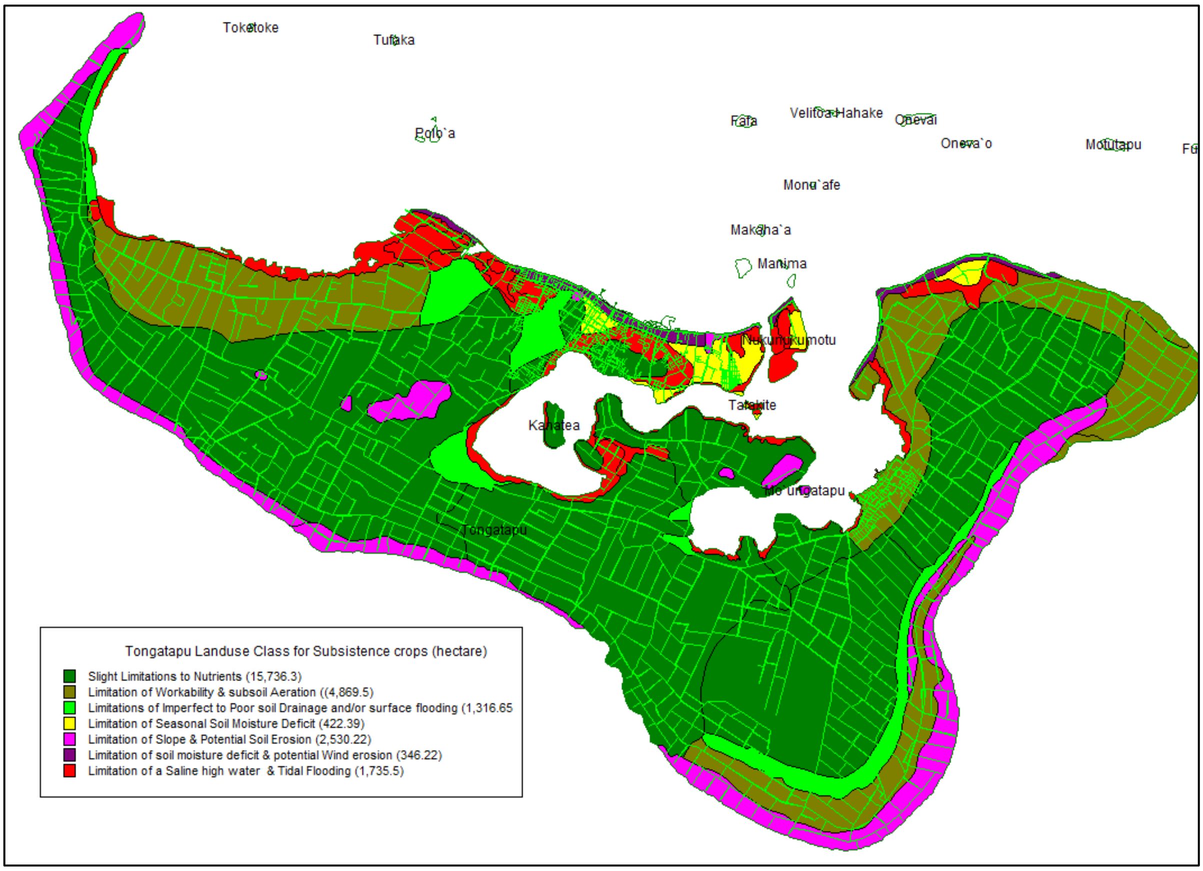

Figure 6: Potential HTG cropping areas of Tongatapu total 21,921.45 ha

6.5 Fallow land on Tongatapu in support of HTG

Table 1 below is based on information sourced from the 2015 TONGA NATIONAL AGRICULTURAL CENSUS MAIN REPORT. The report established that some **7,758ha (45%)** of Tongatapu's agricultural land was fallow at the time of the census.

	Total Agricultural land. ha (acres)	Perennial crop. ha (acres)	Annual crop. ha (acres)	Animal yard. ha (acres)	Pasture ha (acres)	Fallow less than 5 years ha (acres)	Fallow 5 years & above ha (acres)	Total fallow land ha (acres)	% Fallow
Tonga	26,874 (66,406)	1,298 (3,207)	9,712 (23,999)	170 (421)	1,966 (4,858)	10,2972 (25,445)	3,348 (8,272)	13,645 (33,717)	51%
Tonga tapu	17,265 (42,663)	471 (1,163)	7,344 (18,148)	71 (176)	1,572 (3,885)	6,477 (16,006)	1,281 (3,166)	**7,758** (19,172)	45%

Table 1: Agricultural land use statistics for Tonga and the main Island Tongatapu taken from the 2015 TONGA NATIONAL AGRICULTURAL CENSUS MAIN REPORT

6.6 An industrial scale outcome supported from a small HTG footprint

It can be determined from the accompanying baseline economic model (Attachment B) that the HTG cropping footprint to support the 3MWe plus biomethane plant is just 372ha.

This 372ha is merely 4.8% of the 7,758ha of fallow agricultural land on the main island of Tongatapu. This is the very essence of the enabling power of tropical photosynthesis.

6.7 HTG implementation protocol

A Tonga implementation protocol has been established in cooperation with BSW Energy Malaysia and MAFF. This protocol will enable the rapid development of a commercial HTG sector against a modest implementation cost. The implementation protocol is as follows:

- Import 250kg to 300kg of planting stock (sterile cuttings) via airfreight.
- This will support an initial planting area of 450m2 to 500m2.
- After 3 to 4 months (1 month for establishment, then 2-3 months of growth), the first harvest will occur with this first harvest used for replanting a site of approximately 1.5ha.
- Much of the biomass from this site will be used for demonstration, teaching, yield assessments, digestion trials, feed trials etc.
- This 1.5ha area will be enough to start a Tongan HTG sector with no further imports required.
- An approximate budget for this establishment protocol is USD$60,000.

- If a larger budget can be found, it would be advantageous to duplicate or triplicate this implementation protocol with planting material sourced from more than one tropical region.

6.8 HTG supported and enhanced by Redlands Leucaena

Leucaena (Leucaena leucocephala) is a long-lived leguminous forage tree with a proven ability to fix large amounts of atmospheric nitrogen whilst concurrently supporting the production of large quantities palatability, digestible, and energy dense biomass.

Leucaena has been naturalised in Australia for over 100 years and Australia's peak scientific body, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) has been conducting research and development in support of Leucaena since the 1950's.

In northern Australia, Leucaena is incorporated into forage systems in support of Australia's beef industry (Figure 8 and Figure 8) and this has been the main focus of research and development.

In recent years Leucaena research has been expanded to better understand and quantify Leucaena's ability to fix large amounts of soil carbon. Whilst Tongan soils are generally fertile, the depletion of soil carbon is a growing problem.

Leucaena is already present in the Tongan landscape. However, it's not cultivated nor used as a livestock feed.

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Figure 7: Leucaena incorporated into forage systems in support of Australia's beef industry

Figure 8: Leucaena incorporated into forage systems in support of Australia's beef industry

6.9 A sustainable source of nitrogen and a co-substrate in support of HTG

As a long-lived leguminous forage tree, Leucaena has the ability to fix large amounts of atmospheric nitrogen. Given this, Leucaena could potentially be used as a source of Nitrogen in support of growing HTG in Tonga. This possibility is worthy of detailed investigation and trialling.

Beyond its ability to fix large amounts of atmospheric nitrogen, Leucaena's palatability, digestibility, and ability to support high live-weight gains in beef cattle indicate that Leucaena also has a significant role to play as a co-substrate for biogas production.

Again, as a general rule, any biomasses that are readily digestible by cows are also digestible within the digesters of a biogas plant.

6.10 Redlands Leucaena

One of the persistent challenges in using Leucaena within cattle forage systems in Australia has been its susceptibility to psyllid insect (Heteropsylla cubana) infestations. These infestations reduce yields by up to 50%.

A new variety of Leucaena, given the commercial name of Redlands Leucaena, has been specifically bred to address the issue of psyllid infestations whilst concurrently enabling enhanced productivity under more tropical conditions.

Although it's beyond the scope of this report, there's a reasonable expectation that Redlands Leucaena can be used in Tonga to meet the nitrogen demands of the HTG whilst concurrently supplying additional biomass for co-digestion.

Whether an integrated HTG/Leucaena strip-based cropping system or separate HTG/Leucaena cropping systems linked through the strategic use of digestate would deliver the best outcomes needs to be determined through specific trials and testing.

6.11 Enhancing silage outcomes

Indications are that co-ensiling HTG and Leucaena will yield positive silage outcomes. Depending on the frequency of HTG harvesting, and the harvesting methods used, the dry matter (DM) content of HTG green-chop (fresh matter) can be <20%. This is considered a low DM content for ensiling.

Work undertaken by the University of Southern Queensland (Investigating the Economic Viability and Methods of Harvesting and Storing Leucaena) shows Leucaena green-chop has an average DM content of 38% (Figure 9).

Table 4.1: Moisture content of fresh leucaena green chop.

Sample no.	Wet Weight (g)	Dry Weight (g)	MC (wet basis)	DM
1	130	50	62%	38%
2	230	85	63%	37%
3	265	100	62%	38%
4	*285*	*120*	*58%*	*42%*
		Mean:	**62%**	**38%**

Figure 9: Dry matter content of Leucaena green-chop

6.12 Ensiling HTG and HTG/Redlands Leucaena

Whether the HTG is used as a mono-substrate or HTG and Redlands Leucaena are used as co-substrates; this biomass must be ensiled.

An optimally designed, constructed, and operated 'silage clamp' will be essential to the operation of the proposed 3MWe plus biomethane biogas plant.

Ensiling is the simple compression and compaction of organic material of a suitable particle size (approx.7mm) and dry-matter content (approx. 30%) within a confined space to exclude air and create a predominantly anaerobic environment within the 'silage clamp' (Figure's 11 and 12).

Under these compacted and confined conditions, the pH of the biomass drops and certain organic acids are formed. These organic acids and the lowered pH act as natural preservatives, preserving both the energy content and the nutrients carried by the biomass.

The silage clamp is used as an energy bank and the cropping systems provide intermittent inputs into the energy bank whilst the biogas plant makes daily withdrawals.

In essence, this silage clamp is a large organic battery capable of storing vast quantities of energy over time-spans measured in months and years. A comprehensive risk mitigation assessment will form an important part of the detailed planning, engineering, and consent authority approval phase to determine the size of this organic battery.

Figure 10: Silage is created by the compaction of organic material with a suitable dry-matter content (approx. 30%) within a confined space to exclude air and create a predominantly anaerobic environment within the silage clamp

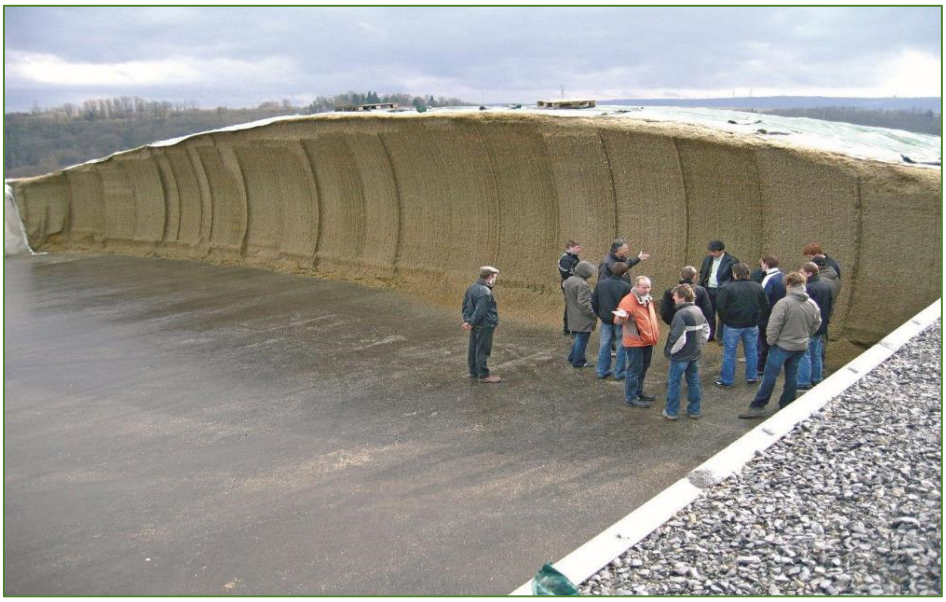

Figure 11: A 'silage clamp' is a large organic battery

7 Technical feasibility Part#1: High level technical overview

As stated in Section 2, at the heart of a biogas plant is the passive biological process of 'Anaerobic Digestion' (AD). AD has evolved over billions of years into biological perfection.

What modern, commercial biogas plants are based on is wrapping layers of infrastructure, technologies, and systems around this AD process in order to control and leverage off what is naturally produced.

A modern, commercial biogas plant is a unique synergy of biological processes and technical systems and how these systems are integrated and managed is central to the feasibility of a commercial biogas project.

Basing the development and implementation of this 3MWe plus biomethane biogas plant on world-best-practice technologies, systems, know-how, and experience is essential to the long-term success of this project.

The selection of the companies, practitioners, and professionals that will design, implement, and commission this project must be considered against their ability to support a 30-plus year in-service horizon.

8 Technical feasibility Part#2: Specific technical responses in support of the 3MWe plus biomethane biogas plant

8.1 The general configuration of the key substrate handling and biological processing system elements

After careful consideration of a wide range of influential factors, the consultant team recommends the following general configuration for the substrate handling and biological processing system elements:

- **3 x solid feeders aligned to a mechanical / thermo-mechanical substrate pretreatment system**: 3 solid feeders will dispense the HTG silage (or HTG/Redlands Leucaena silage) and other solid substrates into a multi-element mechanical / thermo-mechanical substrate pretreatment system.
- **A concrete pre-tank**: A concrete pre-tank will accommodate the receival and dispensing of any liquid, semi-solid, and pumpable opportunity substrates that may be available.
- **A multi-element mechanical / thermo-mechanical substrate pretreatment system**: A multi-element mechanical / thermo-mechanical substrate pretreatment, conditioning, and dispensing system will receive substrate inputs from both the solid feeders and pre-tank and render these substates into an optimised, homogenised, and inoculated biosuspension prior to dispensing into the primary digesters.
- Feeding an optimised, homogenised, and inoculated biosuspension into the primary digesters enables:
    - higher Organic Dry Matter (ODM) loading rates,
    - lowered viscosity of the homogenised biosuspension supporting more efficient mixing, lower power consumption, and a longer in-service life of the mixers,
    - and higher biogas yields against reduced retention times.

- **3 x concrete tank based, high-solids, thermophilic primary digesters:** 3 x concrete tank based, high-solids, thermophilic primary digesters with mixing systems optimised to support the complete mixing of the biosuspension with an ODM loading rate of 6.5kg/m3 and a retention time of 45days.
  The multi-functional and multi-directional interconnection of the 3 solid feeders, the pre-tank, the multi-element mechanical / thermo-mechanical substrate pretreatment system, and the 3 primary digesters will be arranged to enable minor and major servicing to be undertaken whilst still operating the plant at full capacity.
  The frequency and intensity of tropical storms in Tonga means traditional double membrane biogas storage roofs are not applicable for the primary digesters. Therefore, the primary digesters will be equipped with concrete roofs.
- **An advanced, covered lagoon based secondary digester:** An advanced, covered lagoon based secondary digester leverages off Tonga's favourable climate for such systems and this system will offer a further 100 days (minimum) of retention time.
  This covered lagoon based secondary digester will also support large amounts of biogas and digestate storage.
  The lower profile of the advanced covered lagoon and the ability to use the excavated material to form earthen protective barriers around the lagoon as protection against tropical storms are strong advantages of this system. Additionally, the use of heavy-duty HDPE for the lagoon cover further strengthens the technical responses against damage from tropical storms.

8.2 Combined Heat and Power Systems (CHP's) and biogas to biomethane upgrading with CO2 capture

The configuration of the biogas conditioning system, the CHP's, and biogas to biomethane upgrading with CO2 capture will need to be developed through the detailed planning, engineering, and consent authority approval phase. However, a few performance parameters can be established.

- **Efficiency benchmarks and CHP services:** The CHP's must be able to support a minimum 42% electrical efficiency and 45% thermal efficiency. Additionally, rapid start-up and shut down along with ability to supply the full range of grid support services (voltage regulation, frequency control, peak demand response) must be supported by the CHP package.

- **The biogas conditioning and biogas to biomethane upgrading system:** The biogas conditioning system along with the biogas to biomethane upgrading system must be selected against the system's ability produce a minimum biomethane methane concentration of 99.5% with zero methane slip. The system must also enable the capture of the CO2 potentially as a food grade product. It is anticipated that part of the biogas to biomethane upgrading system will be thermal energy driven as there is likely to be a surplus of thermal energy available.
  Minimising energy self-consumption will be a further priority in relation to the biogas conditioning and biogas to biomethane upgrading system.
  There are many variables that will impact the configuration of the biomethane compression and dispensing systems. These variables will need to be methodically work through in cooperation with the existing LPG importer and retailer during the detailed planning engineering and consent authority approval phase.

9 Economic feasibility

The economic feasibility of the 3MWe plus biomethane biogas plant is captured in Attachment's B and C.

The baseline economic model clearly shows that the project is not only feasible, but also profitable and will become more profitable over time.

It should be clearly noted that both debt financiers and equity investors are ready to support this project. This support is contingent on securing 'Green Climate Fund' CAPEX support for the specific project elements identified in Attachment's B and C.

10 Deliverability

10.1 Attracting the best of what the European biogas sector has to offer

This 3MWe plus biomethane biogas plant is large enough and sufficiently technically appealing to attract the best of what the European biogas sector has to offer. Succinctly stated, this biogas plant makes a clear statement that Tonga is serious about developing a full-service Tongan biogas sector.

The deliverability of this project is contingent upon engaging suitably experienced, world-best-practice, biogas and biogas related companies, practitioners, and professionals in support of methodically progressing this project through the three required development phases:

1. conceptual planning (partially completed)
2. detailed planning, engineering, and consent authority approvals
3. construction and commissioning

The selection of the relevant companies, practitioners, and professionals must be considered against their ability to support a 30-plus year in-service horizon.

10.2 Strong relationships have already been established

Strong relationships with a range of relevant companies, practitioners, and professionals have already been established in support of this project. These relationships were forged through the expansive body of work enabled by the Tongan 'Ministry of Agriculture Food and Forestry' (MAFF) and through this UNIDO related work.

10.3 The main deliverability challenges – the agricultural and related systems

The main deliverability challenges this project must address are related to the agricultural systems supporting this project. It is for this specific reason the bulk of the Green Climate Fund CAPEX support has been allocated to the development of these agricultural and related systems. This targeted and specific support is essential to the success of this project.