4. Feasibility Study

WASTE -TO -ENERGY OPTIONS IN MONROVIA, PAYNESVILLE, AND SURROUNDING TOWNSHIPS IN LIBERIA

FUNDED BY THE EUROPEAN UNION

Cities Alliance
Cities Without Slums

HOSTED BY UNOPS

This study was conducted within the context of implementation of the project "Implementing Waste-To-Energy Innovative Approaches in Greater Monrovia"

Title:
Waste -To -Energy Options In Monrovia, Paynesville, And Surrounding Townships In Liberia

4. Feasibility Study

Cities Alliance – 2021

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CONTENTS

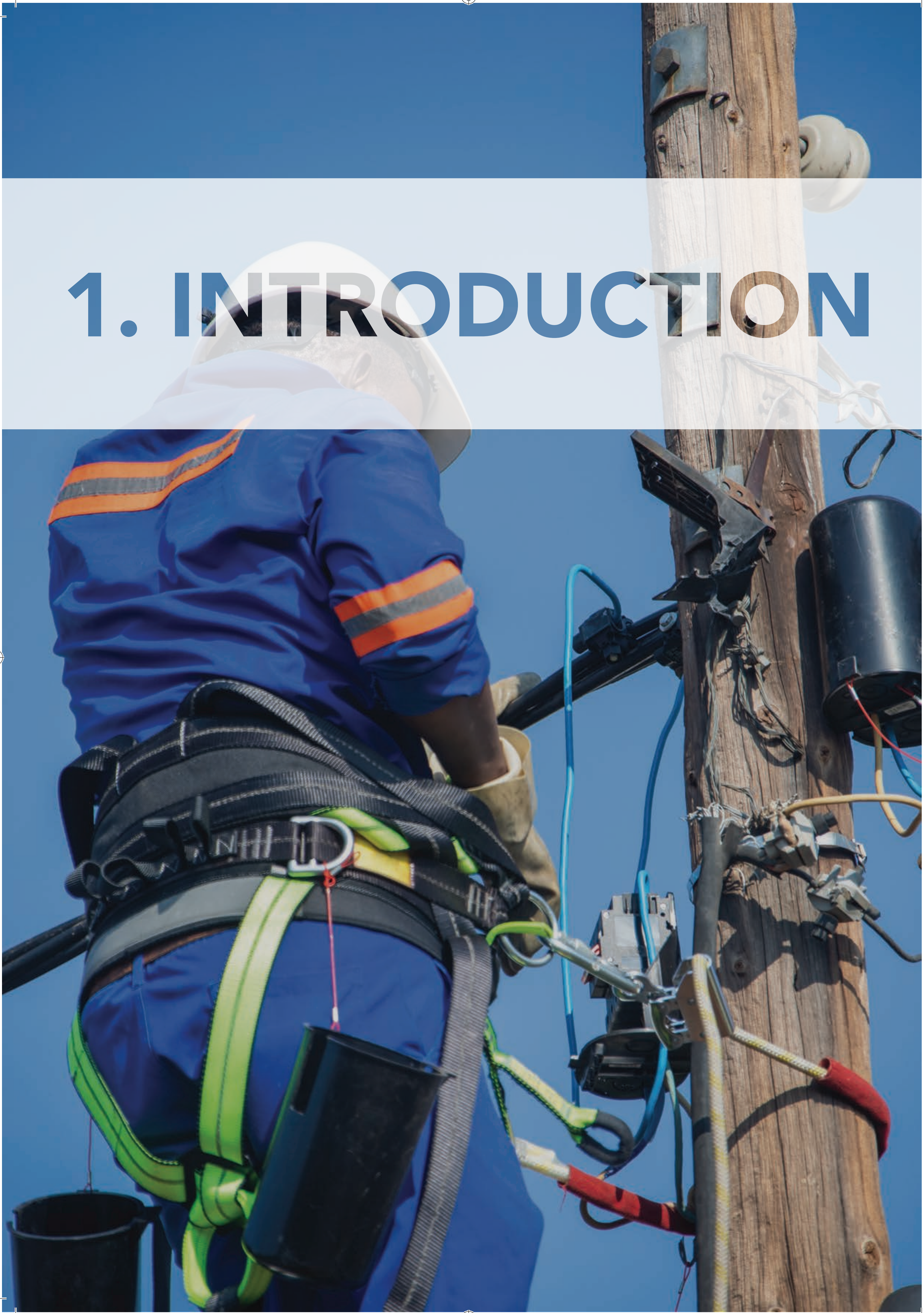
Home Biogas Unit Installation & End User Training

Home Biogas Unit Monitoring and Lessons Learned

ILLUSTRATIONS

TABLES

1. INTRODUCTION



The Feasibility Study on Waste-to-Energy (W2E) Options in Monrovia, Paynesville, and Surrounding Townships in Liberia (W2E Feasibility Study) is a component of the EU-funded UNOPS Cities Alliance Programme. The project is one of numerous ongoing activities related to improving solid waste management in Monrovia, funded by various organisations and donors including Cities Alliance, EU, World Bank, and others. The client for this project is the Cities Alliance Liberia Country Team.

The overall objective of the study is to identify small-scale, community-based W2E initiatives that can be piloted in the project area by Cities Alliance, with implementation to proceed as soon as possible after completion of the Feasibility Study.

WNL Development Solutions Ltd. (WNL) in association with Soft White 60 Corporation (SW60), hereinafter referred to as the Consultants, submitted a proposal to carry out the W2E Feasibility Study in November 2018. Negotiation meetings were held 7 December 2018 as well as on 5 February and 7 February 2019, and WNL/SW60 subsequently entered into a Contract for the assignment with UNOPS on 12 February 2019.

Activities on the project commenced mid-February 2019 with obtaining travel visas and logistical arrangements for the Consultant's foreign staff arrival in Liberia. The project team mobilised to Monrovia for the Inception Mission on 3 and 4 March, with the project kickoff meeting occurring on 5 March 2019.

The first deliverable under Phase I of the Project, the Inception Report, provided a review of the study methodology after the initial approximately 2-week on-site period of the project that included conducting a technology review, site visits/field investigations, and stakeholder meetings. The Inception Report was submitted in draft format to Cities Alliance on 22 March 2019, with the final version incorporating client feedback and resulting modifications submitted on 14 April 2019.

The Inception Report – based on a rapid analysis of available technologies, the municipal solid waste (MSW) profile and the constraints of the project setting in Monrovia, as well as stakeholder inputs – recommended implementation of a very small-scale waste-to-energy demonstration project based on dry anaerobic digestion (Dry AD). The pilot project would deal with organic waste only, comprising the following:

- Two (2) pilot projects with one located in a market area, and another possibly in a non-market area, with the precise locations to be determined in Phase II of the study based on additional field research to identify the locations best suited to the intent of the pilot project.
- Utilising a commercially available Dry Anerobic Digester (Dry AD) unit.
- Utilising the biogas generated to produce electricity and running some small electrical appliances from this electrical source to demonstrate the technology and create interest in the project. Batteries may be used to store power to make the electrical source more stable and reliable.
- Different technical configurations and equipment may be used at the two sites to enable a better comparison between them as to what works and what does not.

- Investigating the use of the biogas for cooking and also possible for vehicle fuel.
- Possibly utilising dried sewage from public toilets to enhance to capacity of the system and also to demonstrate a way of dealing with public toilet waste.
- Possibly utilising the digestate for production of compost/fertiliser.

The proposed project concept was approved by Cities Alliance as a suitable technology and approach for moving forward. The project concept presented in the Inception Report also required a revision to the Consultant's work plan to accommodate Cities Alliance's request that the scope of work for the Feasibility Study incorporate design and preparation of tender documents for the pilot projects. A revised work plan, Work Plan Rev #1, was presented by the Consultant in the latter part of April 2019 and was approved in late May, with a final approved revised work plan submitted on 30 May 2019.

Phase II of the project, the Feasibility Study stage, commenced in late April 2019 according to Work Plan Rev #1. The revised work plan included an international study tour to conduct further technical research and to visit W2E sites utilising AD in Europe and Africa. The results of the international study tour were presented in July 2019 and showed among other things that:

- Dry AD could not be practically implemented in the very small-scale size range contemplated for the pilot projects and therefore the project would need to be based on somewhat more complex Wet AD technology.
- While the Wet AD technology for a W2E system was definitely feasible and had been implemented elsewhere in Africa, the operation of the proposed pilots plants would be more complex than initially anticipated, and that ongoing technical assistance for a minimum of 1-2 years, and perhaps more, would be required to get the pilot systems fully functional on a consistent basis.
- The pilot projects, due to their small size, would not be financially viable, and would require ongoing financial support.

Due to the inability of the Cities Alliance project or the government of Liberia to provide the ongoing necessary financial support and technical assistance, the risk of failure of implementing the proposed pilot projects was viewed as unacceptably high. As such, other options were explored, and a decision was made that the pilot project would comprise the installation and monitoring of approximately 100 micro-scale residential type biogas units that would use utilise organic waste and produce biogas to be used for cooking purposes. These systems would still meet the overall objectives for the pilot project, being small-scale, community-based W2E initiatives that are replicable and scalable. Additionally, the pilot project could be implemented within the available project budget and timeframe, while being technically much simpler and without the same requirement for ongoing Technical Assistance. Thus, it could be implemented within the framework of the Cities Alliance project with much lower risk.

Note: throughout this report various sizes of AD units are referred to. These include as follows:

1. Micro-scale: This applies to residential size AD units (for example the Homebiogas units or Oekobit HoMethan units) capable of handling up to approximately 200 kg/day organic waste.
2. Very small-scale: this applies to systems capable of handling in the order of 200-500 kg/day organic waste, for example the originally proposed pilot systems.
3. Small-scale: This applies to systems capable of handling in the order of 2,000-10,000 kg/day organic waste.

These are very approximate capacity ranges only. In previous correspondence and presentations with the client, the micro-scale and very small-scale systems may have been incorrectly identified as "small-scale" systems. Throughout the remainder of this report, systems are defined generally along the lines of the above classifications. For example, the "Small-Scale Biogas System Testing Phase" (Phase III) included in Work Plan Rev #2 has been renamed within this report to "Micro-Scale System Testing Phase" to properly identify the size of the systems.

However, the reference to "small-scale" systems in relation to the overall project, the project objectives and initial ToR may encompass all of the above sizes of systems and is a more general reference to all types of smaller systems as opposed to larger scale centralised MSW systems.

It was further determined that the volume of organic food waste generated at the residential level in Greater Monrovia would be too low to support the operation of the micro-scale biogas units. Utilisation of the biogas would also present challenges, so the units would need to be located at institutional facilities such as schools and universities, government offices, and private businesses (hotels and restaurants) that had the ability to generate the necessary volumes of organic food waste and also utilise the biogas for cooking purposes. Cities Alliance also decided that an initial testing phase comprising installation of 10 of the micro-scale residential type biogas units should be carried out as part of the current consultancy, prior to fully committing to the installation of the 100 units for the pilot project.

At the same time, it was also agreed that the current consultancy assignment should prepare a proposal for a longer-term solution to the waste management problem in Greater Monrovia, particularly in relation to markets, along the lines of the originally proposed pilot projects utilising Wet AD Technology. It was agreed that the proposed project should be located at Omega Market and of a size that could potentially supply the electrical needs of the new market, as well as to power cold rooms, with the intent that this project could be implemented as a separate funding initiative at a later date.

This change in project approach required a second revision to the Consultant's project scope and work plan and was also to be accomplished within the original consultancy budget. A proposed Work Plan Rev #2 incorporating the above changes as well as the procurement, installation, and monitoring of 10 micro-scale biogas units, was presented to Cities Alliance on 2 August and approved on 6 August through a contract amendment.

The approved Work Plan Rev #2 includes:

- **Phase I: Inception Report (completed in April 2019)**
- **Phase II: Completion of the Feasibility Study**
- **Phase III: Micro-Scale Biogas Systems Testing Phase (re-named as per above)**

As a result of these changes, the Feasibility Study will be completed to a lower degree of detail than previously envisaged. The Micro-Scale Bio-Gas Testing Phase will install 10 units of the residential type biogas systems, prior to the subsequent planned full rollout of the 100 units in 2020.

This report presents the Feasibility Study component of the project, which is the primary deliverable of Phase II, and is intended to satisfy Milestone 3 of the contract.

This Feasibility Study Report, as presented, is considerably different than originally intended, and is not a typical "Feasibility Study Report" due to the change in the scope and project work plan that occurred in July and August 2019, more than halfway through the project. The overall consultancy project now combines three components as follows:

- Initial research, which was completed from March through early July 2019;
- Preparing a design concept for a possible future W2E project at Omega Market based on Wet AD technology; and
- Implementation of a testing phase for 10 micro-scale biogas systems.

As such the "Feasibility Study Report" as presented should be viewed more as a summary of the work completed to date – this includes elements of the feasibility study prior to the scope change and an update on progress of the Micro-Scale Biogas Testing Phase – as well as a conceptual level proposal for a larger future W2E project.

Along these lines, this Feasibility Study Report is organised as follows:

1. Introduction
2. Project Scope and Work Plan Changes
3. Work Completed for Feasibility Study Report

The above sections are essentially a summary of events and work completed on the project to date. This is followed by the sections below, which describe the ongoing and future initiatives of the project.

4. Proposed Pilot Project – Option 2
5. Micro-Scale Biogas Testing Phase Status Update
6. Proposal for Omega Market W2E Project
7. Conclusion

Background and supporting information are included in Appendices I through XI. Due to the large volume of information in the appendices, the overall report is bound in two Volumes:

- Volume I: Main Report (this report)
- Volume II: Appendices

This report was initially submitted as a Draft Report on 16 September 2019. Comments on the report have been received from Cities Alliance and incorporated into this Final version of the report. The final version of this report is being prepared with the benefit of having implemented a portion of Phase III of the project, the Micro-Scale Biogas Testing Phase, and as such, the Conclusion of the report has been modified to provide comments on the original ToR and objectives of the project.

This final version of the report serves as fulfilment of project Milestone 3.

2. PROJECT SCOPE AND WORK PLAN CHANGES

This section of the report describes the original ToR for the Consultancy and the changes in scope and work plan that have taken place over the course of the implementation of the services.

2.1 Original project objectives and scope

The overall objective of the consultancy is to conduct a feasibility study that will identify small-scale W2E pilot projects in the project area (Monrovia, Paynesville, and surrounding communities). The proposed pilot projects could be containerised, modular, or otherwise and will need to be suitable for the local environment, which is a low-income, low-capacity, high unemployment, post-war and post-Ebola crisis situation.

The proposed pilot project(s) should also be replicable and scalable and ideally should be community-based. The pilot project(s) will also need to consider gender inclusivity and mainstreaming.

The study was to include a Business Model of the proposed initiatives, an Action Plan for implementation, possibly ToRs for the design of the system, and transfer of knowledge to relevant stakeholders through facilitation of knowledge transfer discussions and workshops.

The consultancy was originally to be conducted over a period of three months and to include the following phases:

- **Phase I** **Inception Report**
- **Phase II** **Feasibility Study**
- **Phase III** **Action Plan**

The original project ToR and Work Breakdown Structure showing activities and tasks of each phase and relevant Meeting Minutes are included in Appendix IA. The original project deliverable schedule is shown in the following table.

Based on requests from Cities Alliance and insights gained during the implementation of the study, there have been two revisions to the project scope and work plan as described in the following sections. These changes represent a significant change in direction of the project, have been agreed with Cities Alliance, and are being implemented by the Consultant.

TABLE 1: Original Deliverable Schedule

No.	Deliverable	Date
1	Project Kickoff Meeting	5 March 2019
2	Inception Report	20 March 2019
3	Feasibility Study	19 April 2019
4	Action Plan	5 June 2019
5	Workshops	To be determined

2.2 Work plan revision #1

During project negotiation and follow-up meetings on 5 and 7 February 2019, Cities Alliance made it clear that their requirement as an outcome of the feasibility study was to have a waste-to-energy option(s) fully designed and ready for rapid implementation at the conclusion of the Consultant's work (to commence implementation by September 2019).

This required a fairly significant change in the Consultant's scope of work, to incorporate detailed engineering design and preparation of bidding documents into the study, which were not included in the original ToR or budget. To accommodate this request it was agreed that as part of the Inception Report, the Consultant would conduct a rapid assessment of W2E technologies and quickly hone-in on one technology that would be viable and suitable for the solid waste situation and capacity constraints prevailing in Monrovia and the financial limitations of the project. Based on the research carried out in the Inception Stage, it was proposed to proceed to develop two pilot projects on the basis of Dry Anaerobic Digestion. This recommendation was subsequently approved by Cities Alliance as a suitable technology for the pilot project.

After approval of the Inception Report, as earlier agreed with Cities Alliance, the Consultant submitted a revised work plan (Work Plan Rev #1) on 22 April 2019 to carry out the remainder of the project in accordance with the recommendations given in the Inception Report and complying with Cities Alliance's request to incorporate detailed design and preparation of tender documents for the pilot systems within the work of the study. This work plan was approved in the latter part of May 2019, and a final version of Work Plan Rev #1 was submitted to Cities Alliance on 30 May 2019 showing completion of the project by mid-September 2019.

Work Plan Rev #1 is included in Appendix IB along with relevant Meeting Minutes. Contract Amendment #1 also included in Appendix IB was signed on 5 July 2019 to extend the project completion date to 16 September 2019 in accordance with Work Plan Rev #1.

2.3 Work plan revision #2

During Phase II of the project, other significant project scope and work plan changes were discussed and agreed to as a result of various meetings and presentations held between Cities Alliance and the Consultant, the Project Technical Committee, Monrovia City Council (MCC), and Paynesville City Council (PCC) in July 2019 at the conclusion of the study tour carried out by the Consultant in June and July 2019. Key outcomes of the study tour and the resulting decisions made to change the project scope are as follows:

i. Although the Consultants initially proposed Dry AD as the pilot project technology, Dry AD vendors with solutions suitable for the very small-scale size range for the proposed pilot project(s) could not be identified. The location of the pilot project in Liberia was viewed as high risk, which further exacerbated the vendor identification issue.

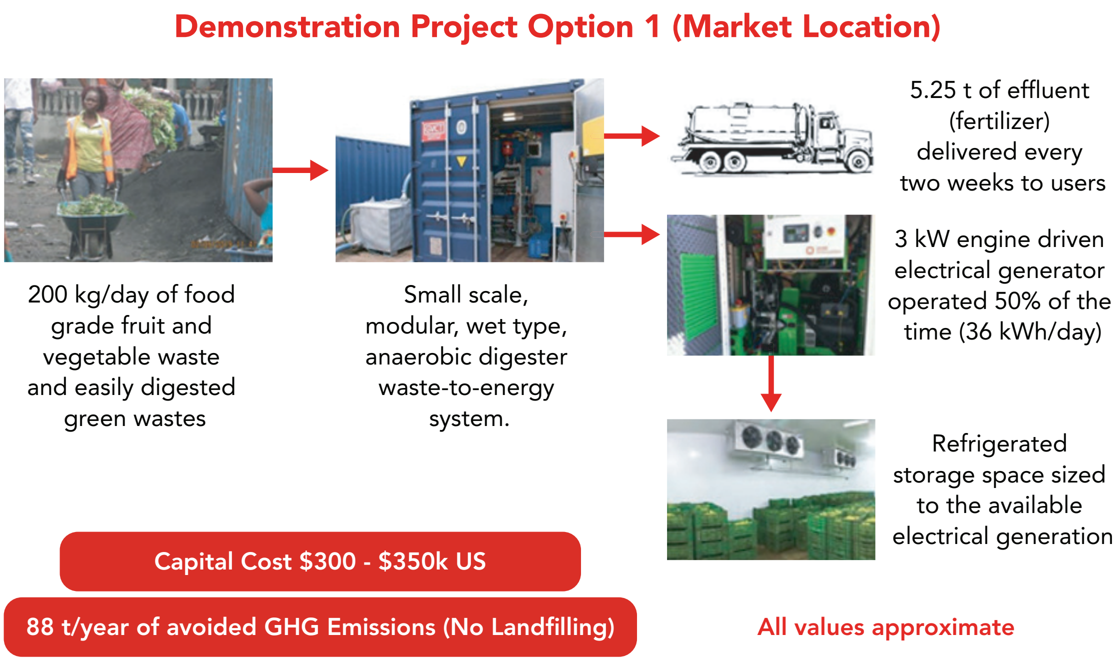
ii. Due to the challenges associated with finding a suitable Dry AD equipment vendor described above, the Consultants instead pursued a Wet AD technological solution, for which suitable vendors and equipment in the right size range could be found, with the technology proven to work within the African context.

iii. Sustainable implementation of Wet AD however, was determined to be more complex than initially anticipated, particularly within the African environment, where organic waste streams are of relatively low energy content. This became apparent during the study tour of installations in Ghana and Kenya. While sustainable Wet AD implementations are certainly possible, each successful African example analysed required a minimum of 1-2 years to achieve smooth running operations, during which time significant financial and technical support was required. The time required to get the systems running smoothly is related to the fact that the AD equipment is designed around developed country waste profiles, which contain a lot more energy, and as such, systems need to be tweaked through trial and error based on the lower energy feedstock. This is compounded with lack of resources available in Africa to modify the equipment to suit the local conditions.

iv. Two options for Wet AD were identified:

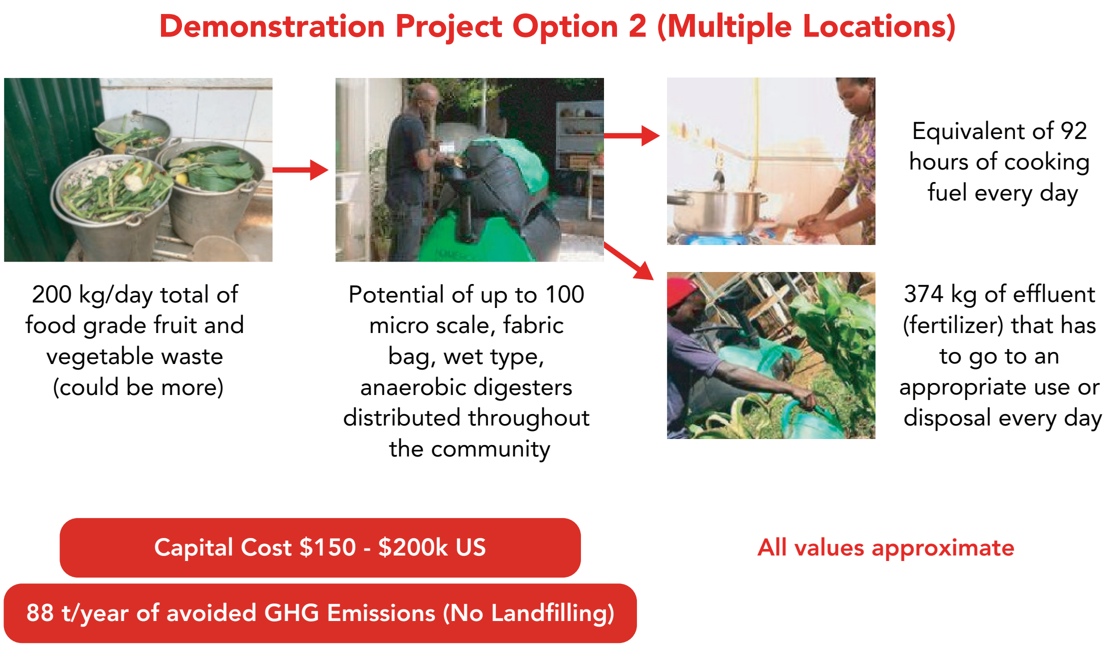
   - Option 1 – Construct a very small-scale Wet AD system to be located at a market site that would produce approximately 3 kW of electrical energy from the biogas generated, with the electrical energy used to power a small cold storage facility, and the digestate used for downstream production of compost by others.

FIGURE 1: Graphical representation of Option 1



- Option 2 – Install approximately 100 micro-scale residential type biogas units, with the biogas to be used for cooking. It was determined that the environment in Greater Monrovia is not suitable to install these units in residences due to low waste volumes, but would be appropriate for institutional facilities such as schools, universities, technical colleges, large government offices, restaurants, and hotels that have enough waste to enable the units to function properly, and could also effectively utilise the biogas for cooking purposes.

FIGURE 2: Graphical representation of Option 2



v. Due to the relative complexity of operations and the need for interim financial and technical support to achieve smooth operations – that is not available from either Cities Alliance or the government of Liberia – as well as the long construction timeframe and the cost of Option 1 (which is at the limit of the project budget), this alternative was viewed as having a high risk of failure.

vi. Due to lower cost, complexity, and project risk, the Consultant then further explored and elaborated on Option 2, which was subsequently agreed by all parties as the preferred option for implementation under the project.

vii. However, it was also agreed by all parties that as a longer-term solution to the waste management problem in Greater Monrovia, and particularly in market areas (a proposal along the lines of Option 1, but of a larger size, to be located at the new Omega Market site and that could potentially supply the electrical needs of the new market, as well as to power cold rooms) should be further explored and should be presented as part of the current feasibility study to enable sourcing of funding for such a project after the conclusion of the current project.

viii. Finally, Cities Alliance indicated that before committing fully to the implementation of Option 2, they would like to test approximately 10 of the small home-based bio-gas units to develop lessons learned to be incorporated into the design of the pilot project for the implementation of Option 2.

Based on the decisions to change the project scope, as outlined above, the Consultant was subsequently requested to submit a proposal for a revised methodology and work plan to incorporate the above, while working within the existing budget of the Consultant's contract. The revised methodology and work plan were presented in the Consultant's Proposal to Incorporate Small Scale Bio-gas Units Testing Phase into Project, dated 2 August 2019. This proposal was accepted by Cities Alliance in Contract Amendment #2, signed on 8 August 2019.

The Contract Amendment has resulted in several notable milestone and deliverable changes, including:

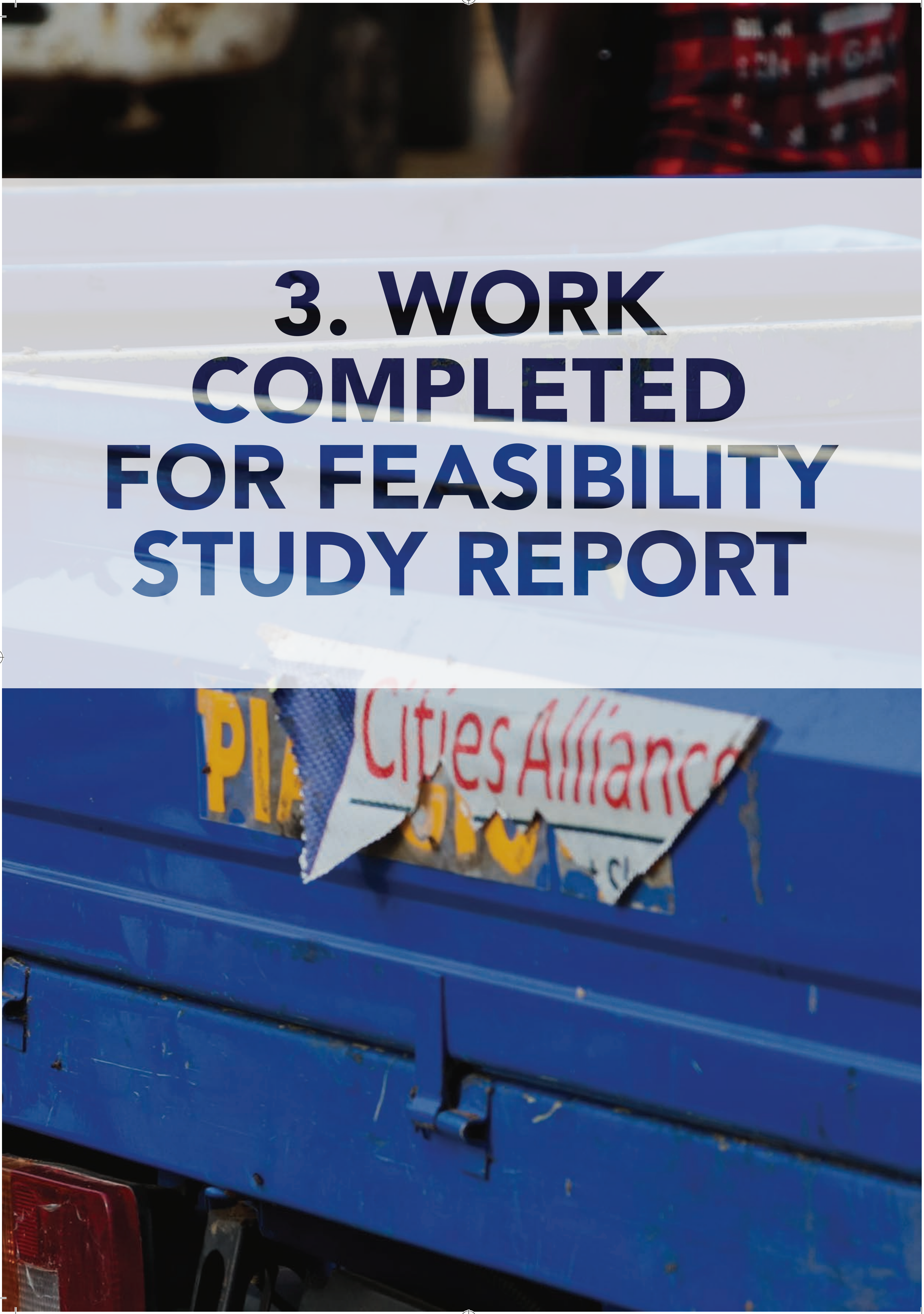
1. Project phases will now be:
   - **Phase I:** **Inception Report**
   - **Phase II:** **Feasibility Study (Completion)**
   - **Phase III:** **Micro-Scale Biogas Systems Testing Phase**

   The Feasibility Study will be done to a lower level of detail, to save budget for implementation of Phase III, which will include the purchase, installation, and monitoring of 10 micro-scale biogas systems (HomeBiogas units). Phase III will also include capacity building and training for counterpart staff from MCC and PCC so that they can continue monitoring the units and to develop capacity for the subsequent planned installation of 100 units after the testing phase.

2. Key milestone delivery dates are as follows:
   - **Feasibility Study:** **31 August 2019**
   - **Units Installed and End Users Trained:** **24 October 2019**
   - **Installation and End User Training Report:** **31 October 2019**
   - **Monitoring and End User Support Completed:** **15 November 2019**
   - **Final Report and Handover of Project Documents:** **15 December 2019**
   - **Contract End Date:** **31 December 2019**

Presentations and Meeting Minutes with respect to the study tour, options reviewed, decisions made, the Consultant's Proposal to Incorporate Small Scale Bio-gas Units Testing Phase into Project (Work Plan Rev #2) and Contract Amendment #2 are included in Appendix IC.

3. WORK COMPLETED FOR FEASIBILITY STUDY REPORT



As stated previously, the overall project approach and work plan changed significantly as a result of a series of meeting in July 2019, when the Consultant was more than halfway through the work of the Feasibility Study Report according to the requirements of the approved work plan at the time (Work Plan Rev #1).

It is important to present this information – of work completed prior to the change in project approach – both as a historical record of work performed by the Consultant and to serve as a future reference for other W2E initiatives. This section of the report therefore presents details of the work carried out by the Consultant in Phase II of the project (Feasibility Study), prior to the change in direction of the project.

Information is presented according to the original 14 activities that were to be included in the Feasibility Study Report. Activities that are no longer being done or shifted elsewhere as a result of the change in project approach and work plan are also described.

At the end of this Section, in sub-section 3.15 we also present a summary of the research carried out by the Consultant during Phase II of the project.

3.1 Rapid assesssment of organic waste

A community-based waste-to-energy concept relies upon the source separation of organics. Additionally, the organics received must be of a type that can be digested. As such, the Rapid Assessment of Organic Waste activity was added to the project to gather data on organic waste characteristics in two, possibly three locations as follows:

1. Red Light Market
2. Duala Market
3. Possibly one other location that would be in a non-market area.

The objective of this activity was to confirm if there is enough organic waste available – and the characteristics of the waste – to undertake the pilot project and also to provide information on organic waste for purposes of planning for project scale-up.

This activity became necessary because a review of available reports indicated that there was no available data on waste characteristics in Monrovia based on actual field sampling – all data in the various reports reviewed was based on information extracted from previous reports that assumed the characteristics of the waste. As no suitable data existed on the actual composition of organic waste available within MCC and PCC, efforts were made to address this shortcoming, specifically, the levels of easily-digested food waste in relation to the more challenging-to-digest lignocellulosic wastes (including green vegetative matter such as leaves, stems, and branches). Subsequently, a programme was put in place to sample the organic wastes at various sites and determine the quantitative and qualitative characteristics of the organic wastes received. This in turn would facilitate a clearer direction on the type, scale, and siting of AD pilot project facilities.

During the Inception Phase of the project, numerous locations, including markets and skip bucket sites, were evaluated for setting up a micro or small-scale AD system. The market locations were deemed to be the most feasible, as arrangements could be made with the CBEs to collect organic waste separately from market vendors. The waste received at the skip bucket locations is already mixed and requires separation. Making arrangements with individual households to separate their organic waste was deemed impractical within the short timeframe of the study. Further evaluation of the market and skip bucket sites were part of a programme referenced as the Rapid Assessment of Organic Waste programme.

3.1.1 METHODOLOGY

The methodology applied at the market locations involved CBEs collecting only organic waste directly from market vendors and delivering the waste to a location within the market equipped with a mass scale and data collection staff. This entailed working with CBEs to coordinate organic waste-only deliveries and having vendors cooperate by separating their waste types. Figures 3 through 5 highlight the consultations and training carried out. The staff conducted a sensory evaluation of the delivery (primary visually and olfactory), weighing the delivery, photographing the delivery, and recording the necessary information. Appendix II contains the data collection sheet utilised. Deliveries were made continuously throughout the day, and the data collection was conducted over a period of five days, after which the data was analysed and summarised.

FIGURE 3: Collaborating with CBEs to complete rapid assessment of organic waste

FIGURE 4: Consulting with vendors on source separation of organic waste

FIGURE 5: Training workers on gathering quantitative and qualitative data on waste organics

3.1.2 RED LIGHT AND DUALA MARKETS

Organic waste data collection at the Red Light Market was conducted 17-22 April while the Duala Market was conducted 2-7 May. Figures 6 to 9 below highlight the various tasks undertaken at the market locations.

FIGURE 6: Gathering a delivery to be weighed and evaluated

FIGURE 7: Fruit waste delivery being weighed and evaluated

FIGURE 8: Vegetable waste delivery being weighed and evaluated

FIGURE 9: Green leafy waste (lignocellulosic waste) delivery being weighed and evaluated

Results

On average, approximately 1,000 kg per day of waste was received at the Red Light Market location. The organic waste receipt rate was approximately 150 kg per hour. Easier to digest fruit and vegetable waste comprised 45% of the organic waste delivered. On average, 50 kg per day of delivered organics would be rejected; essentially, materials that are very difficult to process and digest, such as hard shells, stones, dirt, and other deleterious material. The average particle sizing in the material was 7% semi liquid, 39% less than 5 cm in length, 53% between 5 and 20 cm in length, and 1% greater than 20 cm in length. The particle sizing identified the level of preprocessing required to prepare the organic feedstocks for AD.

The summary analysis of organic waste collection at Red Light Market is presented in Table 2.

Similar overall results were obtained at the Duala Market and for brevity the summary analysis is not presented here.

TABLE 2: Summary Analysis of Organic Wastes at Red Light Market

Day	Duration	Organic Waste Delivered	Average Organic Waste Delivery Rate	Food Waste in Delivery	Percentage of Food Waste in Delivery	Potential Biogas Production from Organic Waste in Delivery
	h	kg	kg/h	kg	%	m^3/day
1	5.25	497	95	454	91%	48
2	7.00	967	138	620	64%	79
3	6.50	942	145	290	31%	62
4	7.00	1,204	172	528	44%	87
5	7.00	1,395	199	375	27%	89
Average	6.55	1,001	153	454	45%	73

	Potential Biogas Production from Food Waste in Delivery	Percentage of Energy from Food Waste in Delivery	Potential Quantity of Digestate Generated from Delivery	Potential Quantity of Rejected Waste from Delivery	Estimated Percentage of Partical Sizes in Organic Waste Delivered			
	m^3/day	%	kg	kg	Semi Solid	< 5 cm	5 to 20 cm	> 20 cm
	45	95%	423	25	17%	29%	48%	6%
	62	78%	822	48	0%	61%	39%	0%
	29	47%	801	47	8%	51%	41%	0%
	53	61%	1,023	60	3%	36%	61%	0%
	38	42%	1,186	70	7%	19%	75%	0%
	45	62%	851	50	7%	39%	53%	1%

3.1.3 MAMBA POINT SKIP BUCKET

The organic waste data collection at the Mamba Point skip bucket was conducted 11-15 June. The Mamba Point skip bucket location was evaluated in a similar manner to the market locations, except for the requirement to manually separate the organics from the mixed waste deliveries. This effort is anticipated to have lower accuracy as a result of the challenges related to separating mixed waste consistently. Figures 10 to 12 highlight the various tasks undertaken at the skip bucket location.

Results

The findings indicated that approximately half of the mixed waste delivery was comprised of organics, and approximately half of the organic waste was classified as easier-to-digest materials, similar to the market locations. For brevity, the summary analysis is not presented here.

FIGURE 10: Sorting mixed waste deliveries at Mamba Point skip bucket

FIGURE 11: Sorted waste being evaluated

FIGURE 12: Example of sorted food waste

3.1.4 SUMMARY OF RAPID ORGANIC WASTE ASSESSMENT

Overall, the organic wastes common in MCC and PCC are fruit and vegetative wastes, comprised of approximately 50% easily digested materials and 50% more challenging-to-digest materials (lignocellulosic materials). No meat or dairy-type organic wastes were identified. This distinction is important; if meat and dairy products are present in the organic waste, it requires pasteurisation of the feedstock, digestate, or effluent to remove pathogens if the digestate and effluent are to be used for other purposes, such as composting or fertiliser. Without the presence of meat and dairy organic wastes, pasteurisation may not be required, which could enable a simpler overall AD process. However, the downside of not having meat and dairy products in the waste stream is that the energy content of the waste is lower.

Results of the rapid assessment of organic waste indicate the following:

- Source separation of the organic waste was successfully achieved at each market site. At Red Light Market, 1,000 kg per day was collected during this pilot exercise, and it is believed that there could be in the order of 2,000 to 5,000 kg per day of organic waste available at Red Light Market alone. It is known that private companies are already collecting organic waste from various markets in relatively large quantities and using it for compost and other applications.
- Separation of organics was also achieved at the skip bucket location, although more complicated. The selected area (Mamba Point) is a relatively high-income area and also included restaurants, so the results from this exercise may not be representative of other skip bucket locations in terms of expected quantities or quality of organics.
- The quantity and quality of the organic waste from the market sites was determined to be sufficient to develop a very small-scale pilot AD W2E project, with potential to develop larger projects at a market (if the land can be made available). This supports the earlier recommendation given in the Inception Report that any pilot project should be based on organic waste from market sites. To support this, as part of our research and study tours, two projects were identified in Kenya and one in Ghana where organics were collected from markets and either used for composting or energy production. Information on these projects is given elsewhere in the report.
- However, with no presence of meat or dairy products in the organic waste stream, and 50% of the organics being lignocellulosic materials, the overall energy content in the waste stream is low, relative to what would be found in a developed country. This will present challenges in optimising the performance and output from an AD system and will reduce the overall energy output and economics of the system (compared to a similar system in a developed country).

3.2 Gathering of data for site selection

This activity was commenced in June and early July with MCC and PCC to identify appropriate sites for the pilot AD W2E systems, either at the market sites, or nearby where organic waste from the markets could be delivered. It was put on hold when the direction of the project changed in early July, as site selection would no longer be required.

3.3 Develop organic waste segregation methods

This activity was to look at methods of organic waste separation for the pilot project and for project scale-up considerations. This activity was not within WNL/SW60's scope of work and was to be done by the Consultant working on the Costed Model for Composting and Recycling Options, with the intent that WNL/SW60 would work closely with the other Consultants. WNL/SW60 made several attempts to coordinate this activity with the other Consultants, but without success, so efforts were eventually stopped. A review of the other Consultant's report did not show any efforts at developing methodologies for organic waste separation. Given that it was confirmed through the Rapid Assessment of Organic Waste at the market sites, that organic waste separation can be easily achieved at a market location, and the change in the direction of the project in July 2019, this activity is no longer required. If, in the future, projects are developed to implement AD W2E systems on a larger scale in non-market areas, development of organic waste separation methodologies would need to be revisited.

3.4 Confirm technical details/costing with vendors and develop vendor shortlist

This activity comprised additional research on AD systems that could possibly be deployed for the proposed pilot projects in MCC and PCC. This included identifying various AD project developers and equipment suppliers followed by discussions on their capabilities, system and equipment capacities, technical details, and estimated costs, as well as to gauge their interest in being involved in a pilot-scale project in Liberia. The focus was on European suppliers due to their leadership in the technology and preferably vendors with experience in Africa, or at least in other developing countries. The outcome of this exercise was intended to develop a final list of possible vendors to be considered for involvement in the implementation of the pilot project, matching up factors such as but not limited to:

- Available equipment in the size/capacity range required
- Performance of their equipment with the volumes and types of organic waste available
- Cost of their equipment
- Track record and reputation of the company
- Experience in environments similar to Liberia and level of interest of the company to be involved in a small pilot project in Liberia
- Ability to visit their factories and projects

Correspondence and discussions with several vendors were initiated during the Inception Stage but were put on hold temporarily until better information on the quantity and characteristics of the available organic waste were established through the rapid assessment of waste flows, described in 3.1 above. Discussions with vendors was re-initiated in May 2019 with the same group previously contacted as well as new vendors subsequently identified.

The following sections present some of the research carried out, vendors and other institutions contacted, types of AD systems reviewed, and insights gained towards the project through our discussions.

3.4.1 TECHNOLOGY REVIEW AND DEVELOPMENT OF TECHNOLOGY MATRIX

An extensive review was completed to identify and classify AD equipment and systems that would be appropriate for the long-term perspective and the pilot demonstration project. Corresponding details as to the configurations, capacities, and contact information for candidate systems were gathered. Table 3 lists 25 systems that were identified for consideration. Both Dry AD and Wet AD systems were reviewed. Additional details on the various systems are provided in Appendix III. This list was used, in part, to identify meetings and site visits for the subsequent International Study Tour that was conducted in June and July 2019.

The equipment systems have been grouped by pilot, long-term perspective, and other categories. Efforts were made to contact suppliers and assess the applicability of their products for the Liberia project. The market focus was deemed to be a major classification tool. The ideal systems were viewed as being pre-packaged, modular, low complexity, and affordable with broad applications to date. All systems were reliant upon receiving source-separated organics, rather than the large centralised-scale systems receiving unsorted bulk MSW. Each system has capabilities to generate biogas that can be used as an energy source for various applications such as heating, cooling, power, and/or transportation fuel.

In summary, the technology review identified the following major commercially available option categories:

1. Simple, micro-scale to small-scale, fabric bag, Wet ADs capable of receiving select types of organic waste (i.e. food grade fruit and vegetable waste and animal manure).
2. Pre-packaged modular, containerised/kit style, Wet ADs setup to handle broader types of organic waste (including food-grade fruit and vegetable waste and easily digested green wastes).
3. Dry-type, sequencing batch-fed digesters with minimal pre-treatment of the organic waste received.
4. Wet-type, continuous fed, complete mixed digesters with pre-treatment of the organic waste received.

The first three categories represent the most likely technologies that could be considered for the pilot demonstration project. In some instances, these technologies could be replicated at many distributed sites throughout the communities to provide an adequate capacity to address the organic wastes generated within those communities. The fourth category is more appropriate for a larger scale system and may be considered for the long term.

TABLE 3: Summary of Technologies and Vendors Identified for the Waste-to-Energy Project

Perspective	Technology Supplier	Location	Product	Technology Mode
Pilot	Qube Renewables	UK	DryQube	Dry, sequencing batch, flexible fabric covered, pile
			QuickQube	Wet, continuous feed, single stage, flexible fabric vessel
			BioQube	Wet, continuous feed, single stage, rigid tank
	Ökobit	Germany	HoMethan	Wet, continuous feed, single stage, flexible fabric vessel
	HomeBiogas	Israel	TG6	Wet, continuous feed, single stage, flexible fabric vessel
	Eggersmann	Germany	Convaero	Composting and biological drying under flexible fabric cover used to prepare organics as a Refuse Derived Fuel (RDF) for industrial applications
	SEaB Energy	UK	FlexiBuster	Dry, continuous feed, horizontal plug flow, rigid tank
	Agrikomp	Germany	Güllewerk Flex	Dry, continuous feed, horizontal plug flow, rigid tank
	Bioferm Energy (Viessmann)	USA (Germany)	EUCOlino	Dry, continuous feed, horizontal plug flow, rigid tank
Long-Term	BEKON (Eggersmann)	Germany	BEKON	Dry, sequencing batch, garage style, rigid container
	GICON	Germany	-	Dry, sequencing batch, garage style, rigid container
	Zero Waste to Energy (Eggersmann)	USA (Germany)	Smartferm (Kompoferm)	Dry, sequencing batch, garage style, rigid container
	Bioferm (Viessmann)	USA (Germany)	Dry Digester	Dry, sequencing batch, garage style, rigid container
	Strabag	Germany	LARAN	Dry, continuous feed, horizontal plug flow, mixed, rigid container
	KGBH	Germany	enbea Bots	Dry & Wet, two stage, garage style & mixed tank, rigid container

Format	Market
Shop packaged kit setup at site	Lower priced technology aimed at developing countries
Shop packaged kit setup at site	Lower priced technology aimed at developing countries
Shop pre-assembled package in shipping container for delivery to site	Competitively priced technology aimed at developing countries
Shop packaged kit setup at site	Lower priced technology aimed at developing countries
Shop pre-assembled package in shipping container for delivery to site	Technology priced to be competitive in its market niche in Europe
Stabilise and dry bulk material in preparation for pelleting, cubing, or bulk fuel	Lower priced technology aimed at developing countries
Shop pre-assembled package in shipping container for delivery to site	Waste Food Sector in Europe
Shop pre-assembled package in shipping container for delivery to site	Agriculture
Shop pre-assembled package in metal clad container for delivery to site	Environment and renewables
Cast-in-place concrete containers outfitted at site	International
Cast-in-place concrete containers outfitted at site	Environmental engineering projects worldwide
Shop fabricated steel or cast-in-place concrete containers outfitted at site	Municipal
Cast-in-place concrete containers outfitted at site	Environment and renewables
Site assembled plant	Environmental services in Europe
Cast-in-place concrete containers outfitted at site	Not confirmed

Perspective	Technology Supplier	Location	Product	Technology	
				Mode	
Long-Term	Hitachi Zosen INOVA	Switzerland	Kompogas	Dry, continuous feed, horizontal plug flow, mixed, container	
	Organic Waste Systems	Belgium	DRANCO	Dry, continuous feed, vertical plug flow, steel tank	
	Valorga	France	-	Dry, vertical tank with pressurised biogas mixing	
	HoST	Netherlands	Mircoferm	Vertical plug flow, cylindrical tank	
	Linde BRT	Netherlands	-	Custom build	
	Orgaworld	Netherlands	Biocel	Custom build	
	Anaergie	Canada	-	Custom build	
	Ökobit	Germany	-	Custom build	
Other	Schmack (Viessmann)	Germany (USA)	Services	Services	
	HomeBiogas	Israel	2.0	Wet, continuous feed, single stage, flexible fabric vessel	

Format	Market
Shop fabricated steel or concrete vessels outfitted at site	Not confirmed
Site assembled plant	Not confirmed
Site assembled plant	Not confirmed
Site assembled plant	Agriculture (nature of the organic feedstocks in Liberia may warrant consideration of ag-type systems)
Site assembled plant	Not confirmed
Site assembled plant	Not confirmed
Site assembled plant	Not confirmed
Site assembled plant	Not confirmed
Services	Not confirmed
Shop packaged kit setup at site	Lower priced technology aimed at developing countries

3.4.2 DRY AD PILOT PROJECT CONCEPTS REVIEWED

The Inception Report proposed that a very small-scale Dry AD treatment system fed with source-separated organics could be set up within a market(s), and the resultant biogas could be used for heating (cooking) and electricity (battery charging and cooling) applications, with the resultant digestate used for soil application. Refer to Appendix III for technical information on Dry AD. The Inception Report also indicated that if a cost-effective Dry AD could not be secured, then a very small-scale Wet AD treatment technology could be considered instead.

Three Dry AD options were identified that could potentially meet the budget and timeline criteria associated with the demonstration project. However, certain limitations were identified for each option. The following discussion outlines these options.

3.4.2.1 Option A – replicate the dry digestion biogas plant in Kumasi, Ghana (KNUST project)

Replicating a research and demonstration project undertaken at the Kumasi University of Science and Technology (KNUST) in Ghana is one option that was considered. This technology is not indicated in Table 3 above, because it is a research project rather than a commercially available system.

In this project, a shipping container was converted to serve as a dry-type, batch-fed, garage-style, anaerobic digester. This project, which was undertaken in 2013, was successful at generating biogas. However, the researchers recommended further refinement to improve biogas production and avoid potential biogas leakage from the container. Figure 13 illustrates the second generation of container converted for the KNUST project. The study team had planned on visiting this project while in Ghana, but due to security concerns at the University of Kumasi (where two Canadian women had been kidnapped just prior to the planned visit), we were advised not to come.

The primary drawback of this approach is that specialised expertise is required to correctly modify, setup, and operate a demonstration project. An example of someone with such expertise is the lead researcher from KNUST, who could potentially be retained to assist, if desired. Overall, this approach is viewed as risky due to several unforeseen challenges that could jeopardise a successful outcome to the demonstration project. The liability associated with a customised or homemade approach in a public setting also represents a significant concern. The cost of such a project was not established. Appendix IV contains a copy of the research paper on the KNUST project.

3.4.2.2 Option B – obtain a BEKON pilot-scale unit

A conversation with Mr. Philippe Laurencelle, the Manager of Sales for BEKON North America, revealed that a pilot-scale BEKON system could potentially be deployed for a demonstration project (refer to section 3.1.1 for additional information about BEKON Company). Figure 14 shows a cut-out view of the containerised pilot scale BEKON unit. Appendix V contains details on the pilot scale plant. The unit processes approximately 1m^3 of feedstock per batch. An approximate cost for the unit would be US $300,000, excluding biogas utilisation equipment, shipping, and setup in Liberia. The technology is also quite complex. This cost is too high for the pilot project and was not considered further.

FIGURE 13: Experimental Dry Anaerobic Digester deployed at the University of Science and Technology (KNUST) in Kumasi, Ghana

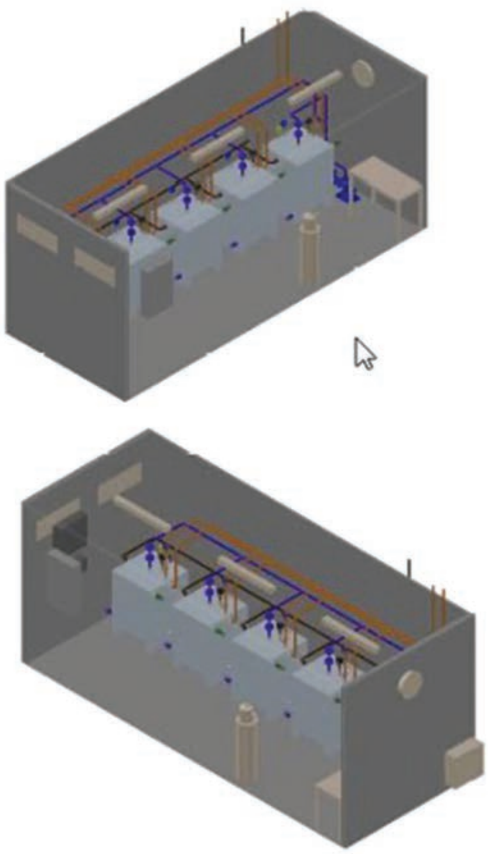


FIGURE 14: Cut-out view of the containerised pilot-scale BEKON unit

3.4.2.3 Option C – set up a Qube renewables dryQUBE

UK-based Qube Renewables (refer to section 3.8.3 for additional details) manufactures the dryQUBE, a fabric-based dry digester that permits biodegradable, stackable feedstocks to be digested in a controlled anaerobic environment. These digesters are quick to install, easy to operate, and require minimal earthworks; all positive features for a developing country setting. Standard modules are 500m^3 in volume. The technology, shown in Figure 15, is ideally suited for ligneous wastes (including straw, sawdust, and/or green waste) that require long retention times (>180 days). The modules can be customised to fit in any available space.

Qube Renewables is currently working on a three-year dry digestion project with Innovate UK, in collaboration with Straw Innovations Ltd., the University of Manchester, and the University of Southampton. The project is focused on the digestion of rice straw in the Philippines to biogas, or R2B. This project has been designed as a trial to generate energy onsite in the form of cooking fuel, electricity, and upgraded biomethane, as well as tackling the issue of unsustainable rice straw disposal. The majority of waste straw is currently burned, causing widespread environmental and human damage.

The dryQUBE is well suited to digesting the type of organic wastes from MCC and PCC, where high lignin-content organic wastes are anticipated. Conversely, actual food waste is anticipated to be relatively low. Examples of organic waste high in lignin include leaves, branches, and shells. The issue with the dryQUBE is the long retention time (180 days vs a more typical 30 days), which has an impact upon both space requirements and costs. Batching significant quantities of waste to suit a dryQUBE could also be challenging, as the demonstration project is anticipated to have only very small-scale organic waste deliveries of around tens of m^3 per day. Standard dryQUBE modules are $500m^3$ in volume. Utilisation of customised non-standard modules could present a risk as they are currently unproven. Appendix VI contains presentation materials received from Qube Renewables on the dryQUBE.

FIGURE 15: Overhead view of a dryQUBE installation in the Philippines

3.4.2.4 Summary of dry ad potential for the pilot project

Dry AD has many desirable features as a long-term solution to the MSW problem in Monrovia with significant greenhouse gas (GHG) reduction and economic benefits. Refer to section 3.10 for a discussion on the case for Dry AD as a long-term solution. This is why Dry Ad was recommended for the pilot project – so that it could set the stage and start to develop the capacity for implementing Dry Ad in the longer-term.

Despite the several advantages that Dry AD could provide, the technology review carried out has shown that the options available for implementation of Dry AD at the scale and budget contemplated for the pilot project are very limited and not attractive. This was compounded by vendors showing a lack of interest in a small project in Liberia. As such, Dry AD technology was ruled out for the pilot project. Fortunately, the technology review showed that there are several good options available for implementation of Wet AD for the pilot project, within the desired price and capacity range.

3.4.3 VENDOR SHORTLISTING

Following on the development of the Technology Matrix, the Consultant narrowed down the list through discussions with the various vendors to identify a short list. Some project developers, research institutes and technical associations that could serve as resources for the project were also identified. Table 4 below lists the organisations and individuals that were shortlisted for possible equipment supply for the project, and/or research institutes and technical organisations that could possibly provide support to the project.

TABLE 4: Short List of Project Contacts

Company	Location	Contact	Title	Email
Biffa/West Sussex Mechanical Biological Treatment (MBT) Plant	Horsham, UK	Dianne Dodsworth	Community Liaison & Environmental Compliance Officer	dianne.dodsworth@biffa.co.uk
QUBE Renewable	Wiveliscombe, UK	Jo Clayton	Director	jo@quberenewables.co.uk
Tropical Power	Oxford, UK	Mike Mason	Chairman	mike.mason@tropicalpower.com
Seab Energy	London, UK	Sandra Sassow	Co-Founder	sandrasassow@seabenergy.com
Ökobit	Föhren, Germany	Philipp Senner Montserrat Lluch Cuevas	Engineer Renewable Energy Engineer	Philipp.Senner@oekobit-biogas.com montserrat.lluch@oekobit-biogas.com
Eggersmann, Convaero, Bio-Dry	Bad Oeynhausen, Germany	Jan Gressmann	Geschäftsbereich biologische Systeme	J.Gressmann@f-e.de
BEKON	Unterföhring, Germany	Mr. Philippe Laurencelle	Manager of Sales for BEKON North America	philippe.laurencelle@bekon.com
German Biogas Association	Germany	Frank Hofmann	International Affairs Representative for Africa & Asia	frank@biogas.org
PlanET Biogas Solutions	Vreden, Germany	Christof Langguth	Sales International	C.Langguth@planet-biogas.com
PlanET Biogas Solutions	Nairobi, Kenya	Patrick Thimba	Agent	pthimba@gmail.com

Company	Location	Contact	Title	Email
Amiran Kenya	Nairobi, Kenya	Evelyn Otieno	Manager	EVELYNE.OTIENO@ amirankenya.com
Sistema Bio	Nairobi, Kenya	Steve Manyasi	Business Development Manager	steve@sistema.bio
Gorge Farm Energy Park	Sulmac Village, Lake Naivasha, Kenya	Mike Nolan	Manager	mike.nolan@ tropicalpower.com
GreenPact	Nairobi, Kenya	Leroy Mwasaru	President	leroy@greenpact. co.ke
Africa Biogas Partnership Programme	Nairobi Kenya	Victoria Ndung'u - Ndirangu	Manager- Monitoring & Evaluation / Carbon Finance	vndungu@hivos.org
Safi Sana Project Site	Ashaiman, Ghana	Gideon Annor Gyamfi	Representative	gideon@safisana.org
Kumasi University of Science and Technology	Kumasi, Ghana	Ebenezer Mensah	Professor	ebenmensah@gmail. com
Generizon	Rabat, Morocco	Manfred Schweda	Representative	generizon@ generizon.com
HomeBiogas	Israel	Alon Civier	Head of Support & Special Projects	alon@homebiogas. com

3.4.4 INSIGHTS GAINED

Valuable insights regarding the project were gained through discussions with several vendors and individuals. A few brief highlights are presented below:

3.4.4.1 Generizon

The Consultants contacted Mr. Manfred Schweda at Generizon, based in Rabat, Morocco. This firm represents several German-based technology providers in the waste-to-energy area, offering turn-key projects. They are currently active within West Africa in Ivory Coast. Mr. Schweda was familiar with Liberia overall, and felt that European companies would be reluctant to pursue a project in Liberia, particularly if it represented their first venture within Africa. However, he supported the approach to pursue source separation of organics and conversion to biogas via AD. The firm had completed similar work in Morocco.

3.4.4.2 GreenPact

The Consultants contacted Mr. Leroy Mwasaru, an AD entrepreneur and the principal of GreenPact in Kenya, to discuss options for deploying AD technology in Africa. Mr. Mwasaru began promoting AD while in high school. He went on to setup his Nairobi seed business related to the development and deployment of AD, comprised mainly of digesters sized from 8 to 10m^3 for institutions, communities, and farms. Typically, digesters are concrete block construction; however, going forward the organisation's plan is to diversify into other designs. Mr. Mwasaru stressed the importance of attitude shifts and cultural changes required to make projects succeed. He also felt that government should play a significant role in the support of AD, as it appears is happening in Kenya.

3.4.4.3 Planet Biogas solutions

The Consultants contacted Mr. Patrick Thimba, the Kenyan agent in Nairobi for PlanET Biogas (a German company). PlanET Biogas is one of the European companies that has been active in Africa trying to establish projects. However, no firm commitments have been made to date. A primary challenge for MSW is that the waste is not sorted. PlanET's technology only handles organic waste, and therefore separation is critical. Mr. Thimba was very helpful and expressed interest in the Liberia project.

3.4.4.4 German Biogas Association

In order to further assess technology providers' interest in participating in AD applications in Liberia, the largest biogas association in the world (German Biogas Association) was contacted. The Consultants contacted the Association's International Affairs Representative for Africa & Asia, Mr. Frank Hofmann. Mr. Hoffman indicated that the German Corporation for International Cooperation GmbH (GIZ) has been active in South Africa. He also indicated that GIZ may be a source of financing for developing in-country projects. Overall, he indicated that German AD companies have not had much success in Africa to date. He believed that past experience may pose a potential barrier to seeking involvement from German companies.

3.5 Develop itinerary for international study tour

Work Plan Rev #1 proposed an international study tour as part of the project, and this was accepted by Cities Alliance. Its purposes were to:

- Gather additional information on proposed technologies
- Have face-to-face meetings with suppliers
- See some of the proposed equipment in actual use
- Develop a better understanding of the operational and maintenance requirements of the systems
- Verify manufacturer's claims
- Learn about project criteria that will lead to success or possible failure of the project

The study tour was viewed as an essential element of the project that should be completed before proceeding with the design of the systems.

To maximise the benefits of the study tour, it was proposed to make site and project visits to as wide a cross-section as possible of the organisations and individuals shortlisted in the previous activity. The site visits would be to carry out inspection of manufacturer's facilities, confirm delivery schedules and quotations with manufacturers, and to visit sites where their equipment has been installed and is in use.

It was initially proposed to conduct visits in the following locations, subject to further discussions with the vendors:

- UK (2 different manufacturers)
- Germany
- Kenya
- Possibly Ghana (Ashaiman waste-to-energy project)
- Possibly Ivory Coast

The UK and Germany are two countries within Europe that are leading the development and deployment of waste-to-energy technologies, installations, and businesses, based upon AD and biogas utilisation. Kenya is one of the countries within Africa leading the development and deployment of AD for the treatment of waste and the production of biogas as a useful energy source. Ghana is a West African country that is also developing AD as a waste management solution and a renewable energy source.

It was initially proposed that two members of the Consultant team would visit UK, Germany, and Kenya on their way to Liberia, with a possible side trip to Ghana and Ivory Coast from Liberia. It was also initially proposed that personnel from Cities Alliance accompany the Consultant on at least some of these site visits.

The itinerary was to be developed in the first week of May, with the study tour taking place from 20-31 May. However, this was delayed due to the need for data from the Duala Market rapid waste assessment, which had encountered some delays as a result of local situations. The itinerary was therefore prepared in late May, with the trip planned for the first 2 weeks of June.

It was determined that Cities Alliance could not accompany the Consultant on the trip. The final selected countries were the UK, Germany, and Kenya, followed by Ghana. The final itinerary had the Consultant BioMass Engineer, Dennis St. George, going to the UK, Germany, and Kenya, while the Project Manager, Paul Maycher, would visit Ghana.

3.6 Book international study tour

The proposed itinerary was approved by Cities Alliance in late May and travel arrangements made accordingly for early June.

3.7 International study tour

The study tour was carried out from 3-12 June in the UK, Germany and Kenya, and 1 July in Ghana, not including travel time to and from the respective countries. Technology vendors, equipment distributors, project developers, and project sites were visited to evaluate best practices and seek guidance from the experiences of others, in order to identify the most suitable technologies and interest for the demonstration project in MCC and PCC. It was not possible to visit all the contacts on the short list, but we were able to cover a wide cross-section and visit the most important ones.

The following provides information on the study tour visits that were carried out.

3.7.1 BIFFA

Monday, 3 June 2019

Biffa/West Sussex Mechanical Biological Treatment (MBT) Plant, Horsham, UK

Primary Contact: Dianne Dodsworth

Plant Tour

FIGURE 16: Biffa/West Sussex Mechanical Biological Treatment Plant, rated for 100,000 tonnes per year of organic waste (310,000 tonnes per year of MSW)

Biffa's (a large waste management firm based in the UK) flagship project, a 310,000 tonne per year MSW Mechanical Biological Treatment (MBT) plant located near Horsham (south of London) UK, opened in 2016 based upon a 25-year agreement valued at £ one billion. The plant receives curbside household waste from the community of West Sussex (a community of over 800,000, with recycling programmes already in place), via trucks. The organic waste processing capacity of the facility is 100,000 tonnes per year, as received.

The facility currently employs 84 staff including truck drivers. The equipment within the plant shreds, sorts, and processes waste. Ferrous and non-ferrous metals are recovered and sold, while a blend, primarily of plastic and paper, is baled as

Refuse-Derived Fuel (RDF) and sold to power-generating stations, primarily within continental Europe. Organics are converted via Wet AD to biogas for fueling engine-driven electrical power generation with electricity exports to the grid. Waste heat is recovered for plant uses. Digestate is de-watered and the solids used as landfill cover for the nearby municipal landfill with water reused throughout the process. Elaborate environmental controls and monitoring are in place to mitigate impacts upon the local community.

The facility is an example of a one-site, complete waste management solution with emphasis upon energy production. The level of complexity and the high capital cost rule out serious consideration of the MBT option in the near term for the MCC and PCC waste-to-energy project. However, if community-based solutions cannot be adapted going forward, then an MBT plant located at the Cheesemanburg Landfill site could be consideration to address GHG emissions.

As part of the visit to the plant, mention was made of Biffa's recently announced support to WasteAid, a non-profit organisation mandated to improve waste management in developing countries. A press release on 8 April 2019 stated:

Biffa PLC, a leading UK integrated waste management company, today announces a three-year partnership with UK based charity WasteAid, which will see the business support WasteAid financially and offer its expertise to help communities in developing countries improve the management of waste. In the UK and developed countries, the collection and management of waste is taken for granted. However, in many developing countries a waste management service simply does not exist, with one in three people having no access to any such facilities. This means that 40% of the world's waste – from homes, businesses, agriculture, hospitals, and industry – is not collected or treated, and as a result, it is often dumped. Much of it makes its way to the world's oceans, with 70% of plastic marine litter coming from places without waste management facilities.

WasteAid works with communities in developing countries to share practical and low-cost approaches to waste management and recycling. Its innovative projects include teaching communities how to turn water bottles into eco-bricks to build homes and schools, as well as converting plastic bags into paving slabs that can be sold to local businesses. By partnering with WasteAid, Biffa will be able to bring financial support and its extensive experience in addressing complex waste issues in the UK to areas with no previous access to waste management. As a leading waste management business that collects 4.1m tonnes of waste from UK homes and businesses a year and processes and treats over 3.7m tonnes of waste and recycling, Biffa is well placed to put its knowledge and operational expertise to good use. The work with WasteAid will not only benefit the environment on a global scale, it will also help to bring a better quality of life to people in these areas as well as create jobs and opportunities.

The organisation's website is https://wasteaid.org/

WasteAid and Biffa should be approached as potential partners or contributors to the ongoing efforts to improve waste management in MCC and PCC.

3.7.2 QUBE RENEWABLES

Tuesday, 4 June 2019

QUBE Renewables, Wiveliscombe, UK, Supplier of Pre-Packaged Micro and Very Small-Scale AD-Based Waste-To-Energy Systems

Primary Contact: Jo Clayton

Meeting and Manufacturing Plant Tour

Based in Somerset UK, QUBE Renewables supplies micro and very small-scale AD biogas systems operating from 3 to 30 kW of electrical power output. The company was formed following a project with the UK military in 2012 to develop a small-scale portable AD-based waste-to-energy system (quickQUBE) for overseas deployments. Since the initial project, various other forms of the technology (i.e. bioQUBE, dryQUBE, lagoonQUBE, and powerQUBE) have been developed and deployed for applications in the food and beverage, agriculture, and humanitarian sectors. Appendix VI contains presentation materials on QUBE Renewable products.

The modular and containerised bioQUBE systems shown in Figure 17 are sized to process organic waste with capacities ranging from 42 to 440 tonnes per year – an appropriate range for a possible market-based AD pilot project in Monrovia. Based upon waste food, outputs of electricity are upwards of between 10,000 and 108,000 kWh per year at the capacities specified. Other options for utilising biogas are available from Qube Renewables. bioQUBE capital costs range from US $116,000 to US $226,000 for the capacities specified.

FIGURE 17: bioQube – A pre-packaged, modular, wet ad system with power generation

Qube Renewables offers training and support for their products. Manufacturing of their systems is completed at Loglogic's facilities in nearby Devon, UK. While visiting Loglogic, a unit was being prepared for delivery to Canada. Figures 18 to 20 highlight some of the internal components within the bioQUBE that are not normally accessible. Overall, the company director, Jo Clayton, expressed interest in the upcoming demonstration project in Liberia. The company has developing country experience in the Philippines.

FIGURE 18: bioQUBE receiving tank mixer

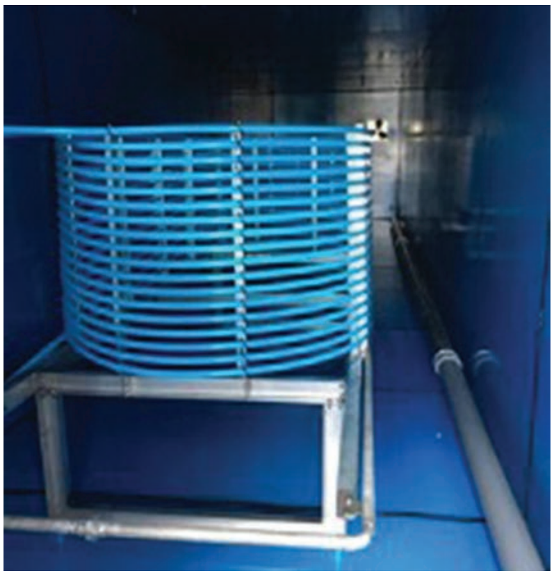


FIGURE 19: bioQUBE digester tank heating coil

FIGURE 20: bioQUBE biogas storage container contents

The bioQUBE system is an example of a complete, packaged system that could be deployed as part of a demonstration project within the currently anticipated budget. Training, support, and interest were all offered by the company. The bioQube is essentially a Wet AD system and is still relatively complex for a developing country and would necessitate reliance upon the supplier to keep the system operational in the near term.

3.7.3 TROPICAL POWER

Wednesday, 5 June 2019

Tropical Power, Oxford, UK

Primary Contact: Mike Mason

Meeting

A meeting was held with Mr. Mike Mason at his home in Oxford, UK. Mr. Mason is the Chairman of Tropical Power, an Engineering, Procurement, and Construction (EPC) company. The purpose of the meeting was to discuss the design of an AD system specifically targeted for applications in Africa currently under development by Tropical Power. Mr. Mason is a professional engineer with an extensive experience in industry. He grew up and worked in Africa and holds a PhD from Oxford University on the topic of AD.

Tropical Power serves energy clients with power plants that use AD, biomass boiler systems, and solar PV. The company's vision is to play a leading role in AD, biomass, and solar technologies in Africa through world-class EPC, cutting-edge innovation and research, and a deep understanding of the countries and communities in which they operate. The company has implemented the largest commercial AD-to-grid connected power system in Africa at 2.5 MW electrical energy. Additional information on the project can be referenced on the 12 June 2019 tour to the Gorge Farm Energy Park in Kenya.

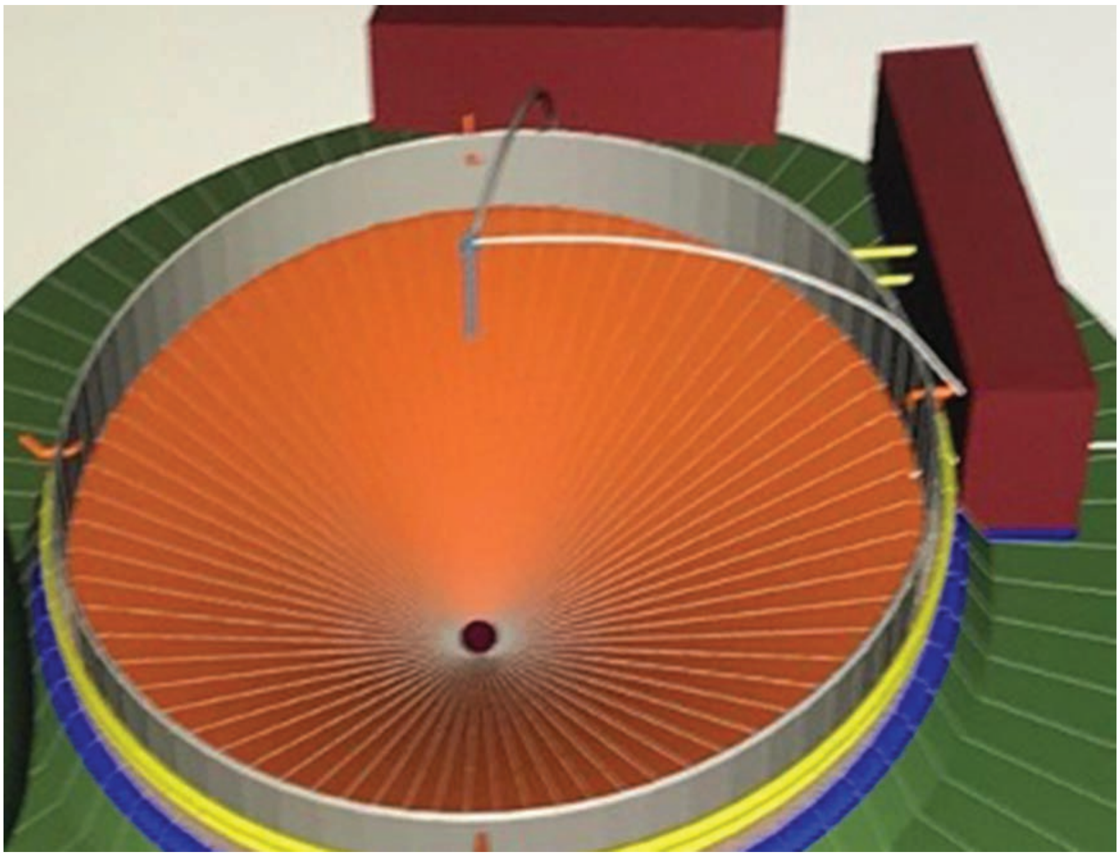


FIGURE 21: Overhead view of Tropical Power AutoCad image of Wet AD concept for Africa

The company has developed a design for a small-scale AD with a capacity of 2.0 tonnes per day dry matter basis, (approximately 4.0 tonnes per day as received basis) with electrical power capacity rated at 80 kW. The construction involves assembly of a prefabricated kit delivered in containers. Once commercially available, the forecasted capital cost of the digester is expected to be US $235,000 USD. Figure 21 highlights a cut-away of the digester tank.

This product is an example of an AD design specifically targeted for applications in Africa. The basis of the design stems in part from experiences gained by operating ADs in Kenya on organic matter consisting predominately of green vegetative matter, similar to the types of feedstocks anticipated in MCC and PCC. Tropical Power has significant experience, capacity, and awareness of Africa along with project development within the African context. There is potential for collaboration on broader funding initiatives related to deployment of AD as a tool to address climate change with Tropical Power.

Notably, the design presented by Tropical Power is unproven in a real-world application. Ultimate performance will be predicated upon verifying certain physical factors used to model the digester's performance, such as the flow viscosity of the mixed digester constituents, which inherently relies upon implementation of the design. This technology is essentially a wet-type digester and is still somewhat complex for a developing country and would need to rely upon the supplier to keep the system operational in the near term. Pricing is merely hypothetical at this time.

3.7.4 SEAB ENERGY

Thursday, 6 June 2019

Seab Energy, Southampton, UK

Primary Contact: Sandra Sassow

Meeting and Tour

Seab Energy is an equipment developer and supplier of prefabricated, modular, very small-scale AD biogas systems, headquartered in London, UK with manufacturing in Portugal. The FlexiBuster is a modular and containerised system that can be sized to process organic wastes with capacities from 0.5 to 3 tonnes per day. The FlexiBuster installation at University Hospital in Southampton, UK was visited. Figure 22 depicts the system, which consists of five digester containers, a biogas storage container, a control/engine generator container, and a feedstock-receiving container. A biogas boiler is also situated at the site. The installation has a capacity of 2.5 to 3.0 tonnes per day of cafeteria food waste. This waste can produce 5m^3/h of biogas, which is enough to supply a 50-kW engine-driven electrical generator at a 90% capacity factor.

This installation was set up to cycle the generation of power. Approvals and permits were a significant aspect of the project due to the site location. FlexiBuster capital costs range from US $170,000 to US $240,000 for 0.5 to 1.0 tonne per day capacities, not including equipment to utilise the biogas. The company offers training and support for all their products. Overall, the company director, Sandra Sassow, expressed interest in the upcoming demonstration project in Liberia. Appendix VII contains case studies and brochures on the FlexiBuster.

FIGURE 22: FlexiBuster installation at University Hospital in Southampton UK rated at 3 tonnes per day of waste food

The FlexiBuster is a complete, packaged system that could be deployed as part of the demonstration phase of the project, but it may be beyond the available budget. Training, support, and interest were all offered by the company. However, the Flexibuster is essentially a wet-type digester that is still relatively complex for a developing country and will require reliance upon the supplier to keep the system operational.

3.7.5 OEKOBIT

Friday, 7 June 2019

Oekobit, Frankfurt, Germany

Primary Contact: Philipp Senner

Meeting

HoMethan, shown in Figure 23, is a small biogas plant that can be used for treating organic waste materials and generating biogas in remote areas that is being advanced by Germany's Ökobit. A meeting was held with Philipp Senner, one of the engineers leading HoMethan deployments. HoMethan is a pre-packaged bag biodigester made of materials typically used in industrial-scale biogas plants and is equipped with a manual stirring system.

The applications of HoMethan to date are primarily small farms, farming households, cooperatives, dairies, and small-scale food processing industries. The design ensures gas retention and offers an increased gas yield based upon the use of quality material and an innovative stirring system, respectively. A HoMethan plant is typically fed with up to 200 kg of manure daily. It subsequently produces 190 kg of bio-fertiliser and 5m^3 of biogas per day, enough for approximately 10 hours of cooking. HoMethan's capital cost is US $3,333 for the digester alone and not including equipment to utilise the biogas. The company offers training and support for their products. Appendix VIII contains promotional brochures on the system.

FIGURE 23: HoMethan installation in Grenada, Caribbean rated for 200 kg per day of manure slurry

Overall, the company engineer, Philipp Senner, expressed interest in the upcoming demonstration project in Liberia. The company has experience in Africa (Zimbabwe), South America, and the Caribbean. The project in Zimbabwe is located at the Saint Rupert Mayer Mission, Makonde, Chinhoyi, Mashonaland, West Zimbabwe. The local contact is Fr Clemence (he is in charge of the community of St. Rupert Mayer) at +263 77 538 5998. Additional support for the project is also being provided by the Technical University Munich in Germany.

HoMethan is an example of a packaged system that could be deployed as part of a demonstration project well within the anticipated budget. HoMethan is a very simple system and appropriate technology for a developing country. Training, support, and interest were all offered by the company.

The HoMethan is essentially a wet-type digester. Biogas production and functionality of the system would need to be tested with the type of organic waste in Monrovia.

Ökobit is also in the process of developing a small home-base biogas system along the lines of the Homebiogas product mentioned elsewhere in the report. However, this system is still in the testing phase and not on the market yet.

3.7.6 EGGERSMANN

Friday, 7 June 2019

Eggersmann, Convaero, Bio-Dry, Bad Oeynhausen, Germany

Primary Contact: Jan Gressmann

Meeting

Conavero Bio-Dry is a membrane-covered system for composting and biological drying of waste. Once sufficiently dried, the waste can be converted into a solid fuel source for use by industry and for power generation. The system is very flexible in terms of budget, area requirements and setup time. These features enable users to implement the system at large-scale waste management plants and at small-scale waste treatment facilities. Conavero Bio-Dry is especially effective in solving odour problems, which are one of the biggest challenges in waste treatment. Convaero Bio-Dry™ was developed primarily for markets with limited financial resources, but where waste volumes and energy demand are growing substantially. Figure 24 highlights a pilot scale Convaero Bio-Dry plant. Appendix IX contains additional information.

Energy consumption for the Bio-Dry Plant is relatively low compared to other waste treatment methods. Standard water content in the output waste (after drying) is 20% or less, depending upon requirements. The system can treat municipal waste, green waste, organic waste, and sewage sludge.

FIGURE 24: Pilot-scale Convaero Bio-Dry plant

The equipment is an example of a packaged system that could be deployed as part of a demonstration project well within the anticipated budget. Convaero Bio-Dry is a very simple system and appropriate technology for a developing country. Training, support, and interest were all offered by the company.

The Convaero Bio-Dry is essentially a biological drying technology and not preferred for the waste-to-energy solution being proposed for the long term. Currently, there are no facilities capable of combusting the dried waste material in MCC and PCC.

There may be opportunities for the palm oil industry in Liberia to use the dried material as fuel. Use as a household fuel source would require further investment in densification equipment and significant effort to remove any deleterious materials; a difficult challenge for MSW.

However, if AD cannot be adapted going forward, Convaero Bio-Dry sites located at multiple points within MCC/PCC or within one large point at the Cheesemanburg Landfill site could be considered as a means to address GHG emissions from organics.

3.7.7 AMIRAN

Monday, 10 June 2019

Amiran Kenya (Distributor for HomeBiogas), Nairobi, Kenya

Primary Contact: Evelyn Otieno

Meeting and Tour

Amiran Kenya is the distributor of HomeBiogas Products in Kenya. HomeBiogas is a manufacturer of pre-packaged wet-type, bag-style, micro anaerobic digesters. Amiran Kenya retails the HomeBiogas 2.0 for US $560. In Kenya, the target markets are rural farms and farm households. Kenyan buyers can typically access soft loans for 15-year terms to purchase the units. Training, installation, and follow ups are also provided to the buyer. Amiran Kenya sales are anticipated to exceed 500 units this year. Figures 25 thru 31 highlight the visit to Amiran Kenya. Appendix X contains more detailed information on HomeBiogas products.

FIGURE 25: Amiran Kenya marketing and sales team for HomeBiogas products

FIGURE 26: HomeBiogas 2.0 Unit

FIGURE 27: HomeBiogas two-burner biogas stove

FIGURE 28: Amiran Kenya warehouses

FIGURE 29: Amiran Kenya HomeBiogas 2.0 inventory

Amiran Kenya will receive one of the first TG6 units being developed by HomeBiogas, which is based in Israel. These units are designed to handle 1.0 tonne per day of organic waste. The HomeBiogas TG6 beta pilot shown in Figure 30 completed component integration testing in May 2019. The TG6 project is funded by the EU Horizon 2020 Programme. Details are listed in Figure 28. The TG6 could be a good candidate for the demonstration project in MCC and PCC.

Amiran Kenya expressed an interest in the Liberia project. Additionally, prior direct contact had been made by the Consultants with HomeBiogas in Israel. Their product is an example of a packaged system that could be deployed as part of a demonstration phase of the project well within the anticipated budget. HomeBiogas 2.0 is a very simple system and represents appropriate technology for a developing country. Training, support, and interest were all offered by the company.

FIGURE 30: HomeBiogas TG6 beta unit components

FIGURE 31: Summary of the TG6 project supported by the EU

Coordination	Fundings	Details
HomeBiogas Ltd. **Project coordinator:** Alon Civier Tel: +972 54 723 6633 **Technical coordinator:** Oshik Efrati Tel: +972 52 322 1554	This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 777770	**Time Table:** Aug 2017 - Jul 2019 **Total Cost:** EUR 2,292,500.00 **EC Funding:** EUR 1,604,750.00 **Instrument:** H2020 MGA SME Ph2 **Project Identifier:** 777770 – HOMEBIOGAS – H2020-SMEInst-2016-2017/ H2020-SMEINST-2-2016-2017

3.7.8 SISTEMA BIO

Tuesday, 11 June 2019

Sistema Bio, Nairobi, Kenya

Primary Contact: Steve Manyasi

Meeting and Tour

Headquartered in Nairobi with outlets in various other locations in Kenya, Sistema Bio is a project developer and supplier of very small-scale, modular fabric-bag AD plants. Sistema Bio is a social enterprise company that emphasises business-to-business relationships and direct sales of products, as described within Figure 32. The $6m^3$ digester retails for US $800, while the $200m^3$ digester retails for US $12,000, not including biogas utilisation equipment. Target markets include rural farms and farm households. Financing mechanisms represent a key ingredient of the marketing programme, along with training, installation, follow-up, and a 10-year warranty. Sales in Kenya are anticipated to exceed 2,500 units this year.

A Nairobi installation fed with household waste was the subject of the study tour, as shown in Figure 33 below. Appendix XI contains Sistema Bio brochures. The Sistema Bio system is an example of a low cost packaged system that could be deployed as part of a demonstration project well within the anticipated budget. Sistema Bio is a very simple system and represents an appropriate technology for a developing country. Training, support, and interest have all been offered by the company. The Sistema Bio system is essentially a wet type digester.

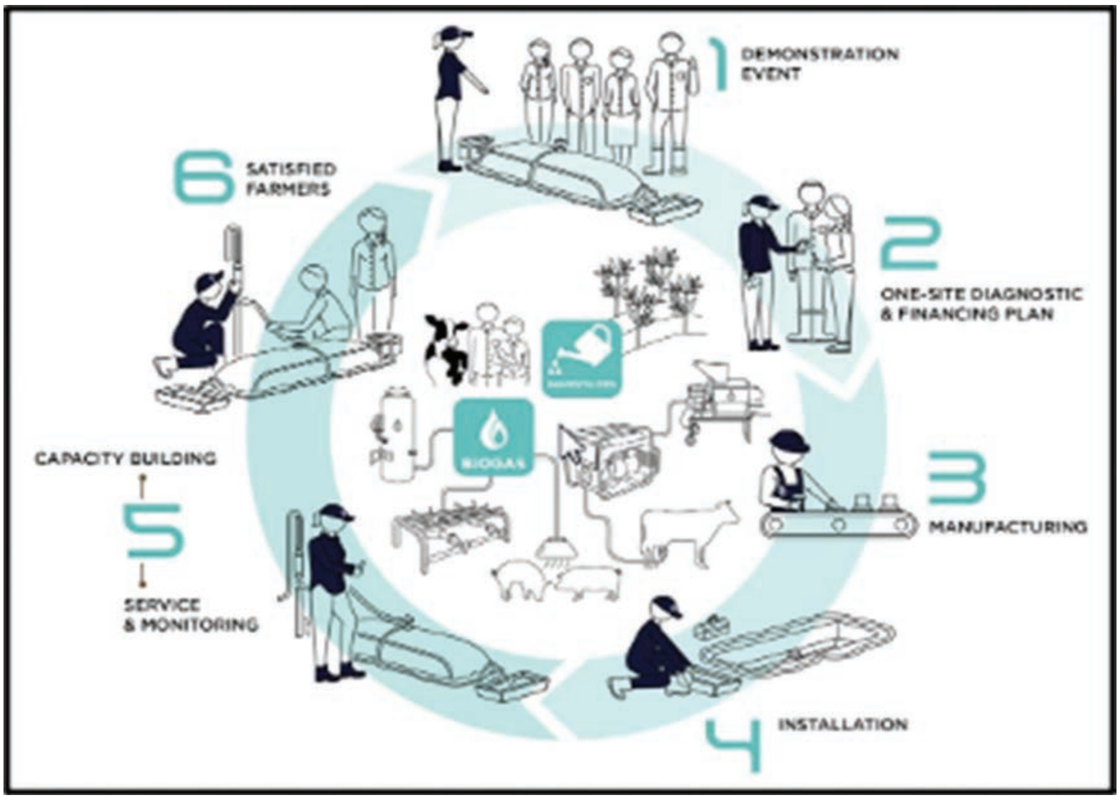


FIGURE 32: Schematic of Sistema Bio offering

FIGURE 33: Sistema Bio very small-scale biogas system visited in Kenya

3.7.9 GORGE FARM

Wednesday, 12 June 2019

Gorge Farm Energy Park, Sulmac Village, near Lake Naivasha, Kenya

Primary Contact: Mike Nolan

Meeting and Tour

FIGURE 34: Entrance to the Gorge Farm Energy Park

The Gorge Farm Energy Park near Naivasha, Kenya is the largest grid-connected AD-based waste-to-energy system in Africa. The project was developed by Tropical Power (refer to visit to Tropical Power Chairman in the UK in section 3.7.3 above) and is depicted in Figure 34.

The Consultants met with Mr. Mike Nolan, the Director of Tropical Power at the Gorge Farm Energy Park. He was an excellent source of practical information and shared the challenges that Tropical Power has experienced bringing its Kenyan project online. Mr. Nolan stressed the importance of African experience in implementing waste-to-energy projects. The overall capital cost of the project was verbally indicated as US $6 million, but it is unknown if this cost included all project features. Based upon the knowledge gained throughout the implementation, Tropical Power believes that the costs could be significantly reduced on future installations. Tropical Power expressed interest in the Liberia project.

The plant handles 100 tonnes per day of wet green vegetative waste feedstock from nearby rose flower production greenhouses. MCC and PCC organic waste is anticipated to have very similar properties. The feedstock is macerated (size-reduced and crushed) and fed into the receiving system manually. The feedstock transfers between three tanks (receiving/mixing, digestion, and effluent holding) during the conversion process. Figures 35 to 41 depict the feedstock and associated process.

FIGURE 35: Rose stem waste

FIGURE 36: Macerated rose stem and leaf waste

FIGURE 37: Feeding macerated rose stem and leaf waste into system

FIGURE 38: Primary anaerobic digester tank

Biogas is fed to a treatment plant for water and hydrogen sulfide removal, and then used to fuel 2.5 MW of engine-driven generators (Figure 39). Electricity supplies the nearby flower farm, and the balance is exported to the grid. The effluent is used by local farmers as a bio-fertiliser.

A fully equipped analytical laboratory (Figures 40 and 41) is set up on site and staffed with two technicians. Ongoing monitoring and testing of process chemistry and biology is a key feature for ensuring productive and reliable performance.

The Tropical Power Gorge Farm Energy Park is an example of a complete, packaged system that could be deployed as part of a long-term option to convert organics to useful energy within MCC and PCC. Mike Nolan cautioned that African feedstocks are dissimilar to those common to European technology providers. He reiterated that African project implementation experience is critical for project success. Substantial capability has been developed within Tropical Power, which represents an excellent source of laboratory and analytical capacity for supporting the demonstration project.

FIGURE 39: Biogas power generation facility

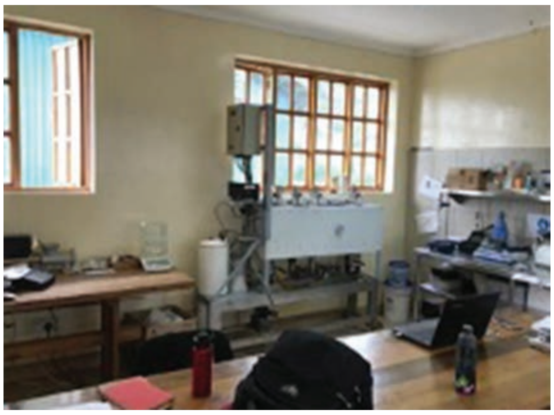


FIGURE 40: Analytical lab view 1

FIGURE 41: Analytical lab view 2

The Gorge Farm Energy Park is a wet-type digester. A similar scale system will not be within the anticipated budget for the demonstration project but could be considered as a longer-term option.

3.7.10 SAFI SANA

1 July 2019

Safi Sana Project Site, Ashaiman, Ghana

Primary Contact: Gideon Annor Gyamfi

Meeting and Tour

Safi Sana Ghana is a Dutch holding enterprise that designs, constructs, and operates waste-to-energy factories in developing countries. The firm is a social enterprise that was established in 2010. Its investment goals are to ultimately address health and sanitation within slum communities. The firm focuses upon converting organic and fecal waste into electricity, soil conditioner, and irrigation water.

Their project site, which toured by the Consultants, is in Ashaiman Ghana, a community of 250,000 persons. The facility is rated to produce up to 100 kW of electrical power. confirmation of capital costs was provided. Figures 42 thru 47 showcase the facility.

The Safi Sana facility is a highly integrated process based on circular economy principles, and electricity, bagged soil conditioner, seedlings and irrigation water are supplied for local use. No confirmation on sales/revenues was available the time of the site visit. The project represents an example of a system that could be deployed as part of a long-term option to convert organics into useful energy in MCC and PCC. It is also a project demonstrating experience within a West African setting. The facility affords a source of laboratory and analytical capability for supporting the demonstration project.

However, the Safi Sana factory is a wet-type digester, which is still a fairly complex process to implement in West Africa. In fact, Safi Sana informed the Consultants that it has taken them several years to get the entire process, including the waste collection aspect, running consistently. The Safi Sana plant utilises waste from public

FIGURE 42: Safi Sana offices

FIGURE 43: Primary anaerobic digester

toilets, which is not proposed for the Cities Alliance-funded project. A similar scale system will not be within the anticipated budget for the demonstration project but could be considered as a longer term option.

FIGURE 44: Power generation module

FIGURE 45: Biogas engine generator

FIGURE 46: Greenhouse production of seedlings using compost derived from organic waste

FIGURE 47: Bagged compost

3.7.11 KEY OUTCOMES OF STUDY TOUR

The following are the key outcomes of the study tour.

1. Anaerobic digestion is emerging as a widely used waste-to-energy technology. There are many installations in Europe and some emerging in Africa. Research also indicates that there are many installed systems in China and India. Most of the systems installed are used for agricultural waste, but there are starting to be some applications for organic municipal waste, mainly food waste. The Safi Sana system that was visited in Ghana is an example of a functional AD system based on organic waste from markets. The study tour confirmed that a small-scale AD system for organic waste from a market site, as planned for Monrovia, can be done.
2. AD technology works, but it is not without challenges related to the local environment. Both operational plants that were visited in Africa, Safi Sana in Ghana and Gorge Farm in Kenya, indicated similar challenges to adopt the technology and equipment – which is designed for western waste streams – to the local wastes that have lower energy content and are more difficult to digest. It takes at least 1-2 years of trial and error to work out the process and adopt the equipment to local conditions and to build capacity of local staff. Significant technical and financial support is required during this start-up period. Both Safi Sana and Gorge Farms (Tropical Power) are interested in supporting a project in Liberia and sharing their accumulated knowledge of designing and implementing systems in Africa; however, this will come at a cost.
3. Dry AD technology, which the Consultants had proposed for Monrovia due to many benefits, does not appear to be an option. This is a relatively newer application of AD, and vendors interested in a project in Liberia with systems of the appropriate size range for the proposed project in Monrovia could not be identified. As such, an initial project will need to be based on Wet AD technology, which is a more complex process. Dry AD however, should not be ruled out entirely as a longer-term option for the waste management problem in Monrovia, and elsewhere within this report, we provide a discussion on the case for Dry AD as a longer term solution.
4. The projects visited appear to have other attributes than simply being financially self-sustaining. The Gorge Farm power project in Kenya to some extent relies on the need to produce flowers in a sustainable fashion, as possible branding for

EU markets, and therefore is not totally reliant on revenues from electricity sales. The Safi Sana project in Ghana, has been receiving financial support from various foreign donors for several years. However, the projects may be economically viable when other benefits are taken into consideration, such as employment generation, offsetting of greenhouse gases, offsetting of costs for alternative methods of waste disposal, etc.

5. A pilot-scale demonstration project based on Wet AD technology can be done in Monrovia. However, it will likely push the limits of the Cities Alliance project budget and will also require considerable technical and financial support for approximately the first two years of operation, and possibly ongoing financial support thereafter. Financial viability of the project, especially at the very small scale being contemplated, cannot be expected.
6. The study tour also confirmed the need for a project "champion" to push through the challenges encountered. Without this, the numerous challenges involved in getting the systems to a point of continuous and efficient operations will not be achieved, and the project will fail. The successful projects the Consultants visited were executed by private entities who had a vested interest in the success of the projects. The Consultant is not confident that the project would be able to overcome the numerous start-up challenges if it is executed by a government agency.

The Client was informed of these outcomes at the conclusion of the study tour, and it is these observations that led to reviewing alternative options for the pilot project, with lower implementation risk. This then led to the change of the project approach and the Consultant's scope of work.

3.7.11.1 Meetings and presentations held after study tour

Several meetings and presentations were held after the study tour to discuss the findings with Cities Alliance and other project stakeholders as summarised below:

- 8 July: Meeting with Cities Alliance to review outcomes of the study tour
- 10 July: Meeting and presentation to the Project Technical Committee on progress update and study tour
- 12 July: Follow-up meeting and presentation to Project Technical Committee to review options for implementation and follow-up meeting with Cities Alliance after
- 15 July: Follow-up meeting and presentation with PCC and Cities Alliance to further review options
- 16 July: Meeting and presentation with Mayor of MCC and Cities Alliance to further review options and gain consensus on the way forward
- 17 July: Meeting with Cities Alliance on next steps
- 24 July: Meeting and presentation with Cities Alliance on revised project approach
- 29 July: Meeting and proposal presentation to Cities Alliance on revised project approach
- 1 Aug: Meeting with Cities Alliance to review revised proposal

- 2 Aug: Submission of proposal for revised Work Plan #2
- 9 Aug: Meeting with Cities Alliance to sign contract amendment and review project work plan

The result of these meetings and presentations was the change in project approach and the Consultant's scope of work and work plan as contained in Contract Amendment #2. Copies of the presentations, meeting minutes, proposal and contract amendment are included in Appendix I.

3.8 Final technology/vendor and site selection

The intent of this activity was to incorporate the findings of the study tour into our previous work and to make a final selection of the technology to be adopted and suitable equipment vendors. After this determination was made, the intent was to then proceed with final site selection for the two pilot projects based on equipment sizing and other parameters. The intent was to select two different types of systems to be used at the two different sites, as this would enable better testing to see what works and what does not and to compare results from the two sites.

Based on the results of the study tour, the final technology selection was determined to be Wet Anaerobic Digestion. Although Dry AD was previously recommended, but suitable equipment vendors with an interest in a very small-scale pilot project in Liberia could not be identified.

Vendor selection and site selection for the proposed pilot sites was underway in late June/early July but was put on hold when the overall direction of the project changed.

The site for Option 1 has been determined as the new Omega Market in the meetings held with MCC/PCC, however the precise allocation of land at the market will be determined at a later date. Possible vendor selection for Option 1 is discussed in Section 6 of the report.

3.9 Preliminary design and costing

Based on the final technology/vendor selection and site selection, the Consultant was to prepare a preliminary design and cost estimate for each of the proposed pilot project sites. This was to include, but not be limited to, preliminary level design of the following:

- Final equipment selection and specification
- Equipment tie-ins to incorporate individual items into a complete functional system
- Equipment foundations
- Buildings and structures to house equipment, office, storage areas, etc.

- Slabs and storage areas for waste feedstock and digestate
- Fencing and security
- Access roads
- Services (water supply, sewerage, power supply, communications, etc)

Preliminary level design drawings comprising plans, elevations, sections, details, etc. were to be prepared along with appropriate technical specifications. Bills of Quantities (BoQs) and preliminary level cost estimates were to be a separate deliverable for Client review.

Work on this activity was terminated in early July due to the change in direction of the project. Under the revised approach and work plan, a conceptual design and cost estimate for a scaled-up version of Option 1 will be developed, as opposed to a preliminary design for the 2 pilot sites and is presented in Section 6 of the report.

3.10 Develop concepts for project scale-up

The intent of this activity was to develop concepts for possible scaling-up of the project. This activity was not included the Consultant's original ToR but was recommend by the Consultant to be included as part of the project in Work Plan Rev #1 and subsequently agreed to by Cities Alliance.

Due to the very limited budget for the pilot project, the scale of the proposed pilot systems would be very small and essentially the pilot projects would be "demonstration projects" only to test the viability of the technology and to create interest in the possible scaling up of the technology as viable waste management solution for Monrovia. Due to the very small scale, it is highly unlikely that the pilot projects will be economically/financially viable or will have any plausible business case associated with them. Rather, they will likely require continued funding to operate. However, a larger scale project may have economic or financial justification with a compelling business case, and the Consultant believed it was desirable to know what the next steps in terms of scale-up could possibly be, and the possible constraints, before investing in the pilot projects. For example, if it is determined that scaling-up of the technology requires quantities of land that are not available within the communities, then scaling up this technology may not be practical. Available quantity and characteristics of organics also needs to be looked at, even at a cursory level, to ensure that the waste flows are sufficient to support the scaling-up. Costs of a scaled-up project are also important factors. In designing the pilot project, it is important to know the possible future directions, and try to incorporate that into the overall design of the project at this point to the extent possible, as this has could have a big impact on sustainability.

For these reasons, the Consultant proposed that scale-up of the project should be reviewed, at least at a cursory level within the current assignment. This work was partially completed prior to the change in direction of the project and is therefore presented herein. Additional work on this activity will not be performed as completion of this activity was replaced in the revised Work Plan #2 with developing a design concept and cost estimate for a scaled-up version of Option 1, as described previously.

3.10.1 LONG-TERM PERSPECTIVE – THE CASE FOR DRY ANAEROBIC DIGESTION

The findings of the Inception Report determined that Source Separated Organics (SSO) converted via AD into biogas was the most suitable W2E approach to mitigate greenhouse gas emissions associated with MSW management in MCC and PCC. The resultant biogas and digestate/effluent from the AD process have value as an energy source and compost/fertiliser source within the community, respectively. The revenues obtained from these two valuable sources could be a means to offset MSW management costs in the longer term.

In the event SSO could not be deployed in MCC and PCC, consideration could be given to the separation of organics from MSW at the end of the gathering and collection process. This would entail the implementation of mechanical and biological treatment processes that would require very large upfront capital investment and pose complex technological challenges to operate and maintain on a go-forward basis (refer to the Biffa MBT plant presented in sub-section 3.7.1 as an example). Subsequently, less emphasis was placed on this approach in light of the current situation in Liberia.

Refuse Derived Fuel (RDF) was given brief consideration as an alternative in the event that anaerobic digestion could not be deployed in MCC and PCC. The challenge with RDF is that there are currently no known users of this type of fuel in Liberia. Generally, RDF is utilised by the industrial and power generation sectors.

Dry type AD technology was viewed as the most suitable technology option to pursue in the longer term, due to several benefits, including:

- Directly addresses the organic waste component of MSW; the component responsible for GHG emissions from land filling
- Fits within a community setting and is easily scalable, as described herein, provided that adequate land area is available
- Affords ease of material handling with minimal preprocessing of organics, whether in dry or wet seasons
- Tolerates contaminants in organics such as glass and metal
- Complies with environmental permitting requirements
- Requires fewer skilled operators and technicians than other related conversion technology options
- Generates dry digestate as opposed to liquid effluent for use as compost or fertiliser, which is significant, as disposal of liquid effluent on a large scale will present a problem in Monrovia given that there is no functional wastewater treatment plant in the area
- Has several European technology providers offering equipment, systems, and technical support.
- Requires considerably less land space – this is an important consideration for Monrovia

FIGURE 48: Dry-type AD modules permit easy scalability

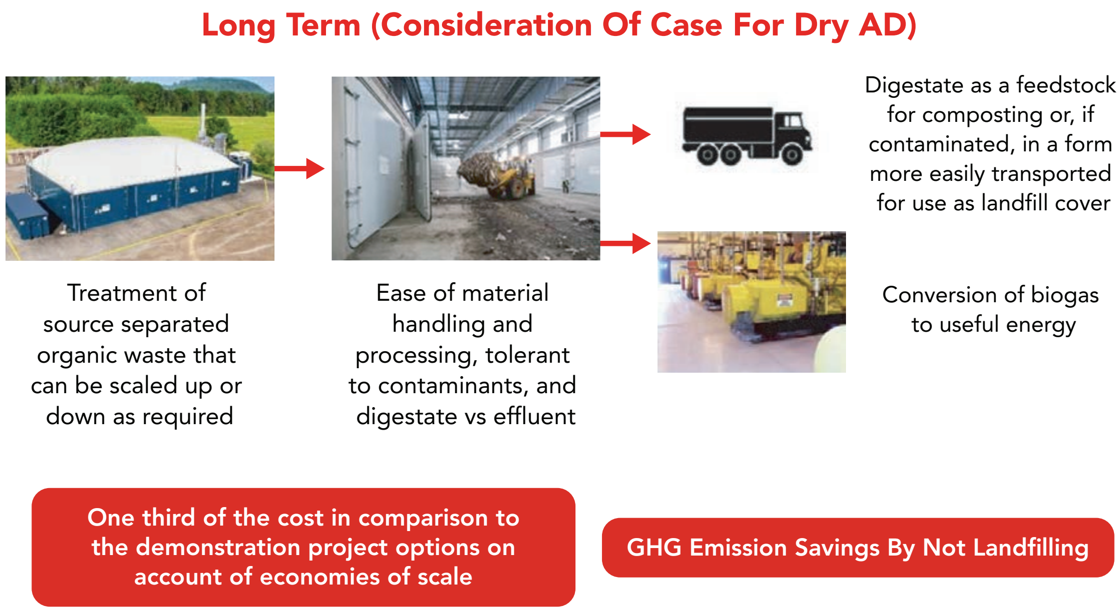
Subsequently, efforts were made during the Feasibility Study phase to more fully evaluate Dry AD within the long-term perspective, as well as from the demonstration project perspective. Wet AD was also kept in the forefront for the demonstration project in the event that suitable Dry AD technology could not be secured (which turned out to be the case as result of additional research). Appendix III contains a more detailed description of Dry AD.

Currently, MCC and PCC generate an estimated 240,000 tonnes per year of MSW, of which 100,000 tonnes per year are considered to be organic wastes. Cities Alliance's goal is to reduce GHG emissions associated with MSW management while bringing value to the local community with a feasible, practical, and cost-effective solution. This perspective places a focus on smaller scale, less complex, lower cost, options that could be strategically distributed throughout communities over time, as funding becomes available.

If AD could be successfully deployed throughout MCC and PCC, an estimated 166,000 tonnes per year of CO_2 equivalent emission reductions could be achieved by not needing to land fill organic wastes from the communities. The biogas generated from 100,000 tonnes of organic waste through a Dry AD process could yield approximately 9.6 million m^3 of biogas per year. With regard to power generation, this equates to approximately 18 million kWh per year of electricity based upon a 30% conversion efficiency – enough to serve the electrical demand of 20,000 households in the Greater Monrovia area. Additionally, an estimated 20,000 tonnes per year of dried digestate could be made available for local markets. If systems are properly operated, it is anticipated that the majority of digestate could be utilised as a compost/fertiliser source. It is important to note that when the scale of systems increases and the control over feedstock decreases, there will be a need to consider pasteurisation of the digestate/effluent. This aspect will ultimately impact utilisation of the effluent or digestate.

Some technology options for Dry AD of organic waste and conversion into useful energy on a small scale (thousands of tonnes per year) are available and anticipated to be scalable and affordable in the long term. Figure 49 highlights an example of this option.

FIGURE 49: Example of small-scale Dry AD of source separated organics within communities



BEKON Energy Technologies, based in Germany, is an example of a potential dry type anaerobic digestion technology that could be adopted in the long term. BEKON's dry fermentation plants were developed from decades of experience in turn-key construction and company-owned operation. Over 50 plants have been installed worldwide, however the majority of these exist within continental Europe.

The smallest version of the plant, the BEKON MINI, has a capacity of 3,000 tonnes per year, and requires at least 750 m² of space, not including any composting operations. This plant would support approximately 100 kW of electrical power generation based upon European waste characteristics. The construction of the BEKON MINI with a capacity of 10,000 tonnes per year in Germany would be budgeted at US $2.8 million excluding land and supporting infrastructure. The cost would be considerably higher in Liberia, due to the need to import all equipment and to utilise foreign personnel for the installation. Figure 50 shows a typical BEKON MINI facility.

The BEKON MINI is a complete, packaged system that could be deployed as part of a long-term solution to convert source-separated organics to energy within MCC and PCC. A preliminary budget for a 10,000 tonne per year organic waste processing capacity in Liberia would be US $6 million, requiring approximately 2.5 ha of land area. Ten facilities dispersed throughout MCC and PCC would be required to deal with the estimated 100,000 tonnes per year of organic waste. To accommodate these facilities, an overall investment of US $60 million and 25 ha would ultimately be required.

FIGURE 50: BEKON MINI rated at 4,500 tonnes per year of waste organic capacity

FIGURE 51: BEKON MINI installation in Switzerland rated at 4,500 tonnes/year of waste organics

The BEKON MINI system is a relatively simple technology compared to Wet AD. Differing organic feedstocks (i.e. less food waste) exist between Europe and Liberia, and the internal equipment (pumps, controls, and power generator) represent operational and maintenance complexities. These differences would have to be considered. For instance, MCC and PCC would need to rely upon the supplier to keep its system functional in the initial years of operation, until local staff and operators are thoroughly trained and capable of independent operation and maintenance.

Concerning land requirements, Figure 51 depicts an aerial view of a 4,500 tonne per year BEKON MINI installation in Switzerland that occupies 2.25 ha. The BEKON unit is the white rectangular object located in the upper center portion of the image. For this installation, the majority of the surrounding land area is committed to composting activities associated with post-digestion. Land requirements are anticipated to be challenging within MCC and PCC.

For perspective, an estimated US $2.0 million annual net positive revenue stream could be realised with the installation of ten x 10,000 tonne per year Dry AD plants (a US $60 million investment) based upon the previously cited outputs, as follows as shown in Table 5.

TABLE 5: Large Scale Dry-AD Project Implementation Possible Revenue Streams

Description	Amount
Income Sources	
Annual electricity sales, at US $0.30/kWh	US $5.4 million
Annual soil conditioner sales revenue, based upon US $0.50/kg of digestate (air dried) sold	US $1.0 million
Potential annual GHG emission reduction credit, based upon US $10 per tonne of CO_2 equivalent.	US $1.6 million
Total Income	US $8.0 million
Less, Estimated annual plant operating costs	(US $6.0 million)
Net Annual Operating Income (excluding depreciation)	**US $2.0 million**

With an investment cost of US $60 million, this would give a 30-year simple payback (US $60/2 = 30). This would not be attractive to any private investors, but could cover depreciation and might be considered by international financial institutions such as the World Bank, considering the other economic benefits that could accrue to the population of Monrovia, including:

- Cleaner environment (reduced health risks and costs, reduced water contamination)
- Local employment generation for construction, operation and maintenance of the systems and source separation of organic waste
- Reduced GHGs (from utilisation of organics, reduced MSW transportation and also possible offset of diesel-driven electrical power generation)
- Reduced MSW transport and landfilling costs
- Improved power supply
- Community engagement opportunities

In summary, Dry AD offers a potential long-term solution to dealing with organics in MSW in MCC and PCC. The technology is commercially available, scalable, relatively technologically simple, and offers potential for revenue streams to offset operating costs. If implemented in a manner that offers the required capacity and operational experience, Dry AD could be successful in a developing country.

3.11 Environmental and social impact review

This activity was intended to be a rapid review of environmental and social impacts of the proposed pilot projects to highlight any potential environmental and social impacts of the project that will need to be considered before implementation, and possible mitigation strategies for negative impacts. Both negative and positive environmental and social aspects were to be highlighted. The information from this review was intended to serve as a starting point and provide background information for a formal Environmental and Social Impact Assessment that will need to be done (by EPA or others) to obtain environmental permits for the project prior to implementation.

Due to the change in approach and work plan for the project, the environmental and social impact review has become a rapid review of the proposed scaled-up Option 1 project at Omega Market. It highlights any potential environmental and social impacts that will need to be considered before implementation and possible mitigation strategies for negative impacts. The environmental and social impact review is presented in Section 6 of the report.

3.12 Institutional/economic and financial/ capacity building analysis

This activity was intended to review the following aspects of the proposed pilot project as well as for future project scale-up:

- Institutional arrangements for the project
- Roles and responsibilities for local authorities, government, NGOs, CBOs, and private sector
- Project regulatory issues
- Economic and financial assessment and cost/benefit analysis
- Capacity building requirements
- Gender mainstreaming

Due to the change in approach and work plan for the project, this activity will now be done for the design concept for the scaled-up Option 1, but to a lower level of detail, considering that the design is being developed to a conceptual level only. The information concerning this is presented in Section 6 of the report.

3.13 Prepare feasibility study report

The Feasibility Study Report was intended to be prepared during the month of July, incorporating all of the above information that was intended to be developed in Phase II of the project, along with recommendations for proceeding with the pilot project.

As stated in Section 1 Introduction, the Feasibility Study Report (this report), is now considerably different than originally intended. It is not a typical "Feasibility Study" due to the change in the scope and project work plan that occurred in July and August 2019, more than halfway through the project. The "Feasibility Study Report" as presented should be viewed more as a summary of the work completed and research carried out to date. This includes elements of the feasibility study prior to the scope change and an update on progress of the Micro-Scale Biogas Testing Phase as well as a conceptual-level proposal for a larger future W2E project.

3.14 Prepare/host stakeholders workshop on feasibility study

The intention was that the Consultant would host a workshop to present the Feasibility Study Report, summarising the results of Phase II of the project and soliciting comments from stakeholders for finalisation of the report. The Consultant was to arrange and fund all the costs of the workshop, at a venue agreed with the Client.

Due to the change in the project approach, and budget limitations to incorporate the testing phase for the micro-scale bio-gas units into the project, the stakeholder workshop has been removed from the project.

3.15 Summary of research carried out by the consultant

The major findings from the Consultant's research indicate that suitable, low-cost AD technologies are available for a Cities Alliance waste-to-energy demonstration project in MCC and PCC based on the proposed budget of the project. There are technology providers and project developers interested in participating/bidding on a demonstration project in Liberia. The major decision will be how to best setup the demonstration phase to replicate the preferred longer-range option for establishing waste-to-energy systems within the communities, in order to address GHG emissions associated with waste management in MCC and PCC.

Further findings from the Consultant's research and study tours include:

1. AD technology works and is currently being adopted in several countries.
2. A high level of interest in supporting the Liberia demonstration project with expertise and experience currently exists.
3. There are limited Dry AD options for the demonstration project (more exist for the eventual scale-up).
4. The complexity involved in initiating and operating AD waste-to-energy projects is higher than originally anticipated.
5. Land and space requirements are considerable, especially if composting is to be included.
6. Technologies are more designed for European waste streams (containing high energy organics) and require considerable support and time commitments to get the process working effectively for African waste streams.
7. Projects are not typically financially self-sustainable.
8. The Liberian project will require a considerable amount of ongoing financial support to run in the near term.
9. There are additional funding sources currently available for MSW in developing countries.

10. Each successful project requires a "champion." There is significant risk of failure if the project is not appropriately monitored, supported, and constantly driven forward by a "champion."

Table 6 summarises the recommended technology options to consider for the proposed demonstration project and for longer term considerations, starting from micro systems to larger-scale systems. The table shows the key parameters for each system. A key factor to consider is the capital cost per tonne of nominal capacity of waste as received (US $/t). Note that the HomeBiogas 2.0 is US $730 per tonne, whereas Tropical Power is targeting US $160 per tonne. The BEKON MINI at US $280 is likely a good benchmark. In general, economies of scale will favor larger waste to energy facilities. This table does not consider operational costs.

TABLE 6: Comparison of Recommended Technology Options to Consider for Demonstration Project and Longer-Term Considerations

Description	Intended Use	Risks	Nominal Capacity as Received (t/year)	
HomeBiogas 2m^3 digester, 2.1 kg/day capacity, marketed in Kenya for US $560	Primarily designed for household organic feedstocks	Simple, Wet AD, no clear experience operating on MCC/PCC feedstocks	0.8	
HoMethane 5m^3 digester, marketed in Germany for approx. US $3,360	Primarily designed for farm manure feedstocks	Simple, Wet AD, no clear experience operating on MCC/PCC feedstocks		
Sistema Bio 6m^3 digester, marketed in Kenya for US $800	Primarily designed for farm manure feedstocks	Simple, Wet AD, no clear experience operating on MCC/PCC feedstocks		
Sistema Bio 200m^3 digester, marketed in Kenya for $12,000	Primarily designed for farm manure feedstocks	Complex, wet type, digester (effluent use/disposal issue) with no clear experience operating on MCC/PCC feedstocks		
Qube Renewables bioQube 500 kg/day capacity, marketed in UK for approx. US $175,000 US	Primarily designed for institutional/community organic feedstocks	Complex, Wet AD, no clear experience operating on MCC/PCC feedstocks	183	
Seab Energy Flexibuster 500 kg/day capacity, marketed in the UK for US $170,000	Primarily designed for institutional/community organic feedstocks	Complex, Wet AD, no clear experience operating on MCC/PCC feedstocks	183	
HomeBiogas TG6 digester, 1.0 t/day capacity, under development, marketed on an annual payment of between US $30,000 for a specific term (5 years plus)	Primarily designed for institutional/community organic feedstocks	Complex, Wet AD, no clear experience operating on MCC/PCC feedstocks, offering hypothetical pricing	365	
Tropical Power conceptual design, 2.0 t/day dry matter volatile solids basis (4 t/day as received), marketed in Africa for US $200,000	Primarily designed for institutional/community organic feedstocks	Wet AD, no clear experience operating on MCC/ PCC feedstocks, offering hypothetical pricing	1,250	
BEKON MINI 10,000 t/year marketed in Germany for approx. US $2,800,000	Primarily designed for municipal organic feedstocks	Complex, Dry AD, no clear experience operating on MCC/PCC feedstocks	10,000	

	Capital Cost (USD)	Capital Cost per tonne of Nominal Capacity as Received (USD/t)	Quantity Of MCC/ PCC Organic Feedstock (kg/day)	Biogas Production From MCC/ PCC Organic Feedstock (m^3/kg)	Claimed Biogas Production (m^3/day)	Annual Biogas Production (t/year)	Annual Effluent Production (t/year)
	560	730	2.1	0.0968	0.20	0.085	1.5
	Available information did not permit comparison on account of manure being the primary feedstock vs fruit and vegetable wastes						
	Available information did not permit comparison on account of manure being the primary feedstock vs fruit and vegetable wastes						
	Available information did not permit comparison on account of manure being the primary feedstock vs fruit and vegetable wastes						
	175,000	959	500	0.0968	48.4	20	359
	170,000	932	500	0.0968	48.4	20	359
	350,000	959	1,000	0.0968	96.8	41	718
	200,000	160	4,000	0.0968	387.4	163	2,460
	2,800,000	280	27,400	0.0968	2,653.5	1,114	Not applicable

4. PROPOSED PILOT PROJECT – OPTION 2

As described previously in this report, at the conclusion of the study tour it became evident that implementation of the AD-based very-small scale pilot projects, as proposed in the Inception Report, would carry a high implementation risk. An alternative Option 2, based on the installation of approximately 100 micro-scale biogas units, was proposed and reviewed, and the decision was made to proceed with this option for the pilot portion of the project. Brief descriptions of the proposed Option 2 demonstration project are given in Section 2 and elsewhere. Presentations made to Cities Alliance, the Project Technical Committee, MCC and PCC in respect to this option are included in the appendices. This section provides a more thorough discussion on the proposed pilot project.

4.1 Overall pilot project concept

The overall project concept is to install up to 100 micro-scale residential type biogas units at various locations in the Greater Monrovia area (MCC and PCC). The most likely equipment will be the HomeBiogas 2.0 unit as shown in Figure 26 and also shown below in Figures 52 and 53. HomeBiogas is the market leader in residential size bio-digesters, but equipment from other companies may also be considered to provide flexibility for procurement of different size units and not to tie the project to one specific vendor. As indicated in Section 3, Sistema Bio and Ökobit also produce micro-scale systems and could be considered for procurement. There are companies in India and China as well that may be interested in bidding for the supply of the units.

FIGURE 52: HomeBiogas Unit 2.0 showing digester and biogas stove

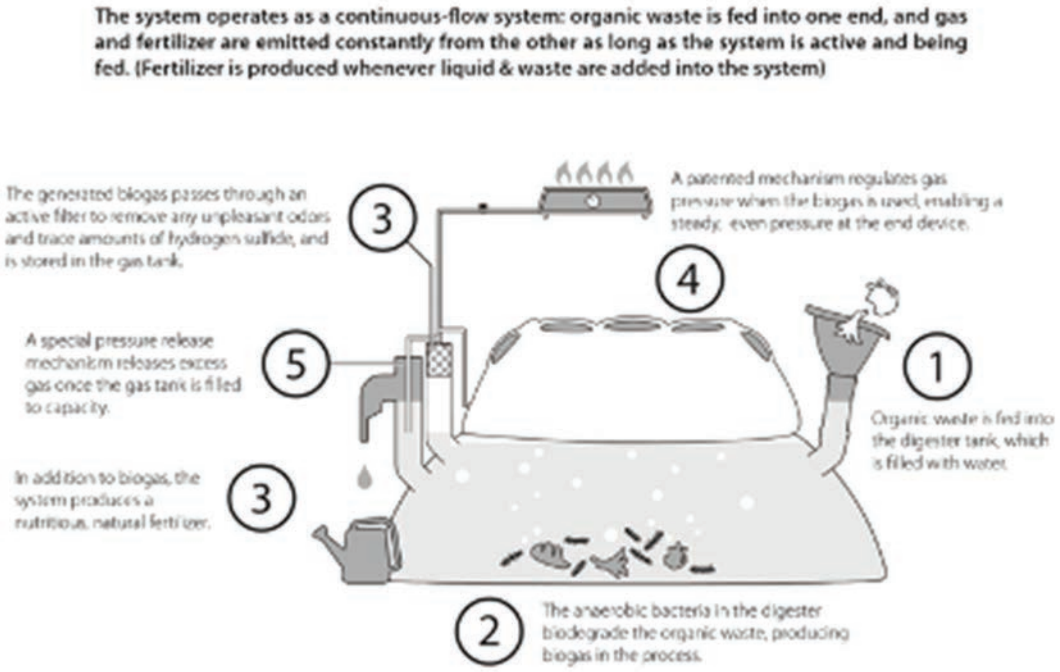


FIGURE 53: Schematic drawing of HomeBiogas Unit 2.0 extracted from the owner's manual

The function and main features of the units are as follows:

1. Organic food waste is loaded into the units. The unit can accommodate up to 6 liters (approximately 2 kg) of food waste per day. Food waste is mixed with water to load into the unit. After several months of continuous operation, up to 12 liters per day can be accommodated in a warm climate such as Liberia, after system operation has stabilised. Ligneous types of waste such as straw, grass, leave, branches, etc. cannot be accommodated in the system.
2. Biogas is generated from the food waste through a Wet AD process.
3. The biogas is utilised for cooking. With sufficient good-quality organic food waste, up to 2 hours of cooking gas per day can be provided. The units come equipped with a biogas stove, and gas piping to connect the stove to the biogas unit. The system comes equipped with a gas filter to remove sulphur from the biogas. The filters need to be replaced approximately every 6 months.
4. Liquid effluent is produced by the system when new waste is added, in the same volume as the amount added. The liquid effluent can be used as a very effective fertiliser.
5. It can take up to three weeks to activate the system, after which biogas is produced on a continuous basis when new organic waste is added.

There is no operating cost associated with the units, other than replacing the gas filters and routine maintenance.

The function of systems from other vendors would be quite similar.

4.1.1 PROJECT RECIPIENTS AND SITE LOCATIONS

These units are designed to be used in a residential setting for a household of approximately 4-6 people, based on developed country standards in terms of volume and characteristics of food waste generated on a daily basis. There will not be sufficient food waste at a residential level in Liberia, and as such, the intention is to install the units in the following types of facilities where it is believed adequate food waste can be readily obtained:

- Schools, universities, and technical colleges with a cafeteria or lunch programme
- Large government offices that have cafeterias or lunchrooms
- Restaurants
- Hotels

Participation in the project by private residences will not be restricted, but they would have to meet the criteria for participation, as described below. Some large higher-income residences may be able to meet the criteria. It also may be possible for a group of houses within a compound, say four houses, to meet the criteria, but they would need to satisfactorily demonstrate how the cooking gas would be shared among the various houses.

The intent is that the systems will be provided to interested recipients free of charge (paid by the project). However, selecting the locations where the units will be installed will be critical to the success of the programme.

The selected locations and recipients must meet the following criteria as a minimum:

1. Generate enough organic food waste on a consistent basis to support the operation of the system.
2. Have the ability to utilise the biogas produced by the system for purposes of cooking.
3. Be able to utilise the liquid effluent generated by the system as a liquid fertiliser. This might require that they construct small enclosures where they can establish a garden.
4. Have a level and secure location to install the unit so that it can be installed correctly and the unit does not get vandalised or damaged by traffic. It may be necessary to install fencing around the units in some locations. The biogas unit will need to be located 10-20 meters from the biogas stove in a location where sunlight reaches the biogas unit.
5. Have access to water supply.
6. Be willing to accept the responsibility of utilising the system in accordance with the intent of the project, including having a designated person that will receive training and take responsibility for operation of the system. This is to avoid installing the system in a location where it will not be utilised as intended.
7. Be willing to participate in monitoring of the system by the project.
8. Be willing to sign a Right-of-Use Agreement and accept the legal, financial, operation and maintenance responsibilities and liabilities associated with the agreement.

A checklist for screening of participants in the initial testing phase has been developed and is presented in Section 5.

It is believed that up to 100 satisfactory locations for installation of the units can be identified within MCC and PCC. However, this will most likely require a project promotional campaign to raise awareness of the project and to create “demand” for the units.

4.1.2 INSTALLATION OF THE UNITS

The intention is that all units will be installed by the project to ensure that installation is in accordance with the manufacturer’s recommendations, meets the specifications and standards developed by the project, and achieves consistency between installations. Recipients will not be permitted to install the units themselves. However, to keep costs down, recipients may be requested to pay for certain elements of the installation, and may do it themselves, in accordance with project specifications – for example, construct fencing or other security elements as required for the installation. Recipients may also need to construct small enclosures for growing of produce (gardens) to enable utilisation of the effluent from the biogas units.

4.1.3 LEARNING OPPORTUNITIES, KNOWLEDGE TRANSFER AND CAPACITY BUILDING

The pilot project will provide excellent opportunities for learning, knowledge transfer and capacity building.

It is hoped that a large portion of the units will be installed in schools, universities, and technical colleges. This will provide extensive learning opportunities for students in the various institutions. The intention is that schools will involve students in the operation of the systems as a way for students to learn about better solid waste management practices, climate change and GHG reduction, anaerobic digestion, circular economy issues, biogas utilisation, etc. The intention is also that the project will work with the educational institutes to incorporate learning of these topics into their curricula, with various learning materials and modules being developed so that they are suitable for different age groups and levels of students, ranging from elementary school to university level.

It is proposed that the project will have an extensive promotional campaign associated with it. The promotional campaign will be necessary to inform the population about the pilot project and to create a level of “demand” for the units. It will also provide an excellent opportunity for widespread knowledge transfer within the community at large about climate change issues, GHG reduction, improved solid waste management, renewable energy, circular economy issues, etc. These topics are largely unknown in the general population at the present time and spreading the word on these issues can have enormous downstream benefits.

It is also intended that counterpart staff from MCC, PCC and other government agencies such as EPA will be extensively involved in the implementation of the pilot project as a means of building their capacity to take on future projects in relation to improved solid waste management practices and W2E applications. Counterpart staff are already involved in the testing phase that is currently underway, and the intent is that their level of involvement will increase for the pilot project rollout. Capacity building for the counterpart staff is intended to comprise a combination of hands-on field experience and training in relation to the selection of recipients, installation of the units and monitoring of the systems, and some theoretical training in anaerobic digestion, biogas utilisation, etc.

4.1.4 GENDER MAINSTREAMING

Gender mainstreaming should be incorporated into the project such that all project policies and decisions ensure that both men's and women's interests are considered and to maximise participation, opportunities, and benefits for women in the project. Women should participate in all aspects of the project, not limited to:

- Selection of the project recipients
- Installation and monitoring of the units
- Management of the units at the various installations
- Project promotional campaign
- Project educational aspects

As women likely are the ones doing most of the cooking and waste management at the locations where the units will be installed, they have the opportunity to learn the most about these systems and to spread the knowledge. These systems can benefit the women involved at the level of cooking and managing waste by reducing the burden of hauling wood and charcoal for cooking and reducing exposure to charcoal and wood fumes. As well, there is the opportunity to grow produce with the effluent from the systems, providing for better diets and perhaps reduced food costs and/or increased income potentials through selling of the produce.

4.2 Comparison against study objectives

The overall objective of this study is to Identify small-scale W2E initiatives that can be piloted in the project area that:

- Are replicable and scalable
- Ideally should be community-based
- Should consider gender inclusivity and mainstreaming

Additional objectives as stated in the study ToR and indicated by the Client include:

- Implementing the pilot project within the timeframe and available budget of the Cities Alliance project
- Piloting ways to reduce GHG and landfill emissions
- Contributing to environmental protection and building local resilience
- Promoting an integrated approach to municipal solid waste management
- Building the capacity of communities, local and national governments to understand, design and manage the integrated solid waste management system of Greater Monrovia

The proposed pilot project satisfies all of these objectives.

4.3 Project benefits

This proposed pilot project will not solve any of the MSW management issues in Greater Monrovia. The scale of the project is too small to make any noticeable difference – with 100 units installed utilising 2 kg/day of organic food waste, the total displaced organic waste volume will be 200 kg/day. This is too small to be noticed, and the volume of organics will be dispersed throughout the Greater Monrovia area. Likewise, GHG reductions will be too small to be noticed. As well, the project does not provide a stepping-stone towards a long- term comprehensive solid waste management solution for Monrovia – to install these types of units en-masse is not a cost-effective solution, and there are better options available for scale-up. The project should therefore not be viewed in the lens of making, or starting to make, a difference for the solid waste management situation in Monrovia.

However, there are many benefits of the project, the largest of which will be to disseminate knowledge on a widespread basis of the following issues and topics:

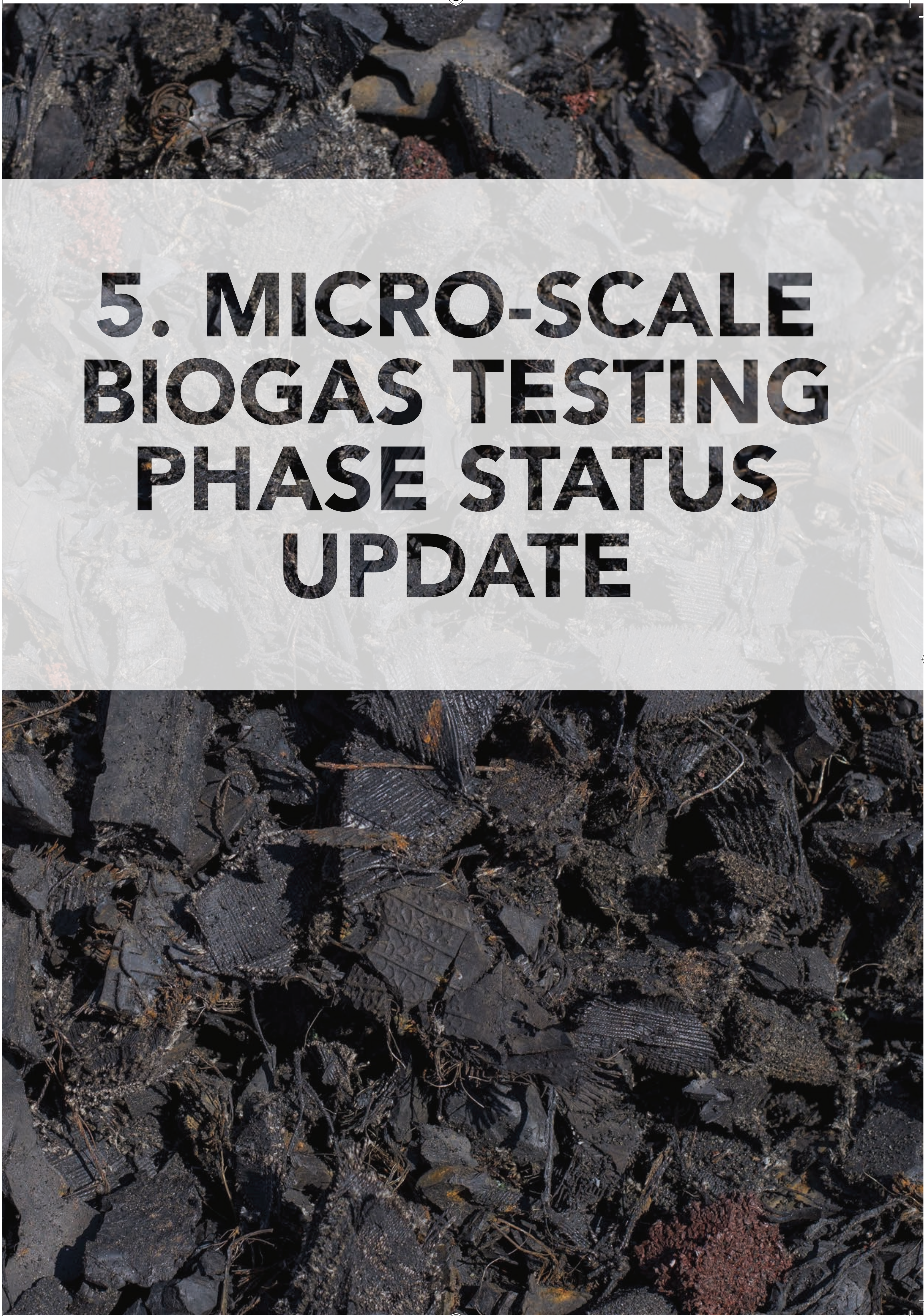
- Climate change
- GHG emissions
- The circular economy
- Improved solid waste management

In particular, linking the project with curricula in educational institutes (at various levels) can create a generation of students that are in-tune with these concepts and will apply them later in life and inform others, including their parents, about it. This will likely be the largest benefit of the project that could reap positive benefits many years into the future.

Other benefits will include:

- Capacity building within government agencies to understand and take on other waste management and W2E initiatives.
- Offsetting the use of charcoal and wood products for cooking in 100 locations including reduced burden for sourcing these materials.
- Ability to grow high-quality produce in 100 urban locations by utilising the effluent from the biodigesters as a fertiliser, improving food security and perhaps creating income opportunities.
- Local employment opportunities during the pilot phase for installation of the units and other project aspects.

The project should therefore be viewed in light of the many potential benefits that can accrue, and that can accrue in the future, rather than in terms of immediate improvements to the solid waste management situation in Monrovia. If the pilot project is successful and is to be scaled-up in the future, it should be scaled up with the objective of continuing to accrue the benefits identified above, rather than as a solution to the overall waste management situation in Monrovia. The project should also be set up to monitor these potential benefits.



5. MICRO-SCALE BIOGAS TESTING PHASE STATUS UPDATE

Phase III of the revised project work plan (Rev #2) is a testing phase for the micro-scale biogas units. Ten (10) units are to be installed and monitored under this phase with the intention that lessons learned during this testing phase will be incorporated into the pilot project.

This section of the report provides an update of the status of this phase as at the time of writing the report.

The following activities are included in the testing phase:

1. Select sites
2. Confirm details of order with vendor
3. Place orders for units
4. Manufacturer order processing
5. Shipping of units to Liberia (by air)
6. Clear units through customs
7. Install units and provide end user training after installation
8. Training workshop (1-day)
9. Monitoring and end user support
10. Summarise lessons learned
11. Report on lessons learned and handover monitoring to government
12. Client comments on report
13. Finalise report and handover project documentation

Additional details on each of the activities can be found in the Consultant's Proposal to Incorporate Small Scale Biogas Units Testing Phase into Project, 2 August 2019, contained in Appendix I.

Work on this phase of the project commenced mid-August with Activity 1 (select sites) and is still underway at the time of writing this report.

For site selection, the following has been accomplished to date:

1. The site selection criteria and checklist to be used have been developed. This checklist is to be filled out by the WNL Local Coordinator for all sites visited. The form used is shown in Figure 54.
2. Numerous sites have been visited to date, and 14 locations with suitable sites have shown interest in the project. Five of these are in PCC and nine in MCC. Some have confirmed their willingness to accept the responsibilities of the project, either verbally or by email, and others we are waiting to hear back from. A summary table of the participants who have expressed interest in the programme is presented in Table 7 after the checklist. If all 14 confirm their willingness to participate, we will need to select the 10 best sites. MCC has apparently indicated they would like to add two additional potential sites. In short, at this stage, based on verbal commitment only, there is more interest in the project than the number of units available.

3. A draft Right-of-Use Agreement in line with UNOPS requirements has been prepared by the Consultant and is currently being reviewed by Cities Alliance. The Right-of-Use Agreement is the formal document that interested recipients will need to sign to confirm their participation in the programme. As soon as the document has been approved by Cities Alliance, the Consultant will get in contact with each of the interested parties and review the Right-of-Use document with them and request that they sign. The Right-of-Use document implies certain obligations to the recipient, and it is expected that some of them may drop out when those obligations are clarified in writing to them. Nonetheless, we are confident that we can achieve ten recipients that will formally confirm their participation by signing the Right-of-Use Agreement.
4. It should be pointed out that the site selection process has taken longer than anticipated, due to low level of participation by MCC and PCC. As a result, the Consultant undertook identifying sites on their own, but this proved challenging as people were reluctant to deal with the Consultant only without any official representation from either Cities Alliance or the government. Level of participation from Cities Alliance, MCC and PCC is now increasing, and site selection activities are moving forward at a better pace and should be concluded soon.
5. Counterpart staff for the programme have been now been identified, one from each of MCC and PCC. The Consultant has started working with these staff and get them more involved in the project during the finalisation of the site selection.

Activity 2 (confirm details of order with vendor) was started in early August in order to receive firm costed proposals from HomeBiogas to enable preparing the proposal for the Phase III portion of the project. This activity has been put on hold until the site selection is complete, so that we can confirm the number of HomeBiogas units to purchase and the necessary accessories that need to be included in the order, as well as the timeframe for delivery. As soon as the site selection activities are complete, we will proceed to confirm the details of the order with the vendor (HomeBiogas of Israel) and place the order.

Due to schedule slippage on the site selection activities, we will review the overall schedule an attempt to accelerate shipping and installation activities to recover lost time.

FIGURE 54: Site selection checklist

PROJECT: **Feasibility Study on Waste-to-Energy Options in Monrovia, Paynesville, and Surrounding Townships in Liberia.**

Installation Criteria Checklist for Pilots of HomeBiogas 2.0

Households / Institution / Business name: ______________________________

Address: ______________________________

Site Proposed By: ______________________ Date: ______________

Visited By: ______________________________

Institution's Representative on Site: ______________________________

Criteria	Yes	No	Comments
Have the capacity to generate quantity of organic waste required to run equipment (HomeBiogas 2.0) up to 6 liters per day of wet organic food waste			
Specify types of organic food wastes at the site			
Availability of secure space to install equipment?			
Distance of proposed location for HomeBiogas unit from cooking location within 20 m			Actual distance (measure)
Have the capacity to utilise the cooking Gas?			Describe what the cooking gas will be used for
Have the capacity to utilise or dispose the effluent?			Describe how effluent will be utilised
Is there a water supply nearby for installation of the unit (1200 liters) and for daily operation (6 liters)?			Describe
Site properly level?			
Major security risks?			Describe

Criteria	Yes	No	Comments
Willingness to devote full commitment and accept all responsibility			Describe who will take responsibility
Have the capacity to address all safety measures?			
Do we need to construct a fence or other security measures?			Describe
When can installation be completed?			
RECOMMENDATION: Is the site suitable for installation of the HomeBiogas Unit (yes/no)	**Yes**	**No**	**Describe**

Name of Individual Willing to Take Full Responsibility:	**Contact / Email:**

Institution Staff:	**Signed:**
WNL Coordinator:	**Signed:**

SITE PHOTOS OPTIONAL:

Comment:	

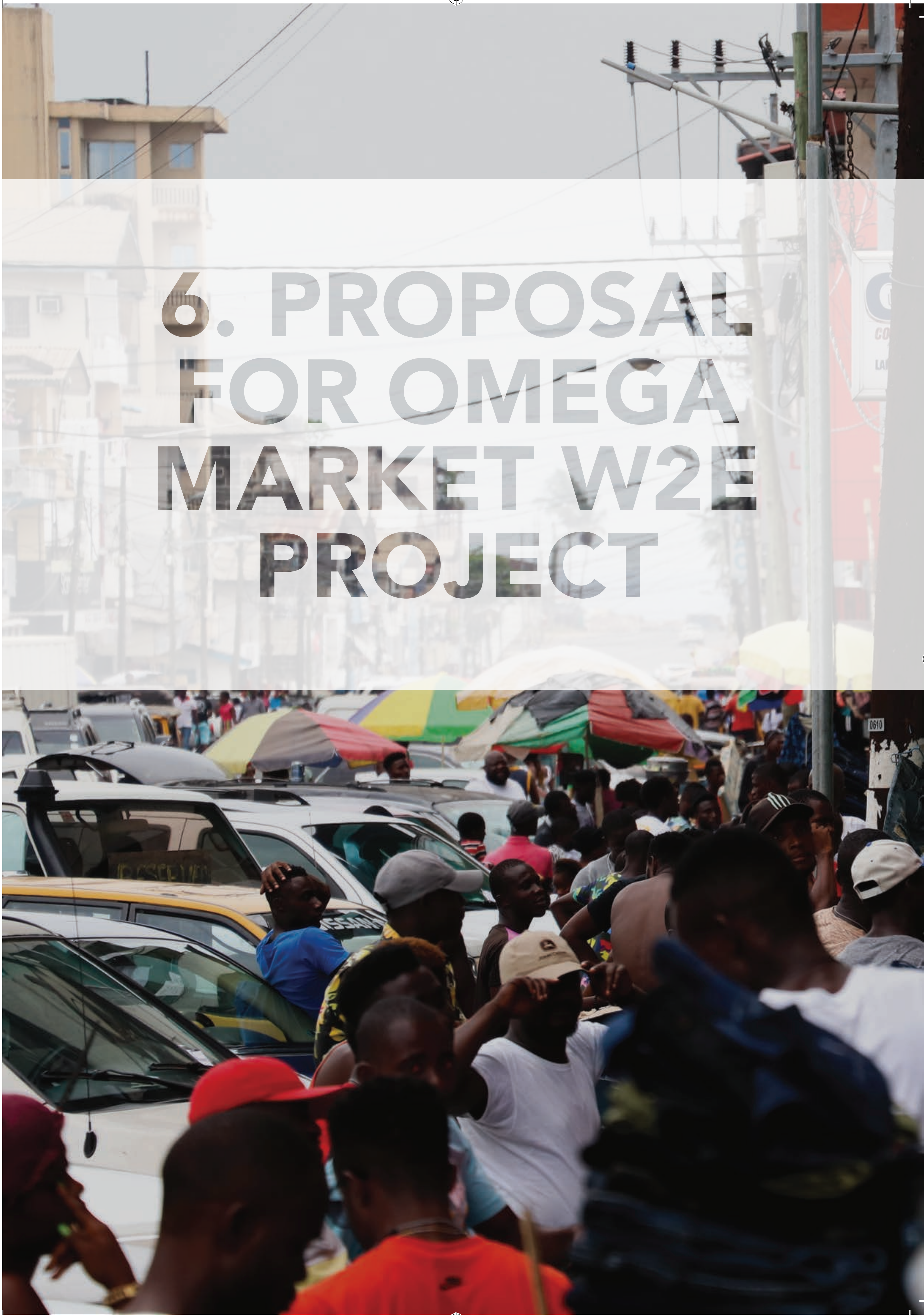
TABLE 7: Preliminary List of Sites for HomeBiogas Units

Project: **Feasibility Study on Waste-to-Energy Options in Monrovia, Paynesville, and Surrounding Townships in Liberia.**

Description: List of Proposed Site for Possible selection for Waste-to-Energy Pilot Project.

S/No	City Location	Name of Institutions	Contact	Accepted Commitment/ Yes or No.
1	Paynesville (PCC)	**Aware International School**	+ 231-0778028353 (Administrator)	Yes (By email)
2	Paynesville (PCC)	**Issacs A. Davies School**	+231-777564796 / 0886564796 (Vice Principal)	Yes (By email)
3	Paynesville (PCC)	**RLJ Kedneja Hotel**	+231- 0886436711 (Manager)	Yes (Verbal)
4	Paynesville (PCC)	**Tropicana Resort**	+231-886529639 / 0770529639 (Manager)	Yes (Verbal)
5	Paynesville (PCC)	**Felecia Catering**	+21886454977 (Owner)	Pending
6	Central Monrovia, Sinkor (MCC)	**Evelyn Restaurant**	+231777001155 (Manager)	Pending
7	Central Monrovia (MCC) Jallah Towns	**Smart Liberia Canteen**	+231 0770357129 (Head Chef)	Yes (Verbal)
8	Central Monrovia, UN. Drive (MCC)	**Mother Pattern College (St. Teresa Convent)**	+231 775202267 (Dean Academic Affair)	Pending
9	Central Monrovia (MCC) Sinkor	**William V.S Tubman Memorial School**	+231 77643456 (Principal)	Yes (Verbal)
10	Central Monrovia (MCC) Sinkor	**University of Liberia (Canteen)**	+231777535225 (Manager)	Pending
11	Central Monrovia (MCC) Sinkor	**Corina Hotel & Restaurant**	+2310770676570 (Manager)	Pending
12	Central Monrovia (MCC) Sinkor	**Stella Maris Polytechnic University**	+231077006243 (Dean of Environmental College)	Yes (By Email)
13	Central Monrovia (MCC) Sinkor	**Muslim Congress High School**	+231 0770883437 (Vice Principal Administration)	Yes (Verbal)
14	Central Monrovia (MCC) Sinkor	**Nancy Doe Market**	+231 0777943927 (Market Secretary)	Yes (Verbal)

6. PROPOSAL FOR OMEGA MARKET W2E PROJECT



6.1 Background

At the conclusion of the study tour, it became evident that implementation of the AD-based very-small scale pilot projects, as proposed in the Inception Report, would carry a high implementation risk for the current project. This is due to the inability to provide the necessary technical and financial support that the project would require over the first couple of years, given the limited time frame and budget of the current Cities Alliance project.

It was therefore agreed that a better approach would be to look at a separate initiative for a larger project along the same lines as the initially proposed pilot project, and to seek separate funding, adequate to support the capital cost as well as the necessary technical and financial support for the first 1-2 years of operations. It was also agreed that the project should be located at the new Omega Market, where there is adequate land available for such an initiative.

This section of the report presents a proposal for the future development a Wet AD-based W2E project to be located at the Omega Market. The proposal includes:

- Description of the overall proposed project
- Project benefits
- Conceptual design of the facility
- AD technology suppliers
- Estimated capital and operation costs
- Potential revenue streams
- Business case analysis
- Environmental, social and gender considerations
- Institutional considerations
- Project implementation considerations
- Summary and next steps

The intent of this section of the report is that it could be extracted and used as a separate document and starting point for discussions with funding agencies to secure funding for the implementation of the project. Based on the research carried out by the Consultant during this study, it became apparent that there are multiple donors active in W2E projects in Africa, and with the potential benefits of this project, we believe there will be several organisations interested in providing funding to such a project.

6.2 Description of proposed project

6.2.1 LOCATION – OMEGA NEW MARKET SITE

Omega New Market Site (Omega Market) is located in Montserrado County along the Monrovia-Kakata Highway, approximately 30 minutes outside of Monrovia north of Paynesville.

The Liberian government is currently constructing the new market with a long-term goal to host 18,000 marketers. The new market will provide significant relief for the severely overcrowded and taxed existing Red Light and Gorbachev markets. (note the new Omega market is actually called Gorbachev market at Omega Village Community but is referred to as Omega Market within this report). The intention is that market vendors from the existing markets will move to the new Omega Market over time. Figure 55 shows some of the current status of construction as of August 2019.

FIGURE 55: Photos showing construction currently underway at Omega New Market site, August 2019

The market site has ample land for development where a W2E project could be implemented, on a green field site. There are also plans to establish local crop production near the market for supplying produce to the market. Given the scarcity of land in other areas of Greater Monrovia, and planned crop production nearby, this site offers the ideal combination of factors that will not be found elsewhere in the region. However, the availability of land around the market may not last long, so it will be important to move forward with discussions with the government regarding the proposed project very quickly so that the land can be secured. Figures 56 and 57 below show the location of the market and the surrounding land.

The Consultant has been able to obtain drawings of the new market from the contractor building the market. Figure 58 and 59 present architectural drawings of the facility.

FIGURE 56: Aerial view of Omega Market site highlighting adjacent undeveloped property

FIGURE 57: Available land adjacent to the market is seen in the top portion of photo behind market area

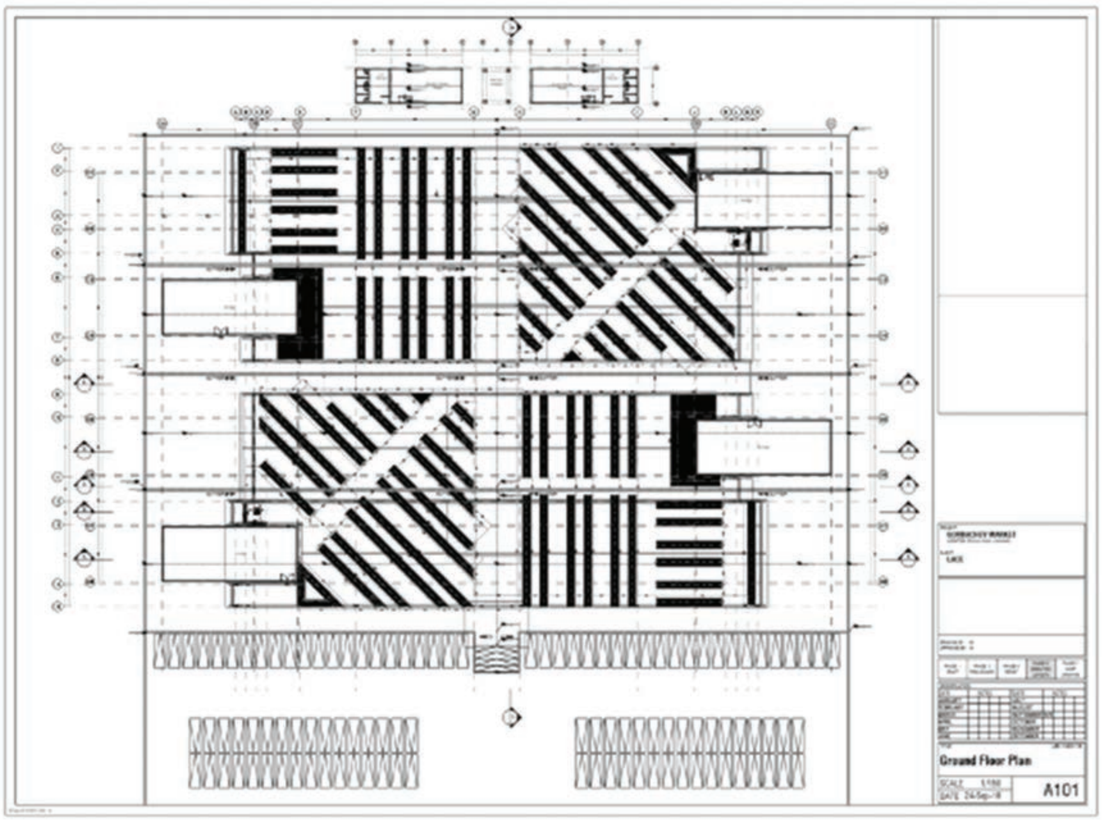


FIGURE 58: Ground floor plan of new Omega Market

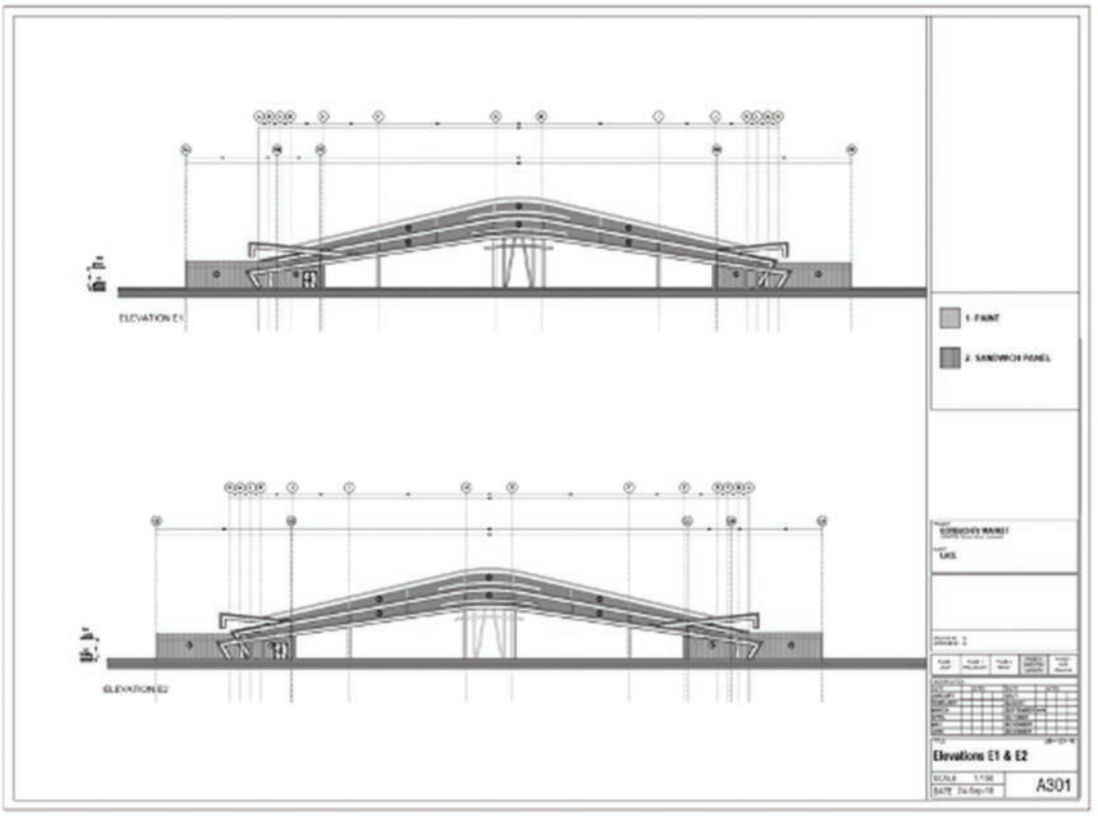


FIGURE 59: Elevation views of new Omega Market

6.2.2 PROJECT CONCEPT

The concept of the project will be to develop a Wet Anaerobic Digestion (Wet AD) based waste-to-energy (W2E) project at the Omega Market site with the following features:

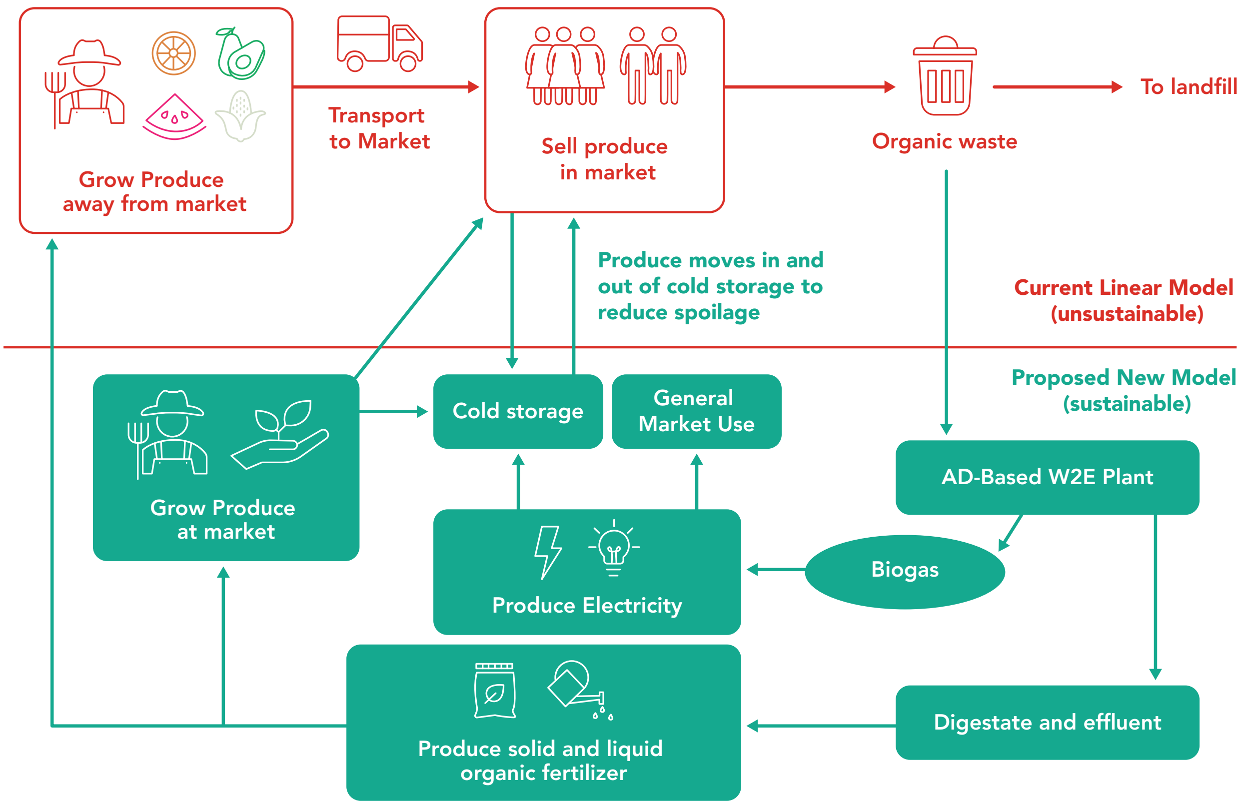
1. The AD plant will use organic waste from the market. This will significantly reduce the waste management needs and problems for the market by utilising the organic waste at site.
2. The organic waste will be converted to biogas through anaerobic digestion (AD).
3. The biogas will be converted to electrical energy through the use of a biogas generator.
4. The electrical energy will provide power supply to the market for lighting and other normal uses.
5. It is proposed to construct cold storage facilities at the market as part of the project with the electrical energy used to run the refrigeration equipment. This will enable longer lifespan and reduced spoilage of produce sold at the market (fruits, vegetables, meat and fish), enhancing incomes of market vendors.
6. The digestate from the AD process can be transformed into compost, organic fertilisers or other value-added products such as "green-coal" that can be sold into the agricultural or other markets. There are currently some private sector companies in the business of composting and organic fertilisers, and to avoid competing with them, it is proposed to sell the digestate to them and have the composting operation off-site, or to make an arrangement with them that they

manage the composting aspect of the facility on-site. If on-site, the compost and fertilisers could be used at the planned farms adjacent to the market to grow more produce that could be sold at the market. There is also potential to use the liquid effluent from the AD process as an organic fertiliser, and this could be sold or used on nearby farms.

The project concept is the same as initially proposed as Option 1 of the pilot project, but to a much larger scale. It has the benefits of not having land and other constraints associated with developing a project at an existing market location. It also has the advantage of nearby farms.

The project supports the concepts of a circular economy, whereby organic waste products are put back into the supply chain to create something of value that can be used again. In this concept, organic waste is transformed into electrical energy – that has high value – and compost and fertilisers that can then be used to grow more organic produce…….and so the cycle continues. A simplified schematic representation of the project concept is shown in Figure 60 that includes the current situation at the top part of the graphic and the proposed new arrangement below.

FIGURE 60: Schematic representation of proposed project



6.2.3 W2E PLANT CAPACITY

The proposed W2E system has been sized to produce an average of **100 kW of net electrical power** that can be used to supply the market. To generate this amount of power will require **approximately 5,000 kg/day of organic waste as feedstock.**

6.2.3.1 Electrical power supply

Approximately 10-20 kW of this power could be used to supply refrigeration equipment for the proposed cold rooms. This is only a rough estimate at this time and the actual power supply requirement for the cold rooms will depend on several factors including:

- The actual size of the cold rooms installed
- The temperature the cold rooms are to be maintained at
- The type of produce to be stored (whether fruits and vegetables only, or if including meat or other products)
- The construction specifications and quality of the cold rooms

Based on the Consultant's prior experience of constructing other cold rooms in Liberia, this range of power supply is believed to be adequate, at least initially.

If 10-20 kW of power is used for the cold rooms, that will leave 80-90 kW for general market uses. While this does not seem to be a lot, the electrical demand of a market is generally quite low and is typically only for lighting and electrical appliances. The market will likely be developed in stages, and given that it is a new market, it could take several years for the market to be fully utilised, as market vendors and consumers must move from existing marketplaces. As such, the 80-90 kW should be sufficient to power most of the market, at least in the initial stages.

While it is possible to develop the W2E system for a larger electrical capacity, there may not be enough organic waste – particularly in the first few years of the operation of the new market – to support more electrical generation (or even to support the proposed 100 kW), and the plant could be over-built, which will negatively impact the economics and make it less sustainable. It is therefore better to view this as a first stage of development of the W2E system to correspond with the initial development of the market, with the intent that the W2E system could be expanded upon in a second phase as the market grows.

The Consultant has reviewed the electrical drawings for construction of the new market, and it is planned to install a 40 kVA generator (approx. 50 kW). However, it was noted on the drawings that the electrical installations are very minimal, and this will likely grow over time. As such, the 100-kW proposed system, with 80 – 90 kW available for general market use is of the correct magnitude. To go larger than this will risk not being able to utilise the power, and to go smaller will risk not providing enough power to supply all market needs. As well, reliable power supply is a scarce commodity in Liberia, and the demand for power will grow to match the availability of power. The availability of a reliable power supply at the market will also serve to attract more market vendors and customers.

Additional discussion on power supply is given in subsequent sections.

6.2.3.2 Waste quantities

In our Rapid Assessment of Organic Waste carried out in the existing Red Light Market, we were able to easily obtain approximately 1,000 kg/day of organic waste (refer to Section 3.1). It was also believed that 2,000 to 5,000 kg/day could be available in the market. Based on this, we believe that sizing the plant for a 5,000 kg/day of organic waste (as received) is reasonable. However, the Consultant recommends that as an essential first step before committing to the development of the proposed project, a more thorough assessment of organic waste quantities (and qualities) available at existing markets should be carried out over a longer time frame, say for a period of one month and repeated in different seasons, to confirm expected waste volumes.

6.2.3.3 Sizing approach and calculations

Approach

The overall approach taken for sizing of the system and developing the conceptual design was to establish the desired electrical power generation capacity (100 kW net output) and to work backwards from there to determine the quantity of waste required. It was hoped that the result would indicate a necessary waste quantity corresponding with the anticipated amounts available – which, fortunately it did. As above, the waste quantity required to generate the 100 kW is approximately 5,000 kg/day which it is believed can be available. Using a basis of 100 kW is also convenient for scaling up or down, for example, if it was desired to produce 150 kW or 80 kW of electricity, various components of the plant would simply need to be scaled up or down as appropriate.

Calculations

An AD process generates biogas, which can then be used to produce electricity. There are various technologies available to convert biogas into electricity, but the most commonly available technology, which will be suitable for this project, is a biogas electricity generator, which has about a 30% efficiency factor in converting energy contained in the gas to electrical energy. This is essentially standard across the board with equipment from various manufacturers. As such, sizing of the AD system comes down to establishing how much gas can be generated on a per unit basis (biogas yield) for a given type of AD process from a certain feedstock, and then this will determine the quantity of feedstock required. Biogas yield is the quantity of biogas generated in m^3 of gas per kg of organic feedstock fed to the digester and is a function of many factors, such as the characteristics of the feedstocks, feedstock preparation, digester design, digester operation, temperature, to name a few.

Normally, to design an AD system, the first step is to determine the biogas yield of the feedstock through laboratory testing comprising continuous stirred tank reactors (CSTR) setup to replicate specific digester conditions to determine the biomethane potential (BMP).

As the feedstocks have not been analysed to determine their BMP or biogas yield, to prepare the conceptual design of the process and the facility, the Consultant has had to make assumptions on the biogas yield of the feedstock. It should be noted that if this project moves forward to detailed design, it will be necessary to carry out the laboratory testing of the feedstocks to establish the biogas yield with more confidence.

The following three scenarios were relied upon for guidance in selecting an appropriate biogas yield on which to base the performance calculations for the conceptual design of the AD facility for Omega Market.

1. The biogas yield calculated for the simple, low cost, bag style, HomeBiogas 2.0 Wet AD system is 0.3401 m^3/kg of feedstock. This is at the high end of the range and is based on feedstock comprised of developed country food waste, which would include meat and dairy products that have higher energetic value and greater digestibility than the organic wastes anticipated from the Omega Market.
2. The biogas yield calculated for the Gorge Farm Energy Park project in Kenya, based on the specifications provided verbally by the operator, was determined to be 0.3056m^3 gas per kg of feedstock. The feedstock at Gorge Park is green waste from flower production, which has similar characteristics to a large portion of the wastes expected at Omega Market.
3. The biogas yield calculated for the Tropical Power conceptual digester based on the specifications provided by the designer was determined to be 0.2445m^3 per kg of feedstock. The feedstock basis specified had very low energetic values and low digestibility and was considered to be very conservative.

As above, the range of biogas yields is from 0.24 to 0.34m^3 gas/kg feedstock, from three different scenarios with feedstocks ranging from very low energetic values and low digestibility to high energetic value and high digestibility. Tables 8–10 below show how the biogas yield was determined for the various scenarios.

TABLE 8: Calculation of Biogas Yield for HomeBiogas 2.0 Unit

Specified Quantity of Food Waste Fed (L/day)	Estimated Food Waste Density (kg/L)	Quantity of Food Waste Fed (kg/day)	Specified Biogas Production (m^3/day)	Biogas Yield (m^3/kg Feedstock)
6.0	0.343	2.06	0.7006	(0.7006/2.06) = 0.3401

TABLE 9: Calculation of Biogas Yield for Gorge Farm Energy Park Project

Specified Quantity of Organic Waste as Received (kg/year)	Specified Sustained Power Generation (kW)	Calculated Biogas Production to Maintain Power Generation (m^3/year)	Biogas Yield (m^3/kg Feedstock)
34,675,308	2,500	10,596,774	(10,596,774/ 34,675,308) = 0.3056

TABLE 10: Calculation of Biogas Yield for Tropical Power Conceptual Design

Specified Quantity of Organic Waste as Received (kg/year)	Dry Matter Within Organic Waste Received (kg/year)	Specified Sustained Power Generation (kW)	Calculated Biogas Production to Maintain Power Generation (m^3/year)	Biogas Yield (m^3/kg Feedstock)
1,386,899	693,450	80	339,097	(339,097/ 1,386,899) = 0.2445

Based on the three scenarios above, the Consultant decided to use a BMP value of 0.3056m^3 gas/kg of feedstock as the basis for preparing the conceptual design of the Wet AD system for the Omega Market. This is the same value as for the Gorge Farm Energy Park in Kenya, a process based on 100% green waste (ligneous) that is difficult to digest. The waste at the Omega Market (approximately 50% fruit and vegetable waste and 50% green waste, or ligneous) is foreseen to have a higher energetic content and better digestibility than at Gorge Park, and thus a higher biogas yield. However, we believe is better to be on the conservative side at this point in assuming the level of potential biogas production. If more biogas can be produced than the assumed value, it will simply benefit the outputs of the project in terms of additional power supply generating capability. This is preferable than to assume a high gas production rate at this point and set false expectations that are not achieved in the field. In any case, the conceptual design of the Wet AD system employs equipment, processes, and practices aimed at maximising the digestibility of the available organic wastes in order to achieve the highest possible biogas yield from the feedstock.

Once the biogas yield was selected, a convergence process was followed using the primary formulas below to balance power generation with organic feedstock based on the biogas yield.

1. Generator Electrical Energy Production= Rated Capacity x Operating Hours x Capacity Factor
2. Engine Fuel Energy Requirement= Generator Electricity Production x Fuel Conversion Efficiency
3. Biogas Fuel Requirement= Engine Fuel Enegy Requirement / Biogas Energy Requirement
4. Biogas Fuel Requirement= Biogas Production
5. Quantity Of Organic Feedstock To AD= Biogas Production / Biogas Yield
6. Quantity Of Organic Feedstock Received= Quantity of Organic Feedstock To AD x (1 + Residual)
7. Quantity Of Effluent= Biogas Production x Mass Balance Factor (Stoichiometry Specific)

8. Aviod ed GHG Emissions= Biogas Production x 0.6 x 25
9. Mass Balance Factor (0.3056 m^3 per kg Feedstock)= 1.698 / 0.252 = 6.724 (See Table 11)

Mass balance calculations are presented in Table 11.

TABLE 11: Approximated Biogas Production Stoichiometry for Biogas Yield of 0.3056 m^3/kg Feedstock

Parameter	Unit Mass	
Organic Feedstock as Received	1.000	
Feedstock Rejected	0.050	
Feedstock to Digester	0.950	1.950
Water to Digester	1.000	
Biogas from Digester	0.252	1.950
Digestate from Digester	0.634	
Water from Digester	1.063	
Digestate and Water from Digester	1.698	
Mass Balance Factor for Calculating Effluent	6.724	

Table 12 presents a summary of the calculated values for various technical parameters for the conceptual design of the Omega Market AD process. The most important parameters are highlighted in the table. Convergence of the power generation, biogas yield, and organic feedstock quantities was achieved. Additional performance information includes effluent production estimates and avoided GHG emission savings.

TABLE 12: Summary of Technical Parameter for Omega Market AD Process

Parameter	Units	Calculated or assumed value	Remarks
Generator Rated Capacity	kW	111	Includes 11 kW power for internal plant use for net output of 100 kW
Hours Per Year	h/yr	8,760	
Generator Capacity Factor	%	90%	Includes for 10% generator maintenance downtime
Electricity Production	kWh/yr	877,489	
Fuel Conversion Efficiency	%	30%	

Parameter	Units	Calculated or assumed value	Remarks
Fuel Requirement	kWh/yr	2,924,964	
Conversion Factor	MJ/kWh	3.6	
Fuel Requirement	MJ/yr	10,529,870	
Natural Gas Energy Content	MJ/m³	37.2	
Natural Gas Percentage	Content	60%	
Biogas Energy Content	MJ/m³	22.32	
Biogas Requirement	m³/yr	471,768	
Biogas Yield	m³/kg Feed	0.3056	
Feedstock Quantity (Net)	kg Feed/yr	1,543,745	
Residuals	%	5.26%	Based on results of rapid waste assessment
Feedstock Quantity (Gross)	kg Feed/yr	1,624,946	
Feedstock Quantity (Gross)	t Feed/yr	1,625	
Feedstock Quantity (Gross) based on 7 days/week operation	t Feed/day	4.45	
Feedstock Quantity (Gross) based on 6 days/week operation	t Feed/day	5.20	
Feedstock Quantity (Gross) based on 6 day/week operation	kg Feed/day	5,200	
Biogas Production	m³/yr	471,768	
Biogas Production	m³/day	1,293	Based on 365 days/yr
Biogas Density	kg/m³	1.15	
Biogas Production	kg/yr	542,534	
Biogas Production	t/yr	543	
Biogas Production	kg/day	1,486	
Effluent Production	kg/day	9,995	Approximately 75% liquid, 25% solid by mass
Avoided GHG	t/yr	8,138	

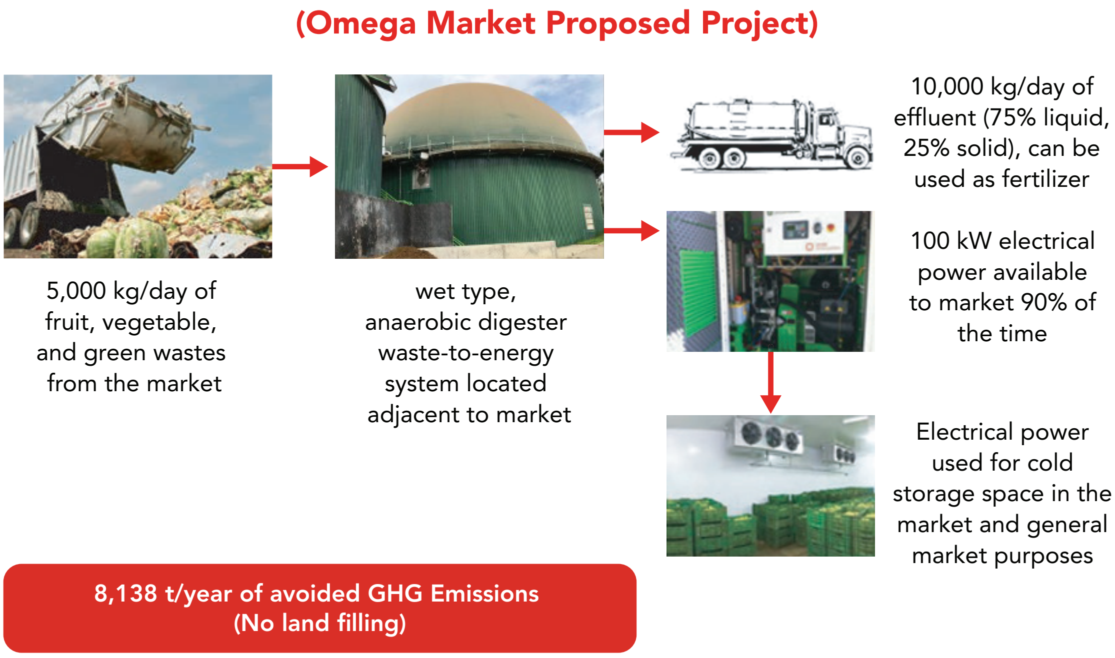
Based on an assumed biogas yield of 0.3056 m³/kg of feedstock, the estimated performance parameters of the system will be as follows:

1. 111 kW electrical energy generated. Approximately 10% or 11 kW of this will be used for internal plant operations, giving a net output of 100 kW. This power supply would be available 90% of the time and can be used to supply the market, for cold storage facilities, and general uses (see discussion below on power supply).
2. 5,200 kg/day of organic waste feedstock will be required every day, based on operating six days a week.

3. Approximately 10,000 kg/day of effluent will be produced. This will be approximately 75% liquid and 25% solid. These fractions can be converted to compost and organic fertilisers.
4. Avoided GHG will be approximately 8,100 tonnes/yr. This is avoided GHG for not needing to landfill the organic waste only and does not consider offsetting diesel generator use at the market, or not needing to transport organic waste to the landfill.

Figure 61 presents this information graphically.

FIGURE 61: Graphical representation of project parameters



6.2.3.4 Additional considerations on generated power supply and Biogas yield

As described above, the electrical output from the W2E facility is estimated at 100 kW, available 90% of the time. This should be more than enough to provide for the power requirements of the market, including cold storage facilities, at least in the initial stages of the market development. However, the market is only open during the day, and at night, the only power requirement would be to cycle the refrigeration equipment and for some sight security lighting. The power requirement at night may be only in the order of 20-30 kW.

One of the advantages of an AD based W2E system is that the energy is stored in the form of gas. This makes it possible to adjust the power output quite easily from the facility up and down throughout the day in response to electrical loads. As such, if less power is supplied at night, it means that more can be provided during the day. It may therefore be possible to increase the power output to say 150 kW for certain periods during the day. This will be much more than the market will require and could be utilised to set up small-scale businesses at or near the market, creating valuable employment opportunities, especially for women. Conversely, the energy storage capabilities of an AD system gives likelihood of achieving the 100 kW electrical output during the day if it turns out that the actual gas yield of the system is lower than what has been assumed in the Consultant's calculations.

It should also be noted that there are ways to increase the biogas yield from the plant (and thus the electrical generating capacity). The calculations above are based on organic vegetable and green waste from the market only. Biogas yield could be increased by adding:

1. Sewage from public toilets
2. Waste cooking oils, fats, greases, etc.
3. Waste meat and fish products

These could all be potentially sources from the market. This is not considered in the current conceptual design, and available quantities are unknown but may be considered in the future. Collection methods for these waste streams would need to be developed.

6.3 Project benefits

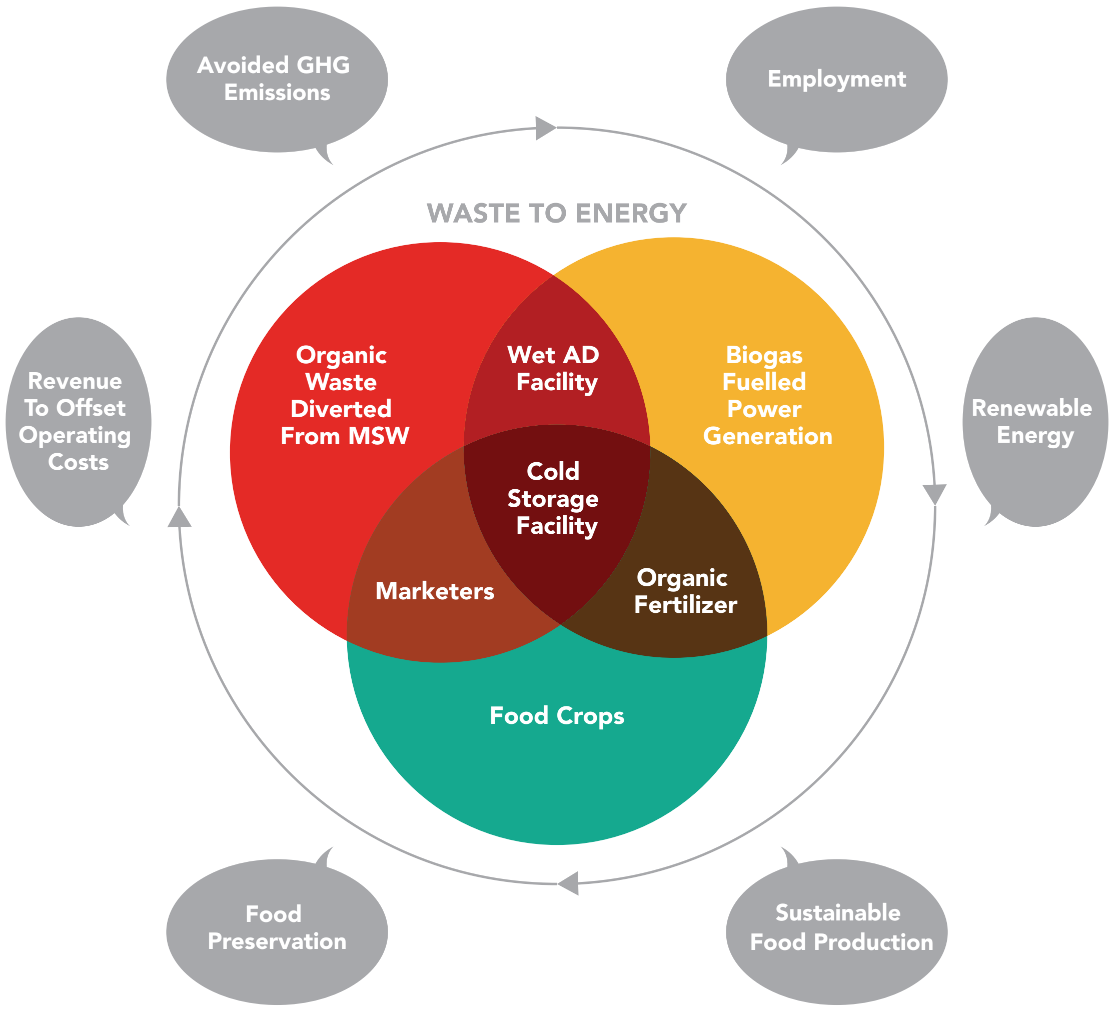
Some of the project benefits were mentioned in section 6.2.2 above. These are further elaborated in Figure 62, which provides a graphical representation of the project benefits and sustainability framework.

The numerous benefits that can accrue from the project include:

1. **Reduced waste management problems** at the new Omega Market. Most of the organic waste from the market would go directly to the W2E plant. Other waste recycling programmes could also be put in place at the market at the same time, significantly reducing the amount of waste that would need to be sent to a landfill.
2. **Renewable electrical power generation** in amounts equal to or in excess of the requirements for the market.
3. **Greenhouse gas avoidance** by not needing to landfill organic wastes or run diesel generators at the market.
4. **Food preservation** through the construction of cold rooms at the market that would be supplied with regular power from the W2E plant. This will reduce food spoilage, enhance the value of food products, and potentially increase incomes of market food vendors and/or enable them to sell their produce at a lower cost, resulting in improved food security for the general population. (It should be noted though that reduced food spoilage may result in lower quantities of organic waste being available as a portion of the organic waste is spoiled produce that cannot be sold.)
5. **Revenue streams to offset operating costs** through the sale of electricity to the market, the sale of digestate and effluent for composting and fertiliser, possible carbon credits, and possibly charging for the use of the cold storage facilities. The revenue streams will support the overall long-term sustainability of the project.

6. **Sustainable and increased food production** through utilisation of organic fertilisers and soil conditioners from the byproducts of the plant. Food production (and employment opportunities) can increase, particularly if the intent of growing crops at the market is implemented.
7. **Employment and business opportunities.** The construction and operation of the AD plant itself will create several jobs. Collecting and sorting waste will also create jobs. Additional small-scale business opportunities, particularly for women, will be created by having a reliable power supply that could be in excess of the requirements for the market. As well, the cold rooms can potentially increase incomes for market food vendors.

FIGURE 62: Graphical representation of project benefits and sustainability framework



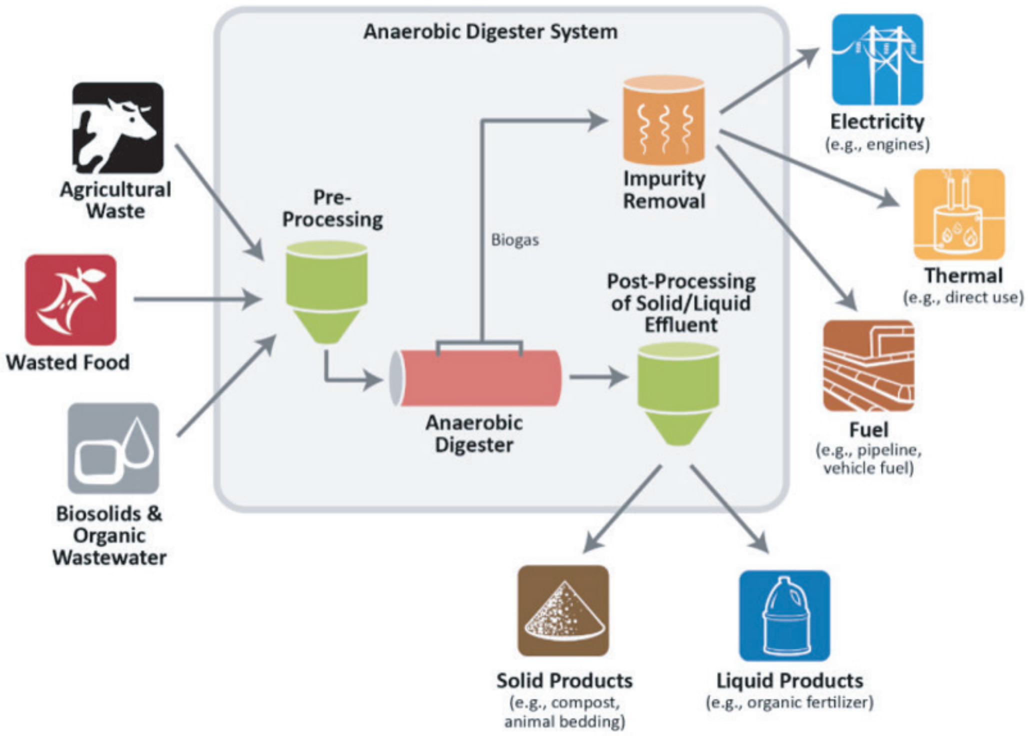
6.4 Conceptual design of the facility

Having developed the overall concept of the project, including determining the key operational parameters, the Consultant proceeded to prepare a conceptual design of the facility as presented in this section.

6.4.1 ANAEROBIC DIGESTION PROCESS AND EQUIPMENT

A graphical representation of a typical AD W2E process is shown in Figure 63.

FIGURE 63: Graphical representation of a typical AD based W2E system



Steps in the AD W2E process are as follows:

1. Organic waste is brought to the facility.
2. Pre-processing of organic wastes prior to entering the anaerobic digester (AD). This is to remove unwanted or large items in the waste stream and to establish a consistent particle size that will maximise the potential gas yield of the system.
3. The pre-processed waste then enters the anaerobic digester, where biogas is produced through the anaerobic digestion process.
4. Biogas is then taken off from the digester and is cleaned to remove impurities.
5. The cleaned biogas is used to create higher value energy such as electricity or transportation fuel.

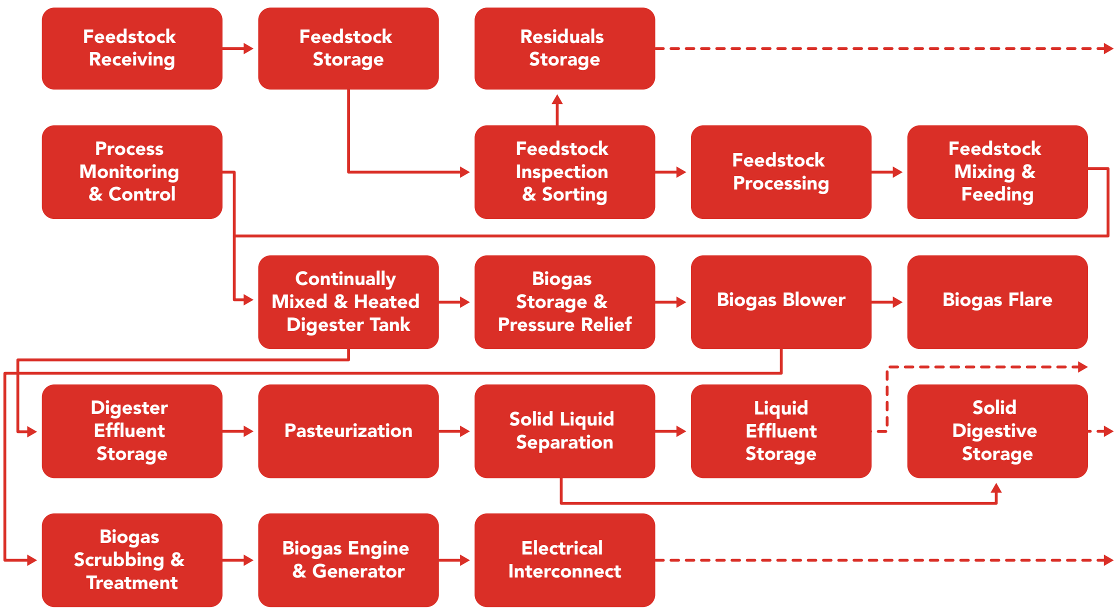
6. Effluent generated by the AD, in the form of a slurry containing both liquids and solids, undergoes solid/liquid separation, and can then be used for compost and organic fertilisers.

The process for the proposed Omega Market facility will be similar to the above, but with the following exceptions:

- It is not proposed to utilise agricultural waste or biosolids and organic wastewater as inputs to the process. Inputs will be waste fruits and vegetables only.
- The biogas will only be used to produce electricity.

In reality, the process is more complex than presented above, with additional steps that are not illustrated in the above graphic. Figure 64 below depicts a conceptual process schematic diagram for the proposed AD-based W2E plant.

FIGURE 64: Process schematic diagram for proposed AD-based W2E plant



Each box represents a function within the process for converting the organic waste into useful energy, solid and liquid effluent factions, and residuals (items in organic waste delivery that cannot be digested, i.e. glass, metal, wood, plastic). Each step is important to ensure the performance and compliance of the system. Value engineering in the final design process and specific manufacturers equipment can subtly alter the number of steps by eliminating certain functions and/or combining functions.

Each of the steps in the process and examples of typical equipment that is used are described in the following.

Feedstocks: Feedstocks consist of 50% fruit and vegetable waste and 50% of the green waste associated with fruits and vegetables. No appreciable fats, oils, and greases would be contained in the waste. Overall, energetic value of the feedstocks is low to medium. The basis for this comes from the Rapid Organic Waste Assessment conducted as part of the Feasibility Study. Deleterious materials (i.e. glass, metal, paper, wood, soil, etc.), referred to as Residuals in the feedstock deliveries, are items that should not pass into the feedstock processing or digester. The percentage of residuals in feedstock deliveries is forecast to be approximately 5%. Feedstocks will be delivered throughout the regular operating hours of the market six days per week (closed on Sunday). On average, 31.15 tonnes per week of waste organics must be generated by the market to operate the W2E plant at the design capacity on a continuous steady-state basis. This delivery rate is equivalent to 5.2 tonnes (5,200 kg) per day as received for the six days per week. The average estimated moisture content of the waste organics is 50% wet basis. Systems will need to be put in place with market vendors and possibly CBEs to collect, assemble and deliver the waste to the AD plant.

Feedstock Receiving: The feedstock receiving is where organic wastes collected from throughout the market will be brought. Deliveries are anticipated to be made either by small trucks or carts. The receiving area components consist of a small office, weigh scale, paved lot, and covered shed to house the inspection, sorting, processing, and storage functions. The aim will be to deal with all deliveries in an expeditious manner, so as to avoid odour and nuisance issues. The shed is 6 m by 10 m and 3m high at the ceiling. The walls will be open to permit airflow throughout the shed. The shed floor will be concrete and sloped for appropriate drainage to a sump for wash down and cleanup.

Feedstock Storage: Within the feedstock receiving shed will be a series of open-ended bins to hold organic waste deliveries following weigh in. Depending upon the contents in the delivery, efforts will be made to group similar types of feedstocks (i.e. fruit and vegetable waste vs green waste) into specific bins. Manual material handling is used for placing deliveries into the bins and removing the contents from the bins. The bins will have floor drains that lead to a sump. Contents in the sump will ultimately be pumped into the digester tank. Semi-liquid and liquid deliveries will be placed into tubs or barrels. The contents of the tub or barrel will be manually added to the feedstock mixing process. The empty trucks or carts will be weighed on departure and the delivery weight recorded. The storage capacity for the facility is approximately 5,000 kg or 15m^3 of organic waste; approximately one day of deliveries. Bin sizing is 2.0 m deep by 2.0 m wide by 1.25 m high side walls.

Feedstock Inspection and Sorting: Within the feedstock receiving shed will be a 3 m by 1 m surface with overhead lighting. Staff will transfer contents from the feedstock storage bins to the surface and spread the contents for further inspection and sorting. Staff will manually separate the feedstock constituents and remove any deleterious materials (i.e. glass, metal, paper, wood, soil, etc.). Deleterious materials will be manually transferred to the residuals storage bin with pails. Inspected feedstocks of an appropriate size will be manually transferred from the inspection surface and placed into a rotating trommel screen equipped with a magnet. The screen will separate the organics by size and the magnet will remove any remaining metal particles. Oversized items will be transferred to a 3 m by 1 m cutting table to be manually size reduced by the staff with knives. Once size reduced, the items will be placed into the temporary holding bins below the trommel screen. The organics passing through the trommel screen will be held in the temporary bins until sufficient quantities are available to proceed with the chopping/grinding operation. Undersized items are not chopped or ground and simply transferred directly to the feedstock mixing and feeding tank manually. The design capacity of the inspection and sorting will be 1,000 kg of waste organics per hour.

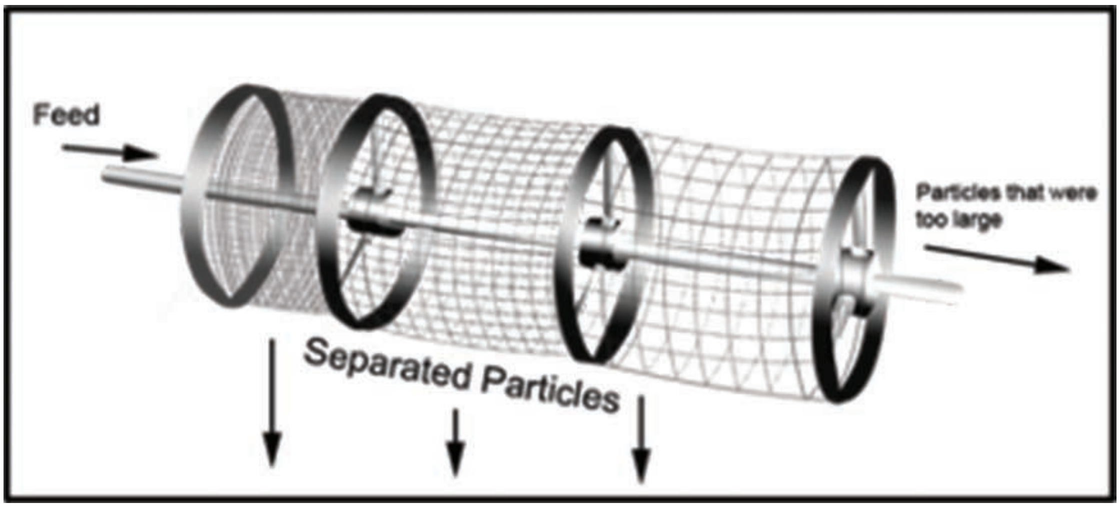


FIGURE 65: Trommel screen for sizing and sorting waste organic feedstocks

Residuals Storage and Transfer: The residuals storage will consist of skip buckets to be picked up on a regular basis by materials recyclers or waste collectors for transfer to recycling facilities or waste disposal. Skip buckets will be transferred by truck. The skip buckets are anticipated to receive an average of 200-300 kg of deleterious items per day.

Feedstock Processing: The feedstocks must be appropriately crushed and size reduced to permit rapid and efficient digestion and conversion to biogas within the Wet AD facility. Therefore, the feedstocks are passed through a chopper/grinder, as shown in Figure 66. The feedstocks will be fed manually onto a conveyor which in turn feeds the chopper/grinder. Chopped and ground material will be delivered to the mixing tank via a conveyer. The undersized organics and the semi-liquid and liquid feedstocks will be added manually into the mixing tank. The design capacity of the feedstock processing will be 1,000 kg per hour of waste organics.

Feedstock Mixing and Feeding: A bulk mixer referenced as a dry feeder will receive the chopped and ground feedstock. The dry feeder will mix the chopped and ground feedstock and meter the material into the digester via a rotary airlock. The design holding capacity of the dry feeder is 2,500 kg or 5m^3 of processed waste organics; approximately half of the daily waste receiving capacity. The dry feeder is capable of feeding rates from between 100 and 750 kg per hour. Steady state operation entails a feeding rate of approximately 185 kg of processed waste organics per hour. Twenty-four-hour, seven-days-per-week feeding is preferred to maintain digester performance. Ideally, the dry feeder is filled to capacity near the end of a shift to permit overnight continuous feeding of the digester.

FIGURE 66: Organic waste feedstock chopping and grinding equipment

Continuous Fed, Single Stage, Mixed, Mesophyllic Digester: A continuous fed, single stage, mixed, mesophyllic digester consists of a circular vertical wall tank with a cover. This vessel serves as the reactor for the anaerobic digestion reactions. Mesophyillic refers to the temperature range (30 to 38 °C) the constituents within the digester are kept at to promote effective anaerobic reactions. As a result, the digester is equipped with internal heating coils. Heat is typically sourced from the engine exhaust, cooling or a boiler. Mixing devices within the digester continually stir the constituents to expose the feedstocks to the various types of bacteria distributed throughout the digester. Initially, the digester is activated by being inoculated with livestock manure or effluent from another digester. Moderate daily rates of feeding the digester will commence until sufficient quality biogas is generated; generally, within 30 days. Once fully operational, the tank level is kept constant and regular daily feeding schedules are maintained to provide stable biogas production. Additional water will be pumped into the tank in the event dry solids are a predominant feedstock. On average, feedstock is retained within the digester for 30 days. The design holding capacity of the digester is 300m^3; approximately 30 days of hydraulic retention. A 10m diameter tank is anticipated. Figure 67 shows an example of a digester.

Process Monitoring, Control and Power: Process monitoring, control and power consists of the instrumentation; computer controls/programmable logic controller (PLC); motor control center; electrical distribution; biogas piping; compressed air supply; valves, pump, auger, conveyor, mixer motors; communications; alarms; and software, as well as sampling of biogas composition and digester constituents for later laboratory and analytical testing. This equipment and testing are relied upon to ensure digester productivity and health are maintained. Feedstock selection, preparation and feeding rates; consistent digester temperature; and thorough mixing are the primary inputs. Stable pH and ammonia levels and balanced carbon nitrogen ratios are critical to maintain digester performance. Situations to be avoided are crust formation on the surface, foaming within the head space, and upsets to the microbiology within the digester. Proper monitoring and ongoing balancing of inputs typically addresses these issues.

FIGURE 67: Example of digester (at Gorge Park Energy Farm Kenya)

Biogas Storage and Pressure Relief: Once operational and fed regularly, biogas production will be continuous. The biogas storage typically consists of the head space between the surface of the digester tank's constituents and the underside of the digester tank's cover. The minimum holding capacity of the biogas storage for the concept digester is 50m^3; approximately one hour of biogas production. The storage is equipped with a pressure relief valve and an alarm. Typically, a flexible fabric cover is employed to permit intermittent storage of the biogas in the event utilisation of the biogas has to be halted. Biogas will be diverted to the biogas flare prior to reaching the pressure relief valve set point. Consideration will need to be given in the final design for higher biogas holding capacity to provide greater flexibility in varying electrical production and thus gas draw-off rate.

FIGURE 68: Biogas storage pressure relief valve

Digester Effluent Storage: In order to maintain the digester tank's level as feedstocks and water are metered in, effluent is drawn off. Also, if process adjustments are required, effluent can be drawn off. Effluent drawn off is delivered to an insulated holding tank equipped with a mixer. This tank is sized to provide a buffer between the effluent from the digester and the subsequent downstream processes of pasteurisation and solid liquid separation. A 6m^3 tank is specified; a holding capacity of approximately 60% of daily effluent production.

Pasteurisation: From the digester's effluent storage tank, effluent is pumped into a continuous flow pasteuriser. The effluent is pasteurised (time and temperature dependent) to destroy any harmful bacteria and pathogens present in the effluent. Requirements for pasteurisation are necessary if human wastes, dead animal wastes, meat products, and dairy products will comprise a portion of the digester's feedstocks. Also, the use of the effluent, such as for application to actively growing food crops, dictates whether pasteurization will be required. The pasteuriser consists of an insulated tank with internal heating coils and mixing. Heat is sourced from the engine generator exhaust and cooling systems and the boiler. Pasteurised effluent is pumped from the pasteuriser. Heat recovery from the pasteurised effluent is an option. Pasteurisation of the feedstocks prior to feeding them into the digester is also an option to promote hydrolysis reactions in the more complex-to-digest feedstocks, such as green wastes. Note that alternative pasteuriser designs would have to be considered to accommodate this process orientation. The minimum size continuous flow pasteuriser has a capacity of 500 kg per hour of effluent with a minimum retention time of 12 minutes at 60 °C.

FIGURE 69: Waste effluent continuous flow pasteuriser

Solid Liquid Separation: Pasteurised effluent is delivered to a press or centrifuge to separate the solid and liquid factions in the effluent. The liquid faction is pumped to a storage tank and the solid faction is augured to an open-ended holding bunker. The minimum capacity of the solid liquid separator, based on the pasteuriser, is 500 kg of effluent per hour.

Liquid Effluent Storage: It is intended that the liquid effluent will be sold as organic fertiliser or used on the proposed farmland adjacent to the market. The liquid effluent storage tank will retain the liquid faction between pickup by potential users. The tank will be sized to hold a minimum of three days' worth of effluent production, or approximately 30m^3. Liquid effluent will be pumped from the storage

FIGURE 70: Solid/liquid separator for effluent

tank to a haulage tanker. During the rainy season there will be reduced demand for liquid effluent. To handle the large volumes of effluent that may need to be stored, during the rainy season or at other times of the year if required, an earthen retention/evaporation pond with a geotextile membrane liner can be constructed. The retention/evaporation pond would be sized to accommodate rainfall in the rainy season. A retention pond of approximately 30m x 20m with approximately 2.5m-high berms would provide sufficient storage volume. The pond would be divided into two cells to permit taking one side out of operation for maintenance purposes.

Solid Digestate Storage: The solid portion of the pasteurised effluent will be piled in an open-ended covered bunker. The bin will be sized to accommodate five days of effluent solids production or approximately 20 tonnes. Regular removal is required to avoid mold forming on the separated solids pile. Solids will be handled with either manual shoveling or a small size loader. The intention is that the solid digestate will be sold to others who will use it to create compost and organic fertilisers, with processing done at their own site.

Biogas Flare: A biogas flare will be required to consume biogas when the pressure in the biogas storage is nearing the pressure relief valve set point or when biogas quality is not sufficient to permit utilisation. The biogas flare consists of an ignition flame combustion chamber, exhaust stack and fuel source. The minimum capacity of the biogas flare will be 75m^3 of biogas per hour; approximately one third more than the average hourly production of biogas.

FIGURE 71: Biogas flare

FIGURE 72: Biogas scrubbing and treatment equipment

Biogas Scrubbing and Treatment: The biogas scrubbing and treatment system comprises equipment for hydrogen sulfide removal and de-watering of the gas. Biogas from the digester passes through an iron filter to remove hydrogen sulfide and an electrically powered cooler to lower the water vapour content in the biogas. Regular iron filter replacement is required. Water condensed from the biogas is pumped to a condensate storage tank. The capacity of the biogas scrubbing and treatment will be $60m^3$ of biogas per hour; approximately the average peak fuel requirement for the power generation system.

Condensate Drainage and Storage: Drains from the biogas piping network will lead to a central sump holding tank. Condensate collected in the sump is pumped to the condensate holding tank. In turn, the liquid in the condensate holding tank is pumped into the digester.

Biogas Blower: A blower driven by an electric motor will convey biogas from the biogas storage through the biogas scrubbing and treatment and to the biogas engine or alternately, the biogas flare.

FIGURE 73: Biogas blower

Biogas Engine Generator: The power generation system will consist of two, gas-engine driven, three-phase, electrical generators rated at approximately 111 kW output. The actual rating will depend on the particular manufacturer's size range specifications. One generator will be for duty, while the other for standby. This will enable cycling the generators for maintenance purposes, maximising uptime and power output. The system will include protection and control panels and can be housed in shipping containers or in a small generator building. The engine is equipped with heat recovery on the exhaust and cooling and coupled to a dual fuel boiler (biogas and propane) for servicing process heating requirements. The anticipated net output from the system will be 100 kW. An estimate 11 kW will be required for operating process motor and control loads within the facility. A very small diesel-driven generator or solar panels should be provided for office operations, to serve as standby in the event that the biogas system is down for extended maintenance if there was a major problem.

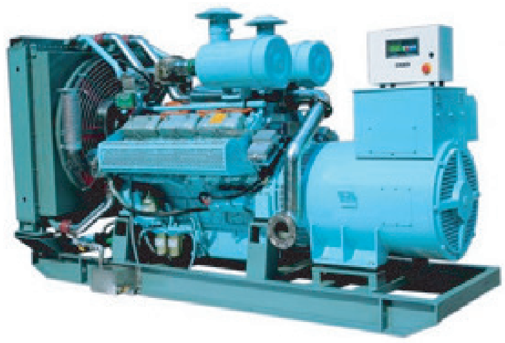


FIGURE 74: Biogas engine generator

As mentioned earlier, electrical loads from the market will change considerably from day to night, so it might make sense to install a smaller generator for overnight use – say 30 kW, and then a 100 kW unit for day time loads, and a 150 kW unit for peak loads. The decision on how to best set this up will require a thorough engineering analysis of electrical loads and various alternatives to adjust the power supply to match loads. This type of analysis is outside of the scope of this study and would be done at the detailed design stage.

Electrical Interconnection: The electrical interconnection will consist of the electrical disconnect, protection, and electrical cabling from the generator building (or container) to a point of interconnection at the market site. The rated capacity of the interconnection will be 100 kW or possibly more if peak loads are considered.

In summary, the equipment components and systems described above comprise a basic Wet AD waste-to-energy system. Value engineering and the selection of pre-packaged, kit-style systems could result in further simplification or elimination of certain components.

In addition to the above, the facility will also require the following:

Laboratory: A laboratory will be required at the site. The laboratory is necessary to sample and test the incoming feedstock, mixed feedstock, partially digested waste in the digester, effluent and gas. The laboratory needs to be well-equipped with all laboratory tools and supplies necessary to run the various tests and staffed by competent laboratory technicians. The laboratory from the Safi Sana W2E plant in Ghana is shown below.

FIGURE 75: Laboratory at Safi Sana W2E plant in Ghana

6.4.2 FACILITY LAYOUT

A conceptual plan view of the proposed facility is shown in Figure 75. The minimum footprint for the plant is in the order of 150m x 100m = 1,500m^2. However, it is recommended that additional space should be allocated to permit future expansion and ease congestion around the facility, therefore it is recommended that a plot of land of 200m x 150m = 3,000m^2 be selected.

The layout shown is only a very conceptual layout to give an idea of how the plant could be laid out and overall land space requirements. It is not possible to provide more detail on the layout at this point without knowing the particulars of the plot of land that could be available. Other layouts are possible also, as long as the overall intent of having the feedstock receiving at one end, and then flowing through the feedstock preparation area to the digester and then to the effluent tanks and holding areas is maintained. The feedstock areas and effluent areas should be at opposite ends of the site, with a good degree of separation to avoid any possible cross contamination.

It should be noted that composting of the solid effluent is being considered as a separate process from the AD W2E plant that would be done by a private company at their own facilities offsite. However, if it was desired to incorporate the production of compost at the W2E site, then considerable additional land will be required, which is not accounted for in the above size estimates.

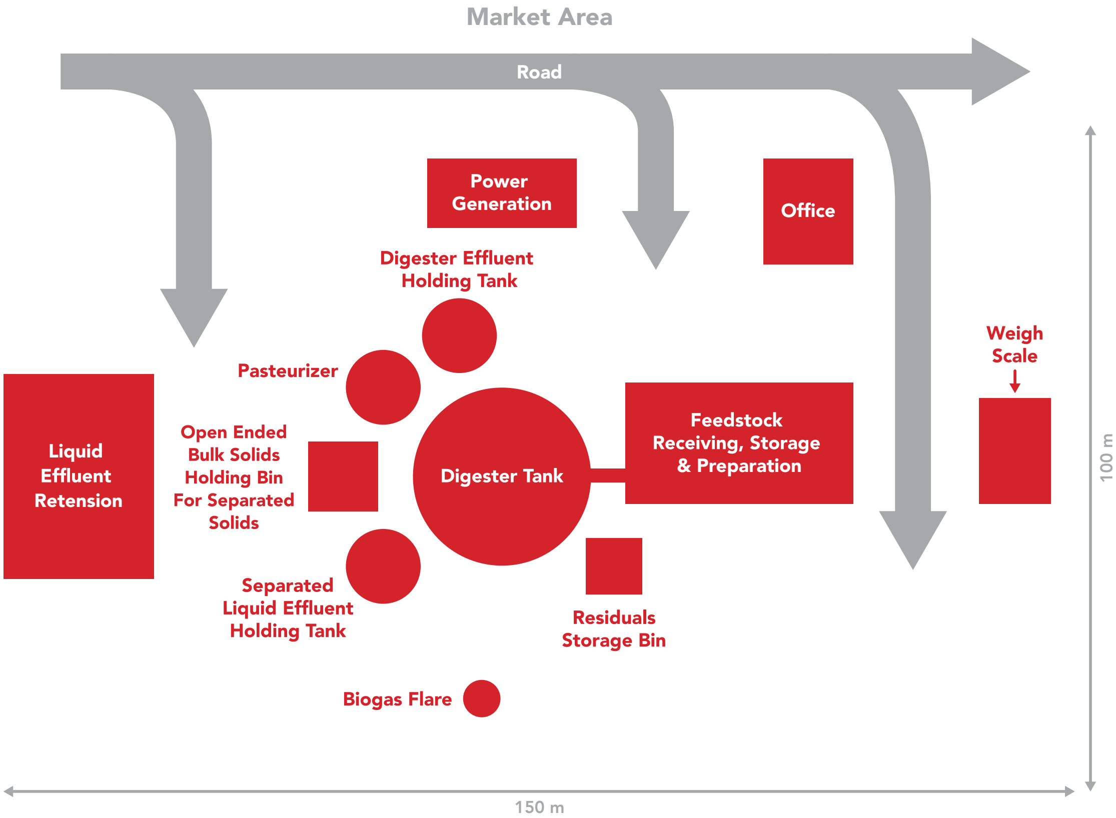
The land selected will need to be level, with decent soil conditions.

6.4.3 PRECAUTIONARY NOTE RE: CONCEPTUAL DESIGN

The design concept presented herein is intended to put the project into perspective in terms of the overall project concept, the sizing of the facility in terms of required quantities of organic feedstock, expected gas generation rate, anticipated electrical power supply output capability, the AD process to be used, the anticipated major items of equipment, and a possible layout of the facility. The information is based on assumed feedstock characteristics and quantities and assumed biogas yields from this feedstock. Given that several assumptions had to be made, the level of accuracy of the conceptual design is expected to be in the range of +/- 20-25%.

Implementation of the project cannot proceed based on the information presented herein. Additional studies, laboratory testing of the feedstock to model the process and detailed design of the process and all supporting facilities will need to be carried out before the project is implemented.

FIGURE 76: Conceptual level plan view of facility



6.5 AD technology vendors

The Consultant recommends that the project be implemented on the basis of a turnkey contract for design, equipment supply, installation and commissioning of the AD plant as well as providing ongoing technical support for the first two years of operation – in effect the vendor will become a technical partner in the overall project. The technology vendor would assume responsibility for the AD plant, while other separate contracts can be implemented for the design and construction of site infrastructure works to support the AD plant such as site preparation, offices, laboratory, water supply etc.

For the AD plant, there are many technology providers and project developers that could be considered. The Consultant strongly recommends that a supplier be selected that has experience with actually implementing Wet AD systems in Africa, of approximately the same size range. The Consultant has identified the following three companies through our research that we believe are good candidates for implementation of the project. These companies have been mentioned previously in Section 3 of the report and are briefly highlighted below.

1. Tropical Power

Tropical Power serves energy clients with power plants that use AD, biomass boiler systems, and solar PV. The company's vision is to play a leading role in AD, biomass, and solar technologies in Africa through world-class EPC, cutting-edge innovation and research, and a deep understanding of the countries and communities within which they operate. The company has implemented the largest commercial AD to grid connected power system in Africa at 2.5 MW electrical.

The company has also developed a design for a small-scale AD with a capacity of 4.0 tonnes per day as received basis (2.0 tonnes per day dry matter basis) with electrical power capacity rated at 80 kW. The construction involves assembly of a pre-fabricated kit delivered to site in containers. Figure 77 (also presented previously) highlights a cut-away of the digester tank. This system is still in the development stage at the time of writing this report but is expected to be commercially available soon.

This product is an example of an AD design specifically targeted to applications in Africa. The basis of the design stems in part from experiences gained by operating ADs in Kenya on organic matter consisting predominately of green vegetative matter, similar to the types of feedstocks anticipated for Omega Market. Tropical Power has significant experience, capacity, and awareness of Africa along with project development within the African context and has expressed an interest in being involved in any future development of an AD W2E project in Liberia.

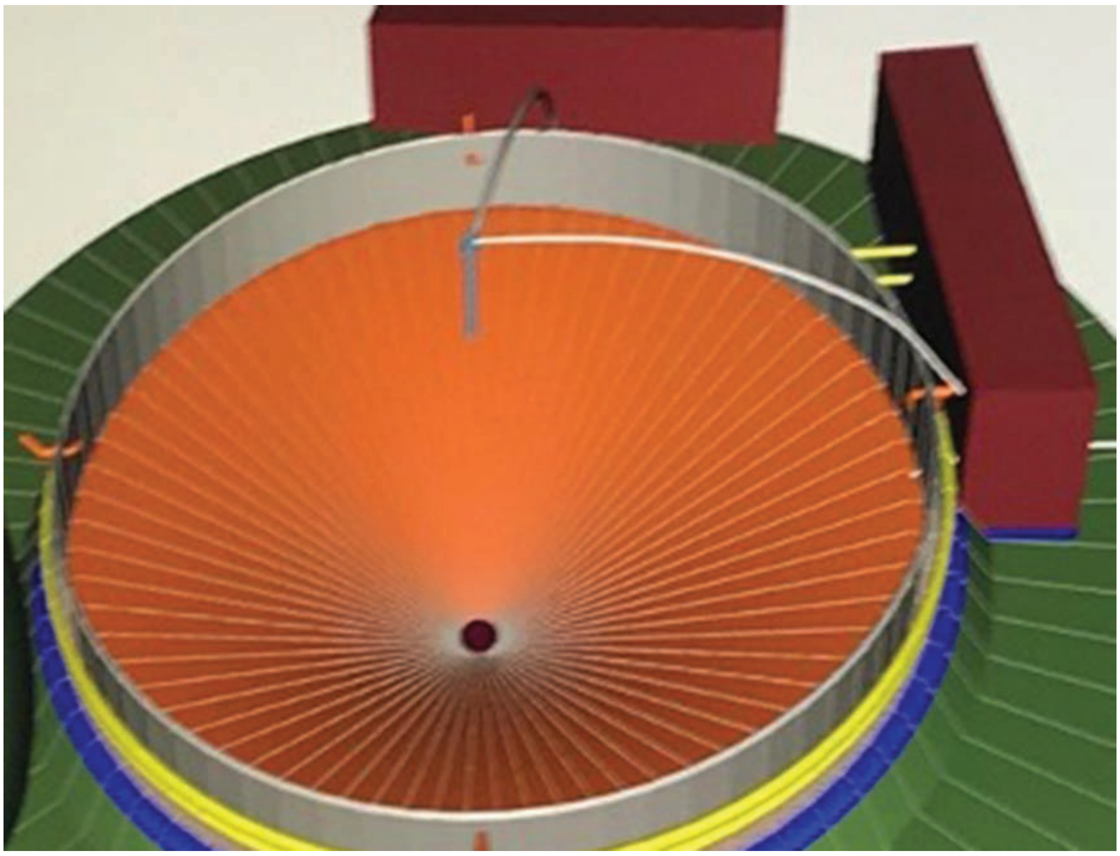


FIGURE 77: View of AutoCad image of digester for Tropical Power Wet AD concept for Africa

2. PlanET Biogas Solutions

PlanET Biogas Solutions' slogan "Driven by Pure Energy: Sustainability for the Protection of the Climate" highlights the company's focus on technology to address climate change issues. Active in national and international markets that offer market growth for their technology, the company claims to be one of the most successful biogas plant construction companies worldwide. Although full-scale sites have not yet been established in Africa, PlanET has an ongoing presence. Figure 78 highlights a micro-scale digester the company supported in Ghana. The company also maintains an agent in Kenya, Mr. Patrick Thimba.

The company supplies small- to medium-scale Wet AD systems with input feedstock capacities as low as 4.0 tonnes per day as received basis (2.0 tonnes per day dry matter basis) and electrical power capacities rated near 80 kW. The construction involves concrete pours for the digester tank floor and walls, and a flexible cover supported by a radial wood frame and central pillar. Figure 79 below shows the scale of PlanET Digester typically offered for this scale of operation.

FIGURE 78: Micro-scale digester installed in Ghana by PlanET Biogas Solutions

Overall, PlanET Biogas Solutions is a technology supplier with experience, capability, and an appropriate scale of technology.

FIGURE 79: PlanET Biogas Solutions anaerobic digester

<u>3. Safi Sana</u>

Safi Sana Ghana is a Dutch holding enterprise that designs, constructs, and operates waste-to-energy factories in developing countries. The firm is a social enterprise that was established in 2010. Its investment goals are to ultimately address health and sanitation within slum communities. The firm focuses upon converting organic and fecal waste into electricity, soil conditioner, and irrigation water.

The Safi Sana site that the Consultant visited in Ghana is very similar to what is proposed for the Omega Market, utilising organic waste primarily from markets and with a design capacity of 100 kW of electrical power. The system operates on a low level of technology that is appropriate for the West African environment. The system is a complete AD W2E system including processing of compost. A photo of the digester and the waste-receiving area of the Safi Sana plant is shown in Figure 80. The experience the company has gained in constructing and getting the Safi Sana plant operational on a consistent basis would be invaluable to the proposed project in Liberia. Safi Sana intends to implement other similar projects in other developing countries and would be very interesting in participating in the proposed Omega Market project.

FIGURE 80: Waste-receiving area with digester behind at Safi Sana W2E facility in Ghana

6.6 Cost estimates (capital and operating costs)

This section presents capital and operating cost estimates for the proposed project. These are conceptual level estimates only, with accuracy in the order of +/- 25%. Some of these costs, particularly for site works, have been established using order of magnitude estimates based on the Consultant's prior experience with similar works and project developments in Liberia and other locations in West Africa. They have not been estimated on the basis of quantity take-offs due to the site location being unknown and hence the extent of works being unknown. These costs estimates are intended to provide perspective on the capital and operating costs only, for preliminary decision making and budgeting purposes. The costs will need to be refined at each successive step in the project implementation process.

6.6.1 CAPITAL COST ESTIMATE

Project estimated capital costs are presented in Table 13 below. Initial studies that would need to be carried out as well as engineering and project management costs are included within the capital costs. Internal administrative costs for the project implementing agency are not considered. Capital costs assume that imported materials for the project can be brought into the country on a duty-free basis. This will need to be confirmed before proceeding with the project, as duties and taxes on imported equipment could be a significant additional project cost in the order of several hundred thousand dollars.

TABLE 13: Project Estimated Capital Costs

Category	Item	Cost (USD)	Total (USD)
Land Acquisition	Property purchase (assumed land is donated by government)	0	**0**
	Permits and approvals (assumed all paid by government)	0	
Initial Studies & Consultations	Additional waste sampling and laboratory testing	90,000	**250,000**
	Site surveys (topographical and geotechnical)	25,000	
	Preliminary engineering design (site facilities)	75,000	
	Environmental and social impact assessment (ESIA)	40,000	
	Stakeholder consultations	20,000	
Material Handling Equipment	For waste collection at the market and internal plant operations	50,000	**50,000**

Category	Item	Cost (USD)	Total (USD)
Site Works and Facilities	Site clearance, levelling, grading, drainage, spill retention berms, landscaping	50,000	**400,000**
	Site roads and walkways	50,000	
	Fencing, security, signage, site lighting	50,000	
	Office building, including furnishings	100,000	
	Water supply borehole and piping	25,000	
	Laboratory (fully equipped)	50,000	
	Effluent retention pond	75,000	
AD W2E plant design	Process development and detailed design	100,000	**100,000**
AD W2E plant – equipment and works	Feedstock receiving	40,000	**1,300,000**
	Feedstock storage	10,000	
	Feedstock inspection & sorting	20,000	
	Residuals storage	5,000	
	Feedstock processing	50,000	
	Feedstock mixing & feeding	75,000	
	Digester	350,000	
	Process monitoring, control	150,000	
	Biogas storage & pressure relief	100,000	
	Effluent storage tank	50,000	
	Pasteuriser	50,000	
	Solids separator	20,000	
	Solid digestate storage bunker	10,000	
	Liquid effluent storage tank	20,000	
	Biogas flare	10,000	
	Biogas scrubbing & treatment	50,000	
	Condensate drainage & storage	20,000	
	Biogas blower	20,000	
	Biogas engine electrical generators	200,000	
	Electrical interconnection	50,000	
Cold Storage	Construction of cold storage facilities in the market	100,000	**100,000**
Eq. Delivery, Assembly, and Commissioning	Shipping, transport to site, assembly and site construction, system commissioning	500,000	**500,000**

Category	Item	Cost (USD)	Total (USD)
SUBTOTAL			**$2,700,000**
Engineering & Project Management @ 20%			**$540,000**
SUBTOTAL			**$3,240,000**
Contingency @ 15%			**$486,000**
GRAND TOTAL			**$3,726,000**
ROUNDED GRAND TOTAL			**$3,700,000**

6.6.2 OPERATING COST ESTIMATE

Estimated operating costs are presented in Table 14. Operating costs are broken down into direct production costs to operate the W2E plant and overhead costs. The cost of technical support from the equipment provider is also included. Internal administrative costs for the project implementing agency are not considered.

Operating costs are based on the following key assumptions:

- Staff from the W2E plant will directly collect the organic waste from the market, such that the W2E plant maintains control over the waste collection activities, as consistent waste collection is critical to the overall success of the project. This implies that organic waste can be obtained from the market at no cost, except for labor and equipment costs for W2E plant staff to do the collection.
- Liquid and solid effluent will be sold to others and are transported away from the site by others, implying that there is no cost for disposal of liquid and solid effluent

TABLE 14: Project Estimated Operating Costs

Category	Item	Monthly Cost (USD)	Annual Cost (rounded) (USD)	Total (USD)
Direct Production Costs	Waste collection - 6 staff @ avg $300/mo each	1,800	22,000	**140,000**
	Waste sorting – 7 staff @ avg $300/mo each	2,100	25,000	
	Plant operators – 5 staff @ avg $600/mo each	3,000	36,000	
	Fueling and maintenance of collection and site equipment	500	6,000	
	Waste disposal (residuals)	800	10,000	

Category	Item	Monthly Cost (USD)	Annual Cost (rounded) (USD)	Total (USD)
Direct Production Costs	Plant equipment regular maintenance	2,500	30,000	
	Plant equipment repair	900	11,000	
Overhead Costs	Management and technical staff – 5 @ avg $2,500/mo	12,500	150,000	**280,000**
	Clerical and support staff – 3 @ avg $500/mo	1,500	18,000	
	Laboratory supplies	800	10,000	
	Office supplies, office equipment maintenance, energy purchase	1,250	15,000	
	Vehicle and local transportation	2,000	24,000	
	Site security	1,500	18,000	
	Internet and communications	400	5,000	
	Insurance and permits	800	10,000	
	Professional services (annual)		20,000	
	Staff training	800	10,000	
Technical Assistance	Annual assistance from technology vendor (first 2 years of operations)		100,000	**100,000**
Cold Room Operation and Maintenance	2 staff @ avg $300/mo each	600	7,000	**10,000**
	Maintenance of cold room equipment	250	3,000	
SUBTOTAL				**$530,000**
Contingency @ 15%				**$79,500**
GRAND TOTAL				**$609,500**
ROUNDED GRAND TOTAL				**$610,000**

As seen above, operating costs are estimated at US $610,000 per year for the first two years of operation, when significant technical support will be required. They would reduce when operations are stabilised and ongoing technical assistance no longer necessary.

6.7 Potential revenue streams

There are five sources of potential revenue streams for the project as follows:

1. Sale of electricity to the market
2. Sale of compost material and fertiliser
3. Carbon offset credits
4. Charges for use of cold storage
5. Charges for waste collection

Each of these is described below.

6.7.1 SALE OF ELECTRICITY TO THE MARKET

In previous sections of the report, it is indicated that 100 kW of net power, 90% of the time will be available for use by the market. This equates to 788,400 kWh/yr as follows:

- 100 kW x 8,760 hr/yr x 0.90 = 788,400 kWh/yr

The current electricity tariff of the Liberia Electricity Corporation (LEC) is US $0.35/kWh. However, this tariff is expected to decline in the coming years. We are therefore assuming an electrical tariff rate of US $0.30/kWh to determine a value of the electricity that can be supplied.

If all of the power were sold at a rate of US $0.30/kWh, the revenue would be:

- 778,400 x US $0.30 = **US $233,520 /yr**

At this point, it is unknown how the value of the electrical power supply would be monetised, and this would need to be worked out before moving ahead with the project. It is assumed at this point that the market can buy the power and include the cost in the rent it charges to tenants, because they have to get power from somewhere. If the market is to purchase power from LEC, it would pay the same amount and need to pass the cost on to market tenants (but with less reliability in power supply). If the market were to run its own diesel generators, they would still incur a similar cost, perhaps higher. It is therefore valid to assign a value of US $0.30/kWh to the power supply that could be generated. However, as stated elsewhere in the report, the demand for power in the market may be lower than 100 kW average, at least in the initial stages. So, the revenue realised from power sales may be lower in the first few years.

6.7.2 SALE OF COMPOST MATERIAL AND FERTILISER

It is estimated that 10,000 kg per day of effluent will be produced, comprising approximately 75% liquids and 25% solids by mass. This equates to:

- 7500 kg/day liquid effluent
- 2500 kg/day compost material (solids)

Solid liquid factions will be separated using a solid/liquid separator as shown in Figure 70. However, the solids portion will not be dry and will still contain a considerable amount of moisture content. As such, we have assumed 3,000 kg/day of the solids byproducts.

The solids portion can be used for producing compost and organic soil conditions. It is assumed that private companies will purchase this material and transport it to their own site for further processing. The assumed value that the material can be sold for is US $0.05/kg. This will need to be confirmed with companies that would be potential purchasers. The annual value of the solids content is therefore:

- 3,000 kg/day x 365 days/yr = 1,095,000 kg/yr x US $0.05 = **US $54,750/yr**

The Consultant has not estimated a value for the liquid effluent. This can be used as an organic fertiliser; however, it is unknown if farmers will pay for this. The liquid effluent would need to be transported to farms (nearby) in a water tanker truck, which would be quite costly. It is therefore assumed that the farmers would cover the cost of the transportation to their farms but would not pay additional amounts for the contents. Under this assumption, no revenue would accrue through the sale of the liquid effluent. It should be noted that if the liquid effluent is not removed from the site by giving or selling to farmers, it will result in significant costs to the W2E operation to either treat the effluent or dispose of it in an environmentally acceptable means.

6.7.3 CARBON OFFSET CREDITS

There is a potential for the project to generate carbon credits, whereby large foreign companies purchase a "carbon credit" from projects in other locations, as a cost, or a "tax" for their carbon emissions in their home country. This is an available alternative to companies instead of investing in technology or process changes that would reduce their carbon emissions.

A "carbon credit" market has been established where carbon credits are traded. The value of a carbon credit depends on many things, particularly the nature of the project – carbon credits are not the same for all projects. However, carbon credits for a biogas project tend to be at the higher end of the scale.

For this project, we have assumed a value of US $10 per tonne of CO_2 equivalent emission reduction, for a renewable energy project. The project is estimated to have an emissions reduction of 8,138 tonnes/yr, giving a potential value of carbon credits of:

- 8,138 tonnes/yr X US $10/tonne = **US $81,380/yr**

Obtaining the carbon credit is by no means guaranteed, and it is a fairly complex procedure to apply and receive a carbon credit, so this should be viewed only as a possibility. Additional research into the possibility of obtaining carbon credits will need to be carried out before proceeding with the project.

6.7.4 CHARGES FOR USE OF COLD STORAGE

The cold storage facilities that are proposed to be located at the market have a value to market vendors and can potentially generate revenue for the project. However, without conducting additional research into this, which is outside the scope of this study, it is not possible to confirm with any certainty how much revenue could be generated. As such we have made an assumption that the cold rooms could generate US $24,000 per year in revenue. This translates to US $2000 per month and based on 30 days a month is equivalent to US $67 per day. If 100 customers used the cold rooms, this would equate to a charge of US $0.67 per day, which is well within the range of affordability for market vendors. In all likelihood, the revenue could be considerably higher. Additional research on how to charge for use of the cold rooms and the appropriate unit cost will need to be done to provide a better value of the potential revenue.

6.7.5 WASTE COLLECTION CHARGES

In the operating cost projections, we have assumed that staff of the W2E plant will collect the organic waste from the market at no cost to the customer. This is on the basis that the W2E plant needs to control the collection of the waste, as this is critical to the success of the W2E plant. If the waste were not collected from the market by the W2E plant, then market vendors would likely need to pay CBEs for the collection of the waste (as happens now at existing markets) or the waste removal could be done by the market and the cost included in the rent. In either case, the market vendors would end up paying a small amount for collection of the waste.

For purposes of this analysis, we have assumed that the W2E plant could charge US $36,000 per year to the market vendors for the waste collection. This is just slightly above the actual cost of the waste collection. Additional analysis needs to be performed to validate this assumption.

6.8 Business case analysis

6.8.1 FINANCIAL ANALYSIS

Key financial parameters from the previous sections are as follows:

Costs

• Capital Cost:	US $3,700,000
• Annual operating cost (first 2 years of operation):	US $610,000
• Annual operating cost including contingency (after year 2):	US $495,000

Potential Revenues

• Electricity sales:	US $233,520
• Compost material sales:	US $54,750
• Cold room charges	US $24,000
• Waste collection charges	US $36,000
Subtotal (before carbon credits)	**US $348,270**
• Carbon credits:	US $81,380
Total including carbon credits:	**US $429,650**
Round off:	**US $430,000**

Assuming that a funding agency would take on the capital cost of the project, plus the operating costs for the first two years to get the project to a point of continuous operation, the above shows that the project will not cover its operating costs. Annual operating costs (after year 2) are estimated at US $495,000, while the revenue is estimated at US $430,000 (assuming that carbon credits can be obtained). This would leave a shortfall of US $65,000 per year.

However, it is possible that operating costs have been estimated on the high side. A contingency of 15% was included in the operating costs, and as stated earlier, cost estimates have been prepared to a level of accuracy of +/-25%.

- If the contingency on operating costs is removed, then operating costs are estimated at US $430,000/yr, equal to the projected revenue.
- If costs are reduced another approximately 10% (which may be possible given the accuracy range of the estimates), then operation costs would reduce to US $387,000 per year, giving a slight operating cash surplus.

This indicates that it is not outside of the realm of possibility that the project could cover its operational costs after the first two years of operations, if support were provided during the first two years. This would of course depend on the revenue stream, which in reality may be lower than what is projected. As well, this does not consider depreciation or capital cost recovery. The project will not generate enough revenue to recover the capital cost, even if payback is stretched over many years.

The above is a very cursory analysis only, but there is no point doing additional financial analysis based on the information that is available at this time. Additional elaboration of the project will need to be done to confirm some of the assumptions made and the costs and revenue streams before additional financial analysis is carried out.

As far as a business case for the project, there does not appear to be a strong business case from a private investment standpoint. The project cannot recover the capital cost and is borderline in being able to generate enough revenue to cover its cash operating costs. There likely would be no interest in the project by private investors unless they were to look at being able to use the digestate to produce a higher value-added product, or as part of a large integrated agricultural operation where additional value streams may accrue.

This result is very much in line with what was reported to the Client at the conclusion of the study tour – that the projects toured did not appear to be financially viable. It should be noted that the projects visited did not mention carbon credits, and this is significant in bringing the project close to being able to support its ongoing operational costs. Without the carbon credits, this project will not be able to generate enough revenue to cover its operating costs.

This is a result of project scale. If the capacity of the system were larger, revenue would increase more than costs and the financials would improve, such that the project would more easily be able to generate enough revenue to cover its operational costs, and perhaps some portion of depreciation/asset replacement. The financial result is also simply due to the fact that this is a waste management project. Waste management projects rarely are financially viable. Waste management projects are executed by governments because they must provide waste management services to the population, and not because they are financially attractive. While deriving energy from the waste and selling it can offset some of the costs, it does not necessarily change a waste management project into a financially positive venture. The driving force behind W2E projects is typically environmental concerns as opposed to being financially motivated.

It should also be noted that this analysis is based on selling the solid portion of the digestate to private companies that would then turn it into compost. If the composting operation were to be done in house, as part of the W2E project, the financial picture could be more attractive. There would also be the possibility of selling seedlings as an additional revenue source, along the lines of what is being done at the Safi Sana W2E project in Ghana. However, we do not recommend this option, as it would put the W2E plant in direct competition with existing private sector operators that are involved in composting, would require considerably more land for the facility, and would further complicate the process. The Consultant therefore recommends keeping the composting operation separate through private sector companies.

6.8.2 ECONOMIC ANALYSIS

The financial analysis above shows that the project will not be financially viable, but has the possibility of being able to recover its operational costs if initial financial and technical support for the first 2 years to get the project to a point of consistent operations is provided through donors. The decision to proceed with the project should be made on the base of economic considerations rather than financial returns.

Section 6.3 discusses the many benefits that can accrue from the project. These are elaborated on below. No attempt has been made to estimate the economic value of these benefits, but combined they are expected to yield a very positive result.

Economic benefits:

1. **Reduced waste management problems** at the new Omega Market. Most of the vegetative organic waste from the market would go directly to the W2E plant. Other waste recycling programmes could also be put in place at the market at the same time, significantly reducing the amount of waste that would need to be sent to a landfill. This will result in reduced waste collection costs for MCC/PCC, reduced transportation costs to transfer the waste to a landfill site and reduced landfilling costs.
2. **Cleaner market environment** providing a more positive environment for vendors and customers and possibly improved health to market workers and customers. There would also be less groundwater contamination around the market area.
3. **Regular power supply to the market** providing enhanced power security, increasing demand for the market, and perhaps leading to new and different businesses entering the market.
4. **Promotion of renewable energy projects** which could result in other renewable energy costs being developed in Greater Monrovia.
5. **Increased opportunities for community engagement.** To move the project forward will require bringing several diverse groups of stakeholders together

working on a common development goal that can benefit many parties and have several downstream benefits in terms of community engagement and improved governance.

6. **Greenhouse gas reduction** to support Liberia's attainment of NDC targets for emission reductions.
7. **Food preservation** through the construction of cold rooms at the market that would reduce food spoilage, providing improved food security.
8. **Increased income for market vendors/reduced food costs.** Reduced food spoilage by utilising the cold storage will enhance the value of food products and could increase incomes of market food vendors through less waste and more product to sell, and/or enable them to sell their produce at a lower cost resulting in improved food security for the general population.
9. **More sustainable and increased food production** through utilisation of organic fertilisers and soil conditioners from the byproducts of the plant at nearby farms. Food production can increase particularly if the intent to grow crops on land adjacent to the market is implemented.
10. **Employment and business opportunities.** The AD plant itself will create approximately 25 full-time jobs and support vendors of numerous goods and services. Additional jobs would be created during the construction of the plant. Spin-off business opportunities and job creation could be significant:
    - The project will support the expansion of private sector companies involved in composting and organic fertilisers.
    - Enhanced farm productivity, incomes, business opportunities and employment opportunities through access to organic fertilisers.
    - Additional small-scale business opportunities will be created by having a reliable power supply that could exceed the requirements for the market. This could spur establishment of new small businesses at or beside the market, which could largely be implemented by women.

6.9 Environmental, social and gender considerations

This section presents a rapid review of the potential environmental and social impacts of the proposed project that will need to be considered before implementation and possible mitigation strategies for negative impacts. The information can serve as a starting point and provide background information for a formal Environmental and Social Impact Assessment that will need to be done (by EPA or others) to obtain environmental permits for the project prior to implementation.

6.9.1 ENVIRONMENTAL, HEALTH AND SAFETY AND SOCIAL CONSIDERATIONS

Table 15 presents key potential environmental, health and safety and social impacts to be considered, including the level of concern and possible mitigation strategies. Positive impacts are described in previous sections.

TABLE 15: Environmental Health and Safety and Social Considerations

Consideration	Possible Negative Impacts	Level of Risk/ Concern	Mitigation Strategy
During Construction			
Displacement and resettlement	Need to displace and resettle people for construction of facility	Low	Land is currently unoccupied. No mitigation required but need to confirm
Construction activities	Noise, dust, nuisance, traffic disruption during construction, damage to adjacent properties	Low	Construction contracts can address minimization of these issues. Construction in unpopulated area with minimal existing buildings around
Worker and community health and safety	Potential for health impacts and personal injury relating to worker and public incidents during construction	Medium	Construction staff including subcontractors working at site to be properly trained in all health and safety issues, and these are to be enforced through the construction period. Contractor to implement approved Environment, Health and Safety and Social Management Plan. Proper security during construction to limit outsiders. Visitors to follow health and safety protocols. First aid facilities on site with emergency medical arrangements in place. Regular monitoring of health and safety issues
Soil, groundwater and surface water contamination, air pollution	Potential for contamination of soil, groundwater, and surface water from spillage of hydrocarbons or chemicals, air pollution	Medium	Contractor to implement Environment, Health and Safety and Social Management Plan. Regular monitoring of environmental compliance.
During Commissioning and Plant Operations			
Waste collection, separation, transportation, storage, processing, and disposal of residuals	Various potential issues ranging from personal injury to spillage and contamination	High	Clearly defined processes for waste handling and safety, provision of adequate training and education, secure facilities, distribution and use of personal protective equipment, ongoing testing, reporting, monitoring and evaluation and support, regular maintenance and cleaning of all plant equipment, apply same standards to haulage companies for disposal
Groundwater and surface water contamination	Leachate from waste and effluent handling and storage can contaminate water resources	High	Clearly defined processes for waste handling and safety, provision of adequate training and education, construction of spill retention berms, proper site drainage with diversion of runoff away from water courses, locate water supply borehole away from and upstream of sources of contamination

Consideration	Possible Negative Impacts	Level of Risk/ Concern	Mitigation Strategy
Erosion	Construction of new facilities causes erosion on surrounding properties	Low	Facility design to ensure no causes of erosion
Air pollution and odours	Air pollution and odours from handling and storage of waste, biogas and effluent	High	Develop waste sorting methods at market to reduce receival of rotting organic waste, design process to handle waste and effluent quickly to avoid waste and effluent staring to rot, cover any rotting waste, dust barriers in waste grinding area, ensure that gas scrubbing equipment is always functional to remove sulphur from gas, regular monitoring of air quality in and around facility, develop process for complaints from nearby residents
Biogas production, storage, and utilisation	Various potential issues ranging from fire hazard and explosion to air pollution, odours and contamination	High	Ensure that gas scrubbing equipment is always functional to remove sulphur from gas, clearly defined processes for gas handling, energy production and safety, provision of adequate training and education, secure facilities, distribution and use of personal protective equipment, ongoing testing, reporting, monitoring and evaluation and support, regular maintenance of all plant equipment, fire suppression equipment on site
Effluent production, processing, storage, handling, transportation, and utilisation (as fertiliser)	Various potential issues ranging from personal injury to odours, spillage and contamination	High	Design process to handle effluent quickly, cover any rotting effluent, monitoring of air quality in and around facility, develop process for complaints from nearby residents, clearly defined processes handling effluent, provision of adequate training and education, secure facilities, distribution and use of personal protective equipment, apply same standard to companies removing effluent
Health and safety	Potential for health impacts and personal injury relating to worker and public incidents at facilities	Medium	Design processes and facility with worker safety in mind, clearly defined processes, safety and health training and education, all employees and visitors provided with personal protective equipment, regular health and safety committee meetings, ongoing health and safety monitoring and reporting, security of site to limit visitors, visitors to follow site health and safety procedures, ensure access to nearby emergency medical treatment, first aid room on site

Consideration	Possible Negative Impacts	Level of Risk/ Concern	Mitigation Strategy
Noise	Noise created by operation of facilities	Low	Operations are very low noise. Gas generator is lower noise than diesel generator. Generators to be provided with insulated sound enclosure. Noise-generating activities such as grinding or waste materials to be limited to daytime hours
Traffic	Increased traffic congestion due to facility operations	Low	Minimal additional traffic created by facility. Facility located in market area which is generally very busy with traffic. Additional traffic to W2E plant will be minimal
Equipment operation	Potential for health impacts and injury to facility workers with various apparatus including crushers and power generators	Medium	Clearly defined policies and procedures, education and training, use of personal protective equipment, ongoing reporting, monitoring and evaluation, and support. Access to any dangerous areas to restricted to visitors
Fertilization	Potential for health impacts due to improper handling and usage	Low	Training and education for all relevant parties, ongoing testing, reporting, monitoring and evaluation, and support
Electricity production	Potential for electrical related injury	High	Clearly signed secure facilities and community outreach and public safety education, ongoing reporting, monitoring and evaluation, and support. Proper training of staff involved in work related to electricity production and distribution

In summary, although there are some important environmental, health and safety and social considerations to be addressed for the project, with many being of high concern, the concerns and risks can be mitigated through the appropriate strategies. Overall, the long term environmental, health and safety and social concerns of the project are low, and these are far outweighed by the potential positive benefits of the project.

6.9.2 GENDER MAINSTREAMING

Gender mainstreaming should be considered in all aspects of the proposed project, including at the planning stage, construction stage, and operational stage and in all policy, hiring, operations, and maintenance decisions. As evidenced by site visits within Monrovia, female participation in waste management activities – including source separation, collection and transfer – is already considerable; however, more work could be done to increase numbers and gender ratios further. Cities Alliance, MCC and PCC should take this into account when planning the project and hiring additional personnel as required to support the project implementation, and the entity that will eventually operate the facility should be required to follow the same gender mainstreaming principles to ensure effective consideration and implementation of gender mainstreaming principles protecting both men's and women's interests.

There are numerous avenues for increased participation and benefits to women in the project, including but not limited to:

- Project planning and design
- Construction activities
- Waste sorting and collection
- Various jobs for operation of the W2E facility ranging from lower level to executive management and board positions
- Operation of cold storage facilities at the market
- Transportation, production and sale of fertilisers and byproducts
- Agricultural production and sales
- New business ventures that can develop based on reliable available power supply and availability of cold storage facilities

Many women assume a leadership role in the management food and waste both within households and within market environments. As such, women will have an important role to play in the success of the proposed project, particularly in their capacity to understand the inputs and outputs of the systems and to spread their knowledge in this regard. This is especially beneficial in communicating the various socioeconomic benefits of the project and to promote future undertakings.

6.10 Institutional considerations

6.10.1 LEGAL AND REGULATORY FRAMEWORK AND PERMITS

As stated within the Inception Report, the institutional and regulatory frameworks for solid waste management and energy are well documented, with no obvious impediments to the implementation of the proposed project.

The following permits, approvals and licenses will likely need to be obtained for the project:

<u>Land Use Permit</u>

It will be required to obtain a Land Use Permit, or Land Lease Agreement with the government for the proposed parcel of land where the project site will be located. This needs to be a long-term agreement (for at least 50 years) and with all proper legal protocols followed so that the land cannot be taken over by future governments or private citizens. The Consultant recommends proceeding with securing the necessary land for the project as soon as possible if a decision is made to proceed with the project.

Environmental Permit

An Environmental Permit will be required from EPA. Issuing of this permit would be based on carrying out an acceptable ESIA Study. The ESIA Study can only be carried out after the plot of land for the project is confirmed and after the design of the project and the facility has at least been elaborated to the next level of detail. There is not enough confirmed information available based on the conceptual level work that is presented in this report to enable a proper ESIA Study to be done.

Permits/approvals/licenses may be required from EPA and/or MCC/PCC for various functions, including:

- Collection of waste feedstock from the market
- Construction of the W2E facility
- Operation of the W2E facility
- Sale of effluent materials

LERC License

The Liberian Electrical Regulatory Commission (LERC) may also need to approve and/or issue a license for the electrical energy generation and sale related component of the project, depending upon the capacity threshold set by LERC governing license requirements for power generation activities. Once the final output of the system is confirmed, LERC should be contacted to determine whether or not a license is required. It should be noted that LERC is only being set up now and is not fully functional yet. As such the Consultant was not able to confirm the requirements around the LERC licensing during the feasibility study.

Ministry of Public Works

It may be necessary to obtain a permit from Ministry of Public Works prior to proceeding with construction activities.

6.10.2 ENTITY FOR OPERATION OF THE W2E FACILITY

Long-term success or failure of this project will depend on the institutional arrangements put in place for the ongoing management and operation of the facility, and the effectiveness of the entity that is operating the facility. The Consultant highly recommends that the facility is managed and operated by an independent entity and not through a department of the government.

It is recommended that a Special Purpose Vehicle (SPV) is set up to own and manage the W2E facility. It is proposed that a community-based not-for-profit enterprise be created. Ownership and control of the project would be vested with the CBE. The Board of Directors of the CBE would have representation from the government, the market association, farmers, compost producers and general citizens to ensure that interests of all parties are considered in decision making. W2E facility management would report to the Board. The CBE could hire staff directly for the management of the W2E facility, or alternatively could hire an operator under a performance-based contract so that the operator can be replaced if they are not performing. This will provide for the necessary independence of the project while still maintaining some influence on the project from government. The CBE (which would be formally registered as an NGO) has the advantage of being able to operate as an independent commercial entity (on a not-for-profit basis) and would be able to independently apply for funding from various donors to support the operational cost of the facility operation and/or future expansion as needed. There are many willing donors in the W2E space that will support an NGO.

This model has been proven successful on other development projects in various sectors.

6.10.3 STAKEHOLDER ENGAGEMENT

The project should maximise stakeholder engagement to ensure that decisions are taken in the best interest of all concerned parties and the population at large. Extensive stakeholder consultations will be required at the project planning stage. If the CBE is set up to operate and manage the facility as described above, it will ensure long-term engagement of stakeholders through representation on the CBE Board.

6.11 Project implementation risks

As with any project there are certain risks that should be considered before proceeding to implementation. The Consultant has identified the following risks that could impact on the overall success of the project.

1. Development of the Omega Market is slower than anticipated. Impacts of this would be that less waste is available, necessitating that waste be transported from existing markets, increasing the cost for waste feedstock collection. It would also reduce the demand for electricity at the Omega Market, reducing the value of the generated power. This risk is considered as fairly high.
2. Satisfactory agreements for the sale of power to Omega Market and/or the setting up of cold rooms at the market cannot be confirmed.
3. Private companies involved in composting are not interested in purchasing the digestate from the facility or go out of business. This would result in a problem to dispose of the digestate by other means, reducing the project revenue stream, or result in needing to incorporate the composting process within the W2E facility.
4. Farmland is not established nearby the market as planned. This would reduce the possibility of using liquid effluent on the farmlands, creating a waste disposal issue for the facility and lowering the circular economy benefits of the project.
5. A suitable sized plot of land near the market cannot be obtained under a long-term agreement.
6. The power supply situation in Liberia improves (note there are several initiatives underway to accomplish this) and the power tariff declines. This would reduce the value of the generated electrical power from the market.
7. New W2E technology is developed that is more cost effective, rendering the system obsolete. This is a low risk in the near term.

Most of these risks can be dealt with through confirmations with stakeholders at the earliest stages, prior to making a decision to proceed with the project.

6.12 Summary and next steps

The foregoing information has presented conceptual-level information of a proposed W2E project for the new Omega Market. The information presented is in as much detail as can be provided at this stage until confirmation on a number of items can be made. The information presented can form a basis for making a decision of whether to proceed with the project and to solicit level of interest from potential donors. The proposed project will not support capital cost recovery, but could generate enough revenue to cover operating costs, if technical and financial support is provided by others for the first two years to get to a state of continuous and efficient operations, and if the assumed revenue streams can be realised. Although the project is not financially viable in terms of possible capital cost recovery, there are many economic and social benefits to the project that need to be considered, such as improved waste management, improved power supply, improved agricultural productivity, job creation, and enhanced opportunities for women. The project promotes the concept of a circular economy, in which waste products are used to create value, rather than simply disposing of them; will reduce greenhouse gases; and will demonstrate and promote the use of renewable energy. It would be challenging to find other projects that have as many positive economic and social spin-off benefits as this one, and implementation of this project could set Liberia on a path for more sustainable development initiatives going forward.

The next step towards the implementation of the project should be to confirm interest from the government of Liberia and possible donors to move forward with the project. If there is a good degree of interest, the following steps are recommended:

1. Confirm project assumptions. This would include:
   - Details of development plans for Omega Market including timing, extent of current development, future development plans, details of proposed farmlands nearby, plans for relocation from existing markets, etc.
   - Possibility of sale of power to Omega Market and the construction of cold rooms
   - Level of interest in purchasing digestate by existing composting companies, including possible volumes and price
   - Availability of land for the project
   - Power system development plans of LEC in the area and any planned tariff reductions
   - Carry out additional waste sampling at existing markets to confirm quantity and characteristics
2. Based on the above clarifications, the project conceptual design and financial projections could be updated, and a GO-NO-GO decision would be made. Assuming a positive decision and a commitment for funding, initiatives would continue as below.
3. Set up CBE as the entity responsible for the management and operation of the project
4. Hire engineering and project management consultant to implement:
   - Site surveys, design, and costing of site works
   - Laboratory testing of waste to confirm biogas yield

  - Develop tenders and contracts for site works and turnkey project for the design, construction, and ongoing technical support of the W2E facility
  - Supervise various implementation contracts

5. Work with the CBE to put in the place the staffing and systems for the long term operation of the facility

An initial step also needs to be to appoint a project "champion" within the Liberian government, who will be passionate about the project and committed to moving the project forward. This needs to be a high-level person with the government who would serve as the single point of contact within the Liberian government for coordination between government departments, donors, the project executing agency, etc.

The Consultant will be please to provide guidance and assistance to Cities Alliance in the implementation of any of the above steps.

7. CONCLUSION

This report has been prepared in fulfilment of contract Milestone #3 for The Feasibility Study on Waste-To-Energy Options in Monrovia, Paynesville, and Surrounding Townships in Liberia. The report was prepared to satisfy the terms of reference for the project and the subsequent revisions to the ToR, scope of work, and work plan that occurred as the project evolved. The Feasibility Study Report component of the project has presented information on the following items:

1. Project scope and work plan changes
2. Summary of work completed to date by the Consultant in Phase II of the project which included a study tour of W2E vendors and projects in Europe and Africa, and a thorough review of available technologies along with recommendations on the most appropriate technologies to implement within the Greater Monrovia setting considering pilot scale, demonstration scale and longer term timeframes
3. Details concerning the proposed pilot project Option 2 that is planned for implementation in 2020
4. Update on progress on Phase III of the current consultancy, the Micro-Scale Biogas Systems Testing Phase, in which ten HomeBiogas units will be installed and tested in various locations within MCC and PCC by the end of 2019
5. A proposal for a larger W2E demonstration project to be located at the New Omega Market

This report completes the work of project Milestone #3 and Phase II of the consultancy services.

Review of Project ToR and Overall Objectives

The final version of this report is being prepared after significant work has been done on Phase III of the project – the Micro-Scale Biogas Testing Phase. At the time of writing this report, eight home biogas units have been installed, and the operation of these units is being monitored. As most of the work of the project has been completed at the time of the finalising this report, it provides an opportunity to reflect on the original ToR and objectives of the project with the benefit of hindsight from the research, experiences and knowledge gained through the activities that have been carried out to date.

The original objective of the project was to identify **small-scale, community-based W2E initiatives that could be piloted in the project area that:**

- Are community-based
- Are replicable and scalable
- Will reduce greenhouse gases and landfill emissions
- Will contribute to environmental protection and building local resilience
- Will promote an integrated approach to municipal solid waste management
- Should consider gender inclusivity and mainstreaming
- Will build the capacity of communities, local and national governments to understand, design and manage the integrated solid waste management system of Greater Monrovia
- Can be implemented within the timeframe and available budget of the Cities Alliance project

These are all laudable objectives, and in fact the proposed pilot project to install up to 100 micro-scale biogas units and utilise the biogas for purposes of cooking satisfies all of these objectives. However, in implementing the testing phase for the installation of 10 micro-scale biogas units (HomeBiogas units) it has been a challenge to identify sites that have sufficient organic waste generation (with reasonable energy content) even to operate these small units. The experience to date on the testing phase indicates that it likely will not be possible to confirm 100 locations that will meet the criteria for the micro-scale biogas units (refer to section 4.1.1, page 75 for criteria). And although the procurement and installation of the home biogas units was relatively straightforward, it was done under highly "idealised' conditions of having the manufacturer's representatives onsite during the installations combined with an experienced team and resources of the Consultant. These conditions are not expected to prevail for the installation of the pilot units, and as such, the Consultant foresees significant challenges to install 100 units during the timeframe of the Cities Alliance project, even if 100 suitable sites could be identified. This is further compounded by a lack of capacity within government organisations to take on the responsibilities of the project. In short, considering the above factors, the Consultant recommends that only approximately 20 additional units of the micro-scale biogas systems should be installed for the pilot phase of the project, rather than 100 as originally envisioned. It is believed that 20 suitable locations can be identified, and by scaling down to 20 units, the prevailing challenges related to installation complexity and lack of capacity within government organisations can be overcome and managed with the right approaches.

The underlying challenge for this project has been the lack of available suitable organic waste that is clean and has a reasonable energy content. Given the local diets and local economic conditions in Monrovia, there is simply a lack of clean organic waste with reasonable energy content to serve as a basis for an effective waste-to-energy project, on the basis of a small-scale community-based project. As well, except for at market locations, there are no mechanisms in place for source separation of organics and it would be a very large challenge to introduce waste separation within the budgets and timeframe of the Cities Alliance project. Furthermore, waste separation is outside of the scope of the W2E Feasibility Study project.

The feasibility study has shown that there are small-scale waste-to-energy technologies available that could be implemented at market sites, because there is sufficient organic waste available that can be easily sorted. There are even some small-scale technologies available that could use mixed-waste from communities. However, in both of these cases, the capital costs are quite high. The projects would not be financially self-supporting and would require significant ongoing support to reach a point of continuous successful operation. The timeframe and budgets for these options are outside of what is available by the Cities Alliance project.

In short, the **options for small-scale, community-based waste-to-energy projects** that can be implemented within the timeframe and budgets of the Cities Alliance project **are very limited**. This is due to a combination of factors, constraints, and challenges, including:

- Low level of organic waste generation and low quality of waste (low energy content). This increases the cost, size, and complexity of any system, because the available technologies are generally designed around higher energy content waste that is found in a developed country setting, or higher energy content agricultural waste.

- The above requires that any system that is installed to utilise low energy content municipal waste will need extensive testing and experimentation and possibly equipment modification to get the process to the point where it can operate continuously and effectively and produce a reasonable amount of energy output.
- There is a lack of capacity in the local environment in Monrovia to carry through on the testing, experimentation, and longer-term operation. Extensive support will therefore be required, at costs that exceed the available budget.
- The project is focused on municipal solid waste. Despite extensive searching, our research has not identified any successful (sustainable) small-scale waste-to-energy projects based on municipal solid waste in developing countries. This is likely due to the same challenges/constraints identified in this report. The Consultant believes that this is just a case of the technology not yet being well-developed. However, several initiatives are underway in many countries, and a few years down the road the landscape and options to consider will likely be different. This is similar to when solar power was in its infancy 20-30 years ago – the technology worked but was fairly complex and not financially viable. As we know, great strides have been made in solar power, and the solar technology that is available today is much less complex, does not require a lot of technical support, and is financially viable even at a very small scale. It is expected that the same thing will happen with waste-to-energy technology in the coming years, given the vast amount of research being done and new products coming to market. But for now, other than the micro-scale biogas units (which utilise higher energy value food waste and where the operation cost is covered by the recipient), to identify small-scale waste-to-energy options based on municipal solid waste that can be implemented relatively quickly and at low budget, and that do not require a lot of ongoing support, is a tall order that is not easily satisfied. There are, however, many examples of successful implementations of simple, small-scale waste-to-energy projects in rural areas, based on farm waste, and some urban projects based on treating sewage and wastewater. If the mandate of the project was expanded outside the scope of municipal solid waste only, then it would open up several other options to consider.

Given the above, without a longer project timeframe – and higher budgets to support the capital cost and to provide technical and operational support for the first few years of operation – there are very limited options to choose from for viable waste-to-energy options. Other options may be available if waste sorting was in place. Waste sorting at a household level would provide better waste streams for conversion to energy. But there is no waste separation in Monrovia, and this is outside of the scope of this project to introduce waste sorting.

In short, within the context of the current project, the micro-scale biogas units appear to be the only viable alternative for a pilot project, hence why this was proposed. But it has been determined that the initial plan of installing up to 100 units of the micro-scale biogas systems is also not feasible, again due to limited volumes of organic waste, and installation of approximately 20 units is more appropriate.

Installation of 20 micro-scale biogas systems, however, is a very small undertaking and will not provide much benefit to the citizens of Monrovia. As well it will not fully utilise the available project budget. The requirement to utilise municipal solid waste to generate useful forms of energy, in a small-scale community-based manner within the confines of Greater Monrovia, is too restrictive, and this mandate cannot be effectively accomplished within the timeframe and budget of the project. In order to reap more benefit from the project, the Consultant therefore recommends the following:

1. Increase the timeframe and budget of the project. Doing this would enable executing a pilot project along the lines of the Option 1 project identified in the feasibility study.
2. If timeframe and budgets cannot be increased to the required level as per 1) above, then the mandate of the project should be expanded to be less restrictive.
    a. If the mandate were changed from **"waste-to-energy" to "renewable-energy,"** this would then introduce other options that can be very beneficial, such as solar power. The pilot project could then be developed on the basis of some waste-to-energy (for example the 20 micro-scale biogas units) plus other forms of renewable energy initiatives involving solar power or solar water supply. At the community level, for example in a school, it may be possible to combine a home biogas unit with solar electrical power for the school and a solar powered borehole for improved water supply. There also may be good renewable waste-to-energy options to consider from sewage (utilising anaerobic digestion), for example at public toilets or at the Monrovia sewage treatment plant (note this was not considered as an option to pursue in the current study as it was limited to "solid" waste only). Initiatives such as this could provide significant benefits to the community and could be accomplished within the project budgets and timeframes. The environmental benefits that are desired would also be accomplished. Waste-to-energy is a subset of renewable energy, so this does not represent a huge change in the nature of the project. It would, however, greatly enhance the ability of the project to come up with viable project options to achieve the goals of the project and Cities Alliance, and to benefit to the population of Monrovia.
    b. It is also recommended that consideration be given to expanding the project beyond the confines of the urban areas of Monrovia. While it is understood that the mandate of Cities Alliance is urban areas, if the mandate was expanded to include areas on the fringes of Monrovia where there is agricultural activity, then several options for waste-to-energy based on agricultural waste would emerge.

HOME BIOGAS UNIT INSTALLATION & END USER TRAINING

1. INTRODUCTION

Background

The Feasibility Study on Waste-to-Energy (W2E) Options in Monrovia, Paynesville, and Surrounding Townships in Liberia (W2E Feasibility Study) is a component of the EU-funded UNOPS Cities Alliance Programme. The project is one of numerous ongoing activities related to improving solid waste management in Monrovia, funded by various organisations and donors including Cities Alliance, EU, World Bank, and others. The Client for this project is the Cities Alliance Liberia Country Team.

The overall objective of the study is to identify small-scale, community-based W2E initiatives that can be piloted in the project area by Cities Alliance, with implementation to proceed as soon as possible after completion of the Feasibility Study.

WNL Development Solutions Ltd. (WNL) in association with Soft White 60 Corporation (SW60), hereinafter referred to as the Consultants, submitted a proposal to carry out the W2E Feasibility Study in November 2018. Negotiation meetings were held 7 December 2018 as well as on 5 and 7 February 2019, and WNL/SW60 subsequently entered into a contract for the assignment with UNOPS on 12 February 2019. Project activities commenced mid-February 2019.

Scope of Work and Work Plan

The initial project scope and work plan included 3 phases as follows:

- Phase I: Project Inception and Inception Report
- Phase II: Feasibility Study
- Phase III: Detailed Design and Action Plan

In July and August 2019, subsequent to the findings of the Consultant's project study tour in Europe and Africa, and after extensive consultations and consensus with project stakeholders, Phase III of the project was changed to comprise the installation and testing of up to 10 micro-scale biogas units (HomeBiogas Units) in various locations in Greater Monrovia. As such, Phase III of the project became the **Small-Scale Biogas Testing Phase.**

A revised project work plan to incorporate the Small-Scale Biogas Testing Phase into the project was submitted to the Client on 2 August 2019, and was approved through Contract Amendment #2, signed on 6 August 2019. The project's Revised Work Plan and Contract Amendment #2 are included in Appendix I.

The Revised Project Work Plan included the deliverables shown in Table 1, with the intention to complete the project by 31 December 2019.

For various reasons, primarily related to additional time being required for completion of the site selection process, the schedule slipped by approximately one month. A request to extend the project completion date to 31 January 2020 was therefore submitted to the Client on 28 November 2019, and was approved on 9 December 2019 through Contract Amendment #3, also included in Appendix I.

TABLE 1: Revised Work Plan

No.	Deliverables and Milestone Summary	Delivery/completion date
1	Submit proposal for revised work plan	01-Aug
2	Start date of new workplan	07-Aug
3	Site selection complete	18-Aug
4	Biogas units ordered	25-Aug
5	Feasibility Study Report	31-Aug
6	Units ready for shipping	01-Sep
7	Units arrive in Liberia	08-Sep
8	Units cleared through port	15-Sep
9	Commence installation of units	16-Sep
10	Capacity building workshop (technology, installation, maint)	18-Sep
11	Units installed and end users trained	24-Oct
12	Installation and end user training	31-Oct
13	Monitoring and end user support completed	Consultant to end monitoring and support 15 Nov. Gov't to continue thereafter
14	Weekly progress and lessons learned updates	Weekly 12 Aug to 15 Nov
15	Report on lessons learned and handover monitoring to gov't	30-Nov
16	Finalise report, handover project documents, final invoice	15-Dec
17	**CONTRACT END DATE**	31-Dec

Objective and Contents of Report

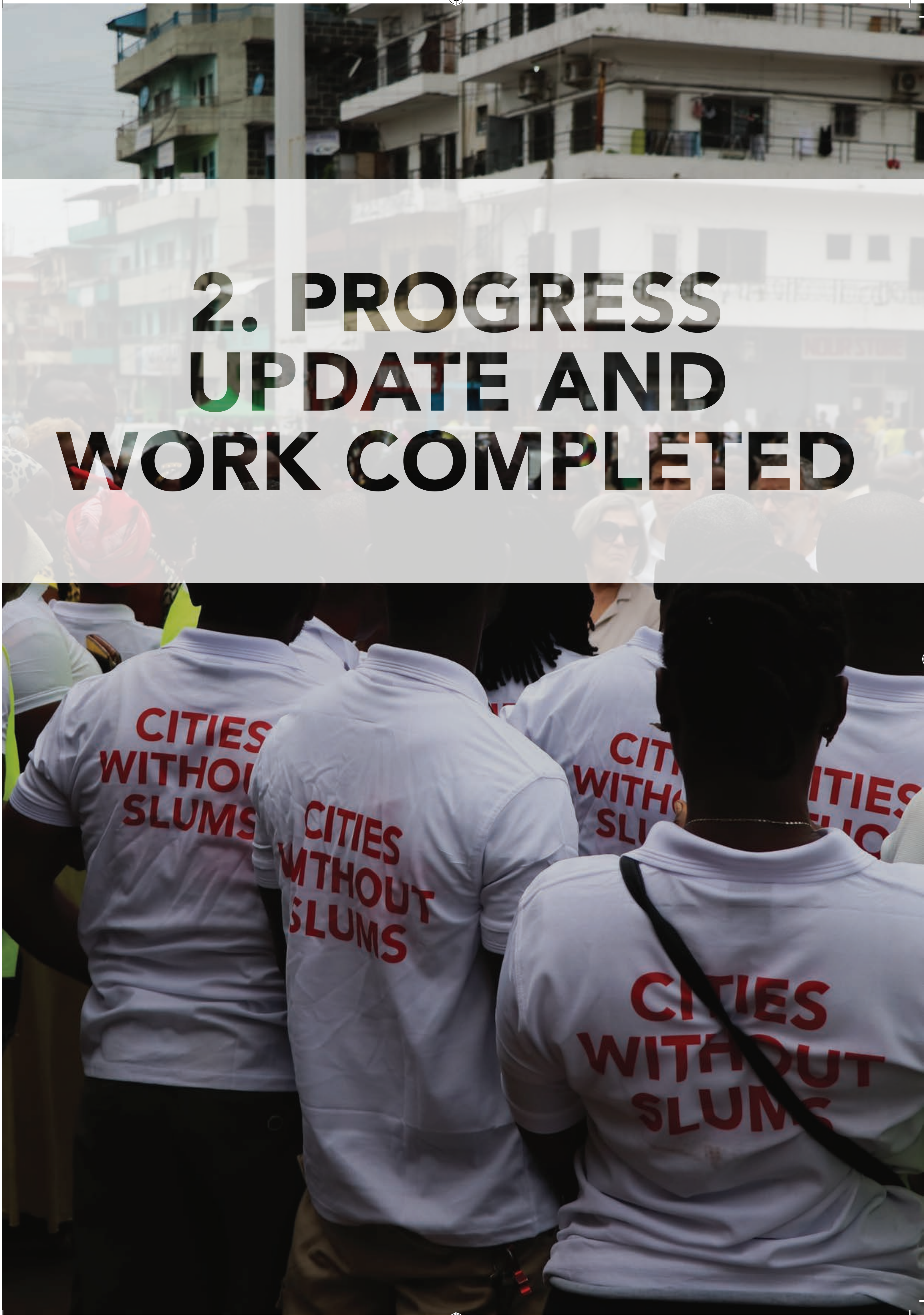
This report is the Installation and End User Training and is submitted in fulfilment of deliverables #1-12 for Phase III of the project, as per Table 1. As per Contract Amendment #3, the date for submission of the Installation and End User Training (this report) was changed to mid-December 2019.

The intent of the report is to provide an update on project progress to date, and to summarise the HomeBiogas Unit installation and training work completed to serve as a payment deliverable for the installation work. Work carried out for activities 3-11 in Table 1 is summarised within the report. Constraints encountered in the installation process are also discussed, as well as plans for the monitoring and end user support activities.

The draft report was submitted on 21 December 2019. Comments on the draft report were received from Cities Alliance on 23 January 2019. The report has been revised to incorporate comments received from the Client and also to update the report to include installation of security fencing around the units that was carried out by Cities Alliance in late December/early January, after the submission of the draft report. The report has also been strengthened to provide additional commentary on the lessons learned from the site selection and installation process of the HomeBiogas units and considerations for subsequent installations of additional units.

This final version of the report serves as the final delivery of milestone #12 for Phase III of the project and serves as a basis for payment of Invoice #4.

2. PROGRESS UPDATE AND WORK COMPLETED



This section of the report provides an update on progress to date against the revised work plan of Contract Amendment #2, according to the deliverables and milestone summary presented in Table 1, repeated below.

TABLE 1: Revised Work Plan

No.	Deliverables and Milestone Summary	Delivery/completion date
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Work completed for activities 3-11 is described below.

2.1 Site selection

Site selection commenced in early August and was expected to be completed by 18 August. The site selection process took much longer than anticipated and was finally completed in early October 2019. Several factors contributed to the long site selection process, as follows:

1. The intention was that the site selection would be done jointly by the Consultant, Cities Alliance, MCC and PCC. However, there was very little input from MCC and PCC in the process, despite repeated attempts by the Consultant to involve them. This resulted in the Consultant needing to identify and screen possible locations primarily on their own. The Consultant encountered reluctance and skepticism from potential participants to engage in discussions about the project, due to the Consultant not being an official representative of the government or the project. Several visits to various locations were required before potential recipients gained confidence that the project was real and opened up to the Consultant.
2. In most cases, it took a long time to get access to the key decision makers in private businesses and schools, etc. so that a decision from management could be made.
3. After several rounds of visits and discussions, at several potential sites it was determined that their volumes of food waste were too low to successfully operate the units, or that the effluent could not be effectively utilised. At some sites, although there was a high level of interest and satisfactory waste volumes, it was determined that a suitable location for the home biogas unit could not be identified. The site must satisfy the following key criteria for a successful home biogas unit installation:
    a. Must be able to generate 2 kg/day of suitable organic food waste for the HomeBiogas 2.0 unit and 6 kg/day for the HomeBiogas 7.0 unit. The waste cannot contain bones or be too high in ligneous material (high fibre vegetative waste). The organic food waste must contain enough energy to create a usable amount of biogas.
    b. There must be a suitable location to install the home biogas unit, in a secure location, on flat ground, within about 20m of where the cooking appliance will be located, and with a reasonable amount of sunlight. The area cannot have a shade over it. The minimum area required is approximately:
        - 3m x 4m for the smaller HomeBiogas 2.0 unit
        - 4m x 6m for the larger HomeBiogas 7.0
    c. The facility must be able to utilise the cooking gas.
    d. The facility must have the capacity to utilise or dispose of the liquid effluent (fertiliser) in an environmentally friendly manner, preferably into a garden.

    To standardise the site selection process, a Site Selection Installation Criteria Checklist Form was developed. The completed forms for the final proposed sites are included in Appendix II.

4. Some potential recipients that satisfied the necessary conditions lost interest due to the extended timeframe in making a final commitment to them, and dropped out of consideration. The extended timeframe was a result of factors described herein, combined with needing to order and ship the units to Liberia.
5. As the site selection commenced before placing the orders for the home biogas units, there were many details of the installation that the Consultant was not fully aware of, contributing to less than optimal time usage for discussions at some sites.
6. In placing the order for the home biogas units, HomeBiogas confirmed that larger units were available, and that they would provide the larger units at no additional cost (for this initial pilot test only). This information was provided only at the last step when the site selection process had already been completed and required re-assessing locations as to potential for utilisation of the larger units.

The final list of proposed sites submitted to the Client for approval on 11 September 2019 included nine approved sites. They comprised eight of the HomeBiogas 2.0 units (smaller unit) plus one HomeBiogas 7.0 unit (larger unit), which was equivalent to the 10 units initially envisaged, given that one of the larger units is equivalent to two of the smaller ones. The list included four sites in PCC and five in MCC, in an attempt to have a relatively even distribution between the two. The list also included four alternate sites for consideration that could be drawn upon in the event that one of the previously "approved" sites dropped out.

The list comprises businesses (hotels and restaurants) and schools that have lunch programmes and/or cafeterias. These facilities are expected to be able to generate enough waste to operate the units, and they have a requirement for the cooking gas. Schools were emphasised in the site selection because the installation of the units and participation in the project provides an excellent opportunity for education and knowledge transfer to students on renewable energy and improved waste management practices.

Key takeaways and lessons learned from the site selection process that should be incorporated into a larger scale effort include the following:

1. It is essential that the project be officially represented on initial visits for potential recipients to have confidence to continue with further discussions. Promotional materials about the project in this regard are highly desirable. If a Consultant is to do the site selection, they should be equipped as a minimum with project promotional materials, and a letter from the client and/or government that the Consultant is officially representing the project.
2. A project promotional campaign should be undertaken to raise awareness of the project, prior to doing site selection.
3. For recipients that are interested, a commitment needs to be made quickly so they do not lose interest and drop out. Along these lines, units should be ordered and shipped to Liberia prior to the site selection process, so that installation can proceed quickly after the confirmation of a site.

Having gone through the site selection and installation process now, site selection for additional planned units will be much easier and faster, particularly if the above items are taken into consideration.

However, due to the lack of involvement of MCC/PCC counterpart staff in the site selection process (and installations), they have not developed the capacity or been able to take advantage of lessons learned, and there are concerns as to their ability to effectively carry out site selection for future planned units. During the installation process, one of the sites was removed (Stella Maris Polytechnic) because the university decided at the time of the installations that it needed the location where the home biogas unit would be positioned for future development. This left eight sites for installations after Tropicana Resort was added to the list. MCC/PCC was requested in November to come up with two additional sites where the remaining units could be installed. At the time of finalising this report (late January 2020) the selection of these sites is still not finalised.

2.2 Biogas units ordered

Several discussions were held between the Consultant and HomeBiogas commencing from mid-September concerning the order for the units and the installation trip. The purchase order was placed on 10 October 2019 after all details had been worked out.

2.3 Feasibility Study Report

The Feasibility Study Report was submitted on 16 September 2019. It was originally intended to submit this report by 31 August 2019. However, finalising the report took longer than anticipated due to the addition of the proposed anaerobic digestion waste-to-energy project for Omega Market into the report. Verbal comments on the Feasibility Study Report were received from the Client and will be incorporated into a final version of the report.

2.4 Units ready for shipping

Payment for the units was transferred to HomeBiogas on 10 October 2019. The order was assembled and shipped by air from Israel on 17 October 2019.

2.5 Units arrive in Liberia

The home biogas units arrived in Liberia on 22 October 2019.

2.6 Units cleared through port

The units were cleared through the port by UNOPS on 25 October 2019 and stored at the National Housing Authority site.

PROJECT: **Feasibility Study on Waste-to-Energy Options in Monrovia, Paynesville, and Surrounding Townships in Liberia.**

DESCRIPTION: **List of Proposed Site for Possible selection for Waste-to-Energy Pilot Project.**

LIST OF APPROVED SITES FOR INSTALLATIONS OF HOME BIO-GAS			
S/No.	**Location/Municipal Jurisdiction**	**Names of Institution**	**Contact**
1	Paynesville City Corp. (PCC)	**Aware International School**	+231-0778028353 (Administrator)
2	Paynesville City Corp. (PCC)	**RLJ. Kedneja Hotel**	+231-886436711 (Manager)
3	Paynesville City Corp. (PCC)	**Isaac A David School**	+231-777564796 / 0886564796 (Vice Principal)
4	Monrovia City Corp. (MCC) Capitol Hill	**STELLA MARIS POLYTECHNIC UNIVERSITY**	+231-77006243 / 088833967 - Env. College Dean / 0775932230 - Canteen Mngr.
5	Monrovia City. (MCC) 12th Street Sinkor	**W.V.S Tubman High School**	+231-778090199 - Head of Maintenance
6	Monrovia City Corp. (MCC)	**Nancy Doe Market.**	+231-777943927 - Market Secretary
7	Monrovia/MCC/24th Street, Sinkor	**Corina Hotel**	+231-777538588 - (Hotel Manager)
8	Weaver St.- Paynesville/PCC	**John Lewis Mthdst Mem High Sch.**	+231-777072588 - School Staff
9	Monrovia City Corp. (MCC) UN Drive	**Mother Pattern College (St. Teresa Convent)**	+231-775202267 (Dean Academic Affairs)
LIST OF SITE STILL PENDING FINAL APPROVAL			
10	Monrovia/MCC/24th Street, Sinkor	**Evelyn Restaurant**	+231-777001155 (Manager)
11	Capitol Hill- Monrovia/ MCC/8th Street, Sinkor	**Smart Liberia Canteen**	+231-770357129 (Head Chef)
12	12th Street-Sinkor/MCC	**JJ Robert High School**	+231-8865552212 - (Principal)
13	Paynesville City Corp. (PCC)	**Tropicana. Resort**	+231-886529639/0770529639 (Manager)

Date of Update: October 11, 2019

	Project Assessment Status	Approval: Yes, No, Not Yet, Pending	Meets the Criteria as per the Checklist for Pilot Implemention	Need to Construct Fence	Remarks
	Done	Yes	Yes	Yes	Construction of mesh fence will be require to prevent from intruder.
	Done	Yes	Yes	Yes	Construction of mesh fence will be require to prevent from intruder. See Checklist for more details
	Done	Yes	Yes	Yes	See. Checklist for additional info
	Done	Yes	Yes	Yes	Larger Homebiogas unit will be installed @ this location.
	Done	Yes	Yes	Yes	See. Checklist for additional info
	Done	Yes	Yes	Yes	See. Checklist for additional info
	Done	Yes	Yes	Yes	See. Checklist for additional info
	Done	Yes	Yes	Yes	See. Checklist for additional info
	Done	Yes	Yes	Yes	See. Checklist for additional info
	Pending	Yes (In a meeting)	Not Confirm	Not Confirm	Still waiting for approval from Management. Assessment Pending
	Done	Not Yet	Not Confirm	Not Confirm	Location confirmed for installation, need final approval from management
	Done	Pending	Yes	Yes	Location confirmed for installation, need final approval from faculty
	Pending	Pending	Not Confirm	Not Confirm	Still waiting for approval from Management. Assessment Pending

2.7 Commence installation of units

Two personnel from HomeBiogas arrived in Liberia on Sunday, 27 October, including the CEO of the company Oshik Efrati. Installation of the units commenced Monday, 28 October 2019. Dennis St. George, the WNL/SW60 Biomass Engineer, arrived in Monrovia on 30 October 30 to assist with the installation activities.

2.8 Capacity building workshop

2.8.1 WORKSHOP OBJECTIVES AND PLANNING

As part of the revised Phase III work plan, a capacity building workshop was to be held while the HomeBiogas personnel and WNL Biomass Expert were on site for the installations.

The objective of the workshop was to disseminate information on the project, overall waste-to-energy topics, as well as the installation, operation and maintenance of the HomeBiogas units to a wider stakeholder audience, as a means of developing understanding of the topic and the project and building capacity among stakeholders. The workshop also served to officially launch the HomeBiogas unit installations.

The workshop was initially planned for late September, but due to the site selection process taking longer than anticipated was re-scheduled for 1 November. This date was selected to enable installing some units prior to the meeting.

Cities Alliance made all arrangements for the workshop with presentations by Cities Alliance, WNL and HomeBiogas. The workshop was held at Corina Hotel, Sinkor, Monrovia.

2.8.2 AGENDA

The workshop agenda is shown below.

Date:	1st of November 2019
Venue:	Corina Hotel (Sam BBQ), Sinkor
Subject:	Official Launch of Home BioGas Digester Units to include a Presentation on Installation, Operation and Maintenance of the Units. The presentation will be followed by illustrational installation of one of the units at Corina Hotel.
Participants:	Representatives from all stakeholders (MCC, PCC, EPA, LWSC, MPW NACOBE etc.), Recipient institutions, WNL team, Home BioGas team and CA team

Time	Topic	Rep
8:00-8:30	Registration	CA
8:30-9:00	Breakfast	All
9:00-9:05	Introduction of the workshop by Cities Alliance	CA
9:05-9:10	Overview of the assignment/study	CA
9:10-9:15	Remarks	EU
9:15-9:20	Remarks	MCC
9:20-9:25	Remarks	PCC
9:25-9:30	Remarks	Recipient representatives
9:30-10:00	Presentation on Bioenergy sources and options (include short Q&A)	WNL
10:00-10:30	Presentation on the Feasibility study conducted (include short Q&A)	WNL
10:30-11:00	Presentation on the options formulated (include short Q&A)	WNL
11:00-11:30	Presentation on Home Biogas Technology	Home BioGas
11:30-12:30	Illustrational installation of the Units at Corina Hotel	Home BioGas
12:30-13:30	Lunch Break	
13:30-14:00	Questions and Answers	WNL/Home BioGas
14:00-14:30	Presentation of the modality, management, monitoring and onward implementation of the units.	CA
14:30-15:00	Wrap-up of the presentations and discussions	WNL/Home BioGas
15:00-15:05	Closing Remarks	CA

2.8.3 INVITEES

The list of proposed invitees and participants is shown below.

List of Potential Invitees to the Home Biogas Units Workshop		
No.	**Name of Institution**	**Number of Invitees Per Institution**
1	Environmental Protection Agency	2
2	European Union	2
3	Liberia Energy Regulatory Commission	2
4	Liberia Water and Sewer Corporation	2

List of Potential Invitees to the Home Biogas Units Workshop		
No.	**Name of Institution**	**Number of Invitees Per Institution**
5	Liberian Business Association	2
6	Liberian Institute of Public Administration	6
7	Ministry of Internal Affairs	2
8	Ministry of Lands Mines & Energy	2
9	Ministry of Public Works	6
10	Monrovia City Corporation	2
11	National Association of CBEs	4
12	National Housing Authority	2
14	National Wash Commission	2
15	Paynesville City Corporation	2
16	University of Liberia	2
	Totals	40
	Site Representatives (10 sites)	20
	WNL Staff	4
	CA Staff	6
	Home Biogas Staff	2
	Grand Total	**72**

2.8.4 ATTENDANCE

The workshop was very well attended. In total 86 people attended (including workshop presenters), including 18 women. The attendance register for the workshop is included in Appendix V. A wide and diverse group of people attended from many different private sector, NGO, and government organisations including:

- Future Leaders Initiative
- JEMB
- NDW
- HomeBiogas unit recipients (confirmed and potential)
- LWSC
- MCC
- PCC
- NPHIL
- NHA

- NACOBE
- City Sanitation
- Green Planet
- EPA
- OCEANS
- EU
- Green Joe
- Various News Media Organisations
- Water Aid Liberia
- Environmental Service Enterprise
- Alpha Sanitation
- WHRM
- SKD Venture Services
- Cities Alliance
- WNL
- HomeBiogas

2.8.5 TOPICS PRESENTED

The following topics were covered:

By Cities Alliance:

- Introduction to the workshop
- Project overview
- Monitoring and onward implementation of the units
- Closing remarks

By WNL:

- Overview of the Cities Alliance Waste-to-Energy Feasibility Study assignment
- Background on renewable energy and waste-to-energy concepts (biomass and waste)
- Review of work completed by the Consultant to date and implementation options to consider
- Review and update on the small-scale biogas units (HomeBiogas unit) testing phase

By HomeBiogas:

- Overview of the technology
- Installation of HomeBiogas units
- Operation and maintenance of HomeBiogas units

Copies of the presentations are included in Appendix III. Photos of the workshop are shown below.

WNL/SW60 Biomass Engineer Dennis St. George presents on waste-to-energy concepts and the work done by the Consultant during the project.

CEO of HomeBiogas Oshik Efrati giving presentation on the HomeBiogas units.

2.8.6 OUTCOMES

Outcomes of the workshop were positive.

- Attendance was good and widespread among stakeholders.
- Several good questions were raised during the presentations.
- The level of enthusiasm for the project and interest in the topic were high.
- Several positive comments were made to the Consultant at the end of the workshop.

It is believed that the workshop achieved its intended goals of disseminating information and raising awareness of waste-to-energy topics, the Cities Alliance project, and the installation, operation, and maintenance of the HomeBiogas units to a wide stakeholder audience. The workshop increased stakeholder awareness and knowledge, thereby improving capacity within the stakeholder community on waste-to-energy opportunities and initiatives.

2.9 Units installed and end users trained

This section of the report describes the process and activities undertaken for the installation of the units. This included the following steps:

1. Installation of the units at the recipient locations
2. Activation of the units and confirmation of gas production
3. Feeding of the units and end user field training
4. Final training and handover of units to recipients
5. Official project launch event

6. Installation of fencing
7. Follow-up support

Each of these are described below.

2.9.1 INSTALLATION OF HOMEBIOGAS UNITS

HomeBiogas personnel were on site in Monrovia for one week (27 October to 3 November 2019). During this time, they provided extensive training on installation of the units to the WNL Local Coordinator, Septimus Nyanforh, and other participants in the installation exercise, including counterpart staff of MCC/PCC, to enable them to continue with the installations after the departure of the HomeBiogas staff. WNL Biomass Engineer Dennis St. George was also on site from 30 October 30 to 5 November to assist with the installations and present at the workshop on 1 November.

During the installations, two sites were dropped (Stella Maris Polytechnic and Nancy Doe Market) because suitable locations on these properties for the home biogas unit could not be confirmed. One site was added: Tropicana Resort. The final list of sites where units were installed (eight sites) is as follows:

1. 1. Aware International School
2. 2. RLJ Kedneja Hotel
3. 3. Isaac A Davies School
4. 4. W.V.S. Tubman High School
5. 5. Corina Hotel
6. 6. John Lewis Methodist High School
7. 7. Mother Pattern College
8. 8. Tropicana Resort

The list comprised five schools and three private hotels. The larger HomeBiogas 7.0 units were installed at Corina Hotel and RLJ Kedneja Hotel, as they have the waste volumes and gas usage to support these larger units. The rest of the sites received the smaller HomeBiogas 2.0 units.

Additionally, HomeBiogas decided to donate one of their toilets to the project, and the toilet – along with the cost of the construction of a small building for the toilet and a sink –was donated and installed at Isaac A. Davies School. WNL donated the cost of connecting water supply piping to the sink in the toilet building.

Installation of the units commenced on 28 October and all units were completed by 6 November 2019, including the initial activation with cow manure. The installation took a total of 10 working days to install the eight units, including activation. This compressed schedule for the installations was made possible by exceptional work efforts by the HomeBiogas personnel as well as the WNL Local Coordinator, installation team, and Dennis St. George, and is not representative of normal timeframes for the installations of the units that should be expected on subsequent installations. Subsequent installations may take double this amount of time or more, depending on the arrangements put in place for the execution.

Sample photos from the installation work are shown below.

Installing 7.0 unit at Corina Hotel. Photo shows filling the unit with water.

Installing 2.0 unit at Isaac A. Davies School

Installing 7.0 unit at RLJ Kedneja Hotel

HomeBiogas personnel training WNL Local Coordinator Septimus Nyanforh on installation methods

Installation of 2.0 unit at Tropicana Resort

Construction of toilet building at Isaac A Davies School under tight timeframe

Completing installation of 2.0 unit at W.V.S. Tubman High School

Installing piping for HomeBiogas toilet at Isaac A Davies School

Competed installation at Mother Pattern School

2.9.2 ACTIVATION AND CONFIRMATION OF GAS PRODUCTION

After installation of the units, it is necessary to activate them to start producing gas. This is normally done by loading the unit with fresh cow manure – 100 liters is required for the HomeBiogas 2.0 units, and 300 litres for the large 7.0 units. The cow manure is mixed with water to produce a consistent slurry that is then poured into the unit.

The initial activation was done immediately after installation of the units and was completed for all eight units by 6 November. To speed up the production of biogas from the units, HomeBiogas recommended doing a second activation of the units with cow manure. This second activation commenced 8 November and was completed on 13 November 2019.

Following the second activation, the units were tested for gas production and the ability to produce flames from the burners. This was completed for all eight units on 26 November.

For some of the units, although they were producing gas, the gas had a low methane content. This was observed by the color of the flame, with a red/orange colored flame indicating lower methane gas content and a blue colored flame indicating higher methane gas content. HomeBiogas recommended giving a few more days for the activation process before feeding the units with food waste.

Sample photos are shown below.

Cow manure used for activation of the units

Activation of unit at Corina Hotel with cow manure

Methane gas production at top of unit being observed

Testing of double burner of 7.0 unit to confirm flame

Confirming operation of unit

2.9.3 FEEDING OF THE UNITS AND END USER FIELD TRAINING

To provide additional time for activation, feeding of the units with food waste commenced on 2 December 2019. At this point, all units were producing a good, blue-colored flame indicating good methane content and full activation of the units.

Plastic buckets of the appropriate size for each unit (HomeBiogas 2.0 and 7.0) were provided by WNL to each of the recipients. The buckets were marked with a line to show the level in the bucket where the food waste (combined with water) should be filled to. This was followed by WNL providing hands-on field training to recipient staff on the basic operation and maintenance requirements of the units, including:

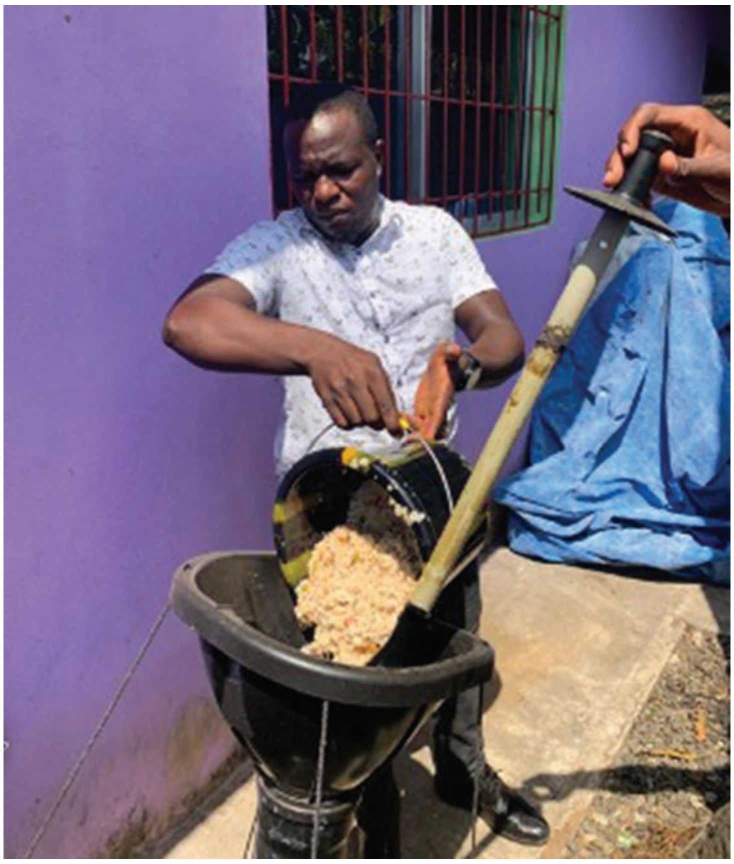
- The type of waste that could be fed into the units (and what cannot be fed)
- How to mix the waste with water
- The methods of feeding the units
- Opening and closing of gas valves
- Operation of the cooker
- Effluent extraction
- Maintenance requirements

Actual cooking with the HomeBiogas units was done at a couple of locations as part of this exercise. Some of the sites were visited on multiple occasions to carry out the field training.

A few photos of the feeding and field training exercise are shown below.

Training and initial feeding of unit

Training and initial feeding of unit



Training and initial feeding of unit

First cooking with the HomeBiogas unit

2.9.4 FINAL TRAINING AND FORMAL HANDOVER OF UNITS

The training exercise culminated with the final handover visit. During this visit, operation and maintenance of the unit was reviewed once again, and recipients were provided with copies of the HomeBiogas Owner's Manual. The contents of the manual were reviewed so that the recipients would know where to find relevant information. Copies of the manuals for the HomeBiogas 2.0 and 7.0 units are included in Appendix IV.

Recipients were then requested to sign the "HomeBiogas System Installation Attestation Form" that was prepared for the purpose of official handover of the units to the recipients. The form and the responsibilities of the recipient were reviewed prior to signing. By signing the form, the recipients were attesting:

1. That the unit has been successfully installed at their facility.
2. That operation and maintenance training was provided by the Consultants and received by at least one staff member of the recipient. In most sites multiple personnel had received the training.
3. That the recipient accepts responsibility for ongoing operation, maintenance, and security of the system in accordance with the Right-of-Use Agreement previously signed between the recipient and UNOPS/Cities Alliance.
4. That the Consultant was released from any further responsibility and liability concerning the installation, operation, and maintenance of the units.

The formal handover of the units took place from 2-8 December 2019. The forms were then signed by Cities Alliance on 10 December 2019. Copies of the forms signed by the recipient, the Consultant and Cities Alliance were delivered to the recipients. Copies of the forms are included in Appendix V.

Some photos of the final training received and signing of the forms are shown below.

Final training at Corina Hotel

Final training on operation of the stove

Signing of the attestation forms

2.9.5 OFFICIAL PROJECT LAUNCH EVENT

An official project launch event was held at Isaac A. Davies School on 5 December 2019. Cities Alliance provided gravel and fencing around the HomeBiogas unit and painted the toilet building for the event. WNL contributed by arranging and paying for the water supply piping and connection to the sink in the toilet building.

The event was attended by a wide group of stakeholders and was considered very successful. Photos from the event are shown below.

HomeBiogas unit and toilet facility prepared for the launch event

Students from Isaac A. Davies School and representatives from Cities Alliance and EU in attendance

2.9.6 INSTALLATION OF FENCING

As described in Section 4 of the report, the budget of US $15,000 committed to the project by WNL was fully utilised for the installation of the first eight units. As such, installation of the fencing around the units could not be accomplished within WNL's budget. It was determined that fencing around the units was essential as tampering had taken place at some of the sites even before the official handover. Cities Alliance therefore hired a local contractor to install the fencing. Construction of the fencing commenced 23 December 2019. The WNL Local Coordinator provided oversight of the construction of the fencing from 23 December to mid-January 2020.

Some photos of the fencing are shown below.

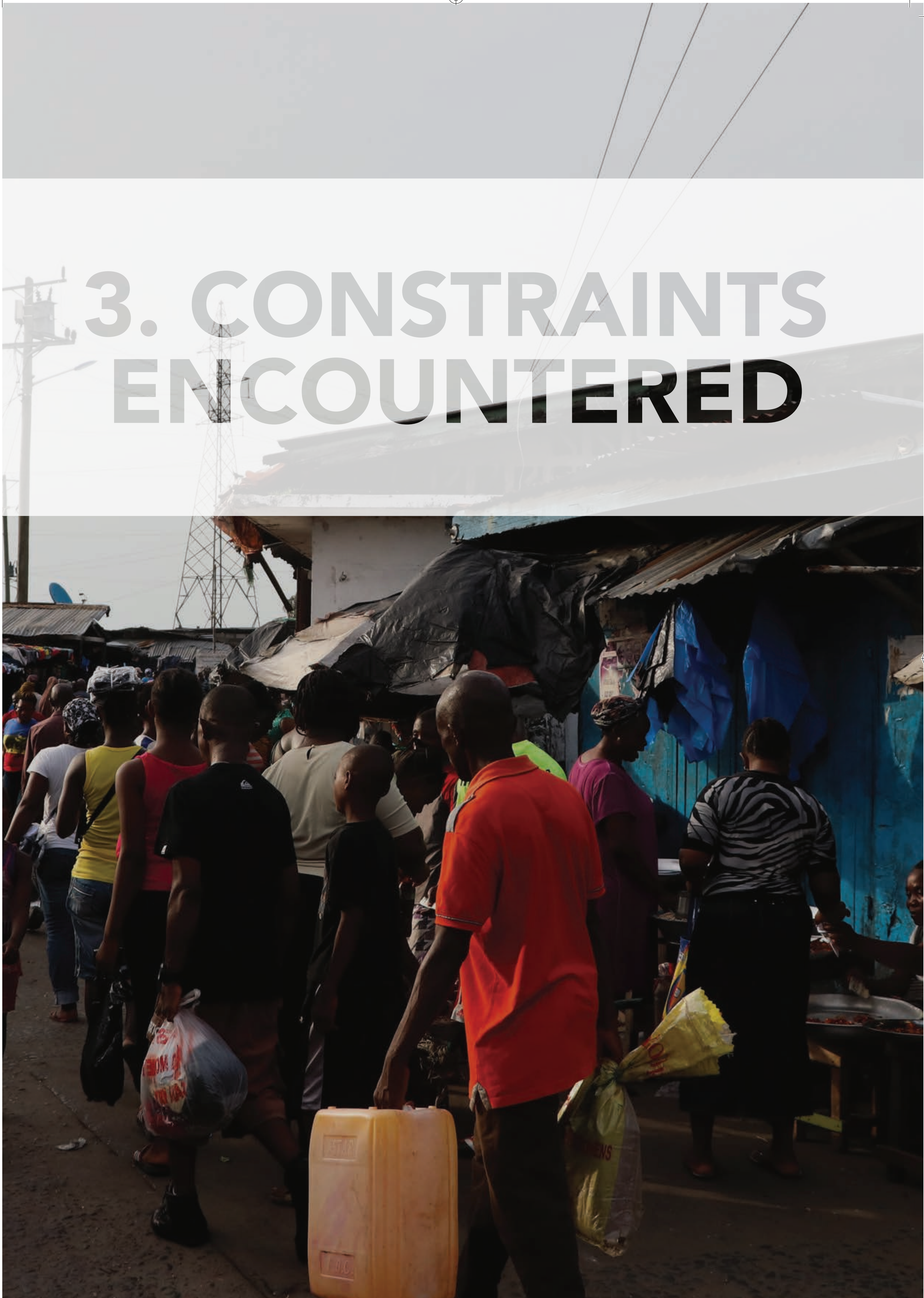
Fence installed at Tropicana Resort

Fence installed at William V. S. Tubman High School

2.9.7 FOLLOW-UP SUPPORT

After installation of the units, follow-up support was provided as part of the monitoring stage of the project. Please refer to Section 5 of the report.

3. CONSTRAINTS ENCOUNTERED



3.1 Site selection

As described in Section 2.1, site selection proved to be more challenging than originally anticipated. Some of the external factors and key takeaways relating to this are described in Section 2.1, and it is believed that if subsequent installations are undertaken these issues can be dealt with.

Notwithstanding the external factors relating to the site selection process, identifying suitable sites was still an unexpected challenge and constraint. The Installation Criteria Checklists are presented in Appendix II. In addition to finding a willing recipient, the site must satisfy the following key criteria for a successful HomeBiogas unit installation:

1. Must be able to generate 2 kg/day of suitable organic food waste for the HomeBiogas 2.0 unit and 6 kg/day for the HomeBiogas 7.0 unit. Furthermore, the waste cannot contain bones or be too high in ligneous material (high fibre vegetative waste). In short, the organic food waste must contain enough energy to create a usable amount of biogas.
2. There must be a suitable location to install the HomeBiogas unit. It must be in a secure location, on flat ground, within about 20 m of the cooking appliance , and the area must receive a reasonable amount of sunlight. The area cannot have a shade over it. The minimum area required is approximately:
    - 3m x 4m for the smaller HomeBiogas 2.0 unit
    - 4m x 6m for the larger HomeBiogas 7.0
3. The facility must be able to utilise the cooking gas.
4. The facility must have the capacity to utilise or dispose of the liquid effluent (fertiliser) in an environmentally friendly manner, preferably into a garden.

This is more challenging than it appears on the surface. Even within the sites that were selected, two situations occurred as follows:

- Stella Maris Polytechnic, one of the best candidates for the units and very enthusiastic about the project, in the end declined to have a unit installed, because they wanted to construct some future buildings in the most suitable location for the HomeBiogas unit. An alternative suitable location on their site could not be identified.
- After the installation of the unit at Isaac A. Davies School, it was established that there was not enough waste generated at the school, despite the fact that it is a relatively large school with about 200 students. Students have therefore been requested to bring waste from home, and the school has agreed that they will make other arrangements for collection of waste. Their ability to generate the waste over the longer term will be confirmed through monitoring of the installation.

Finding locations with enough organic waste with reasonable energy content will be the largest constraint in rolling out more units. This is a function of the local environment and not likely to change in the near future. The local diets, combined with local economic conditions, simply result in low levels of organic waste, and the waste that is available is often of low energy content.

Schools that have lunch programmes and/or cafeterias were identified as good candidates for the HomeBiogas units, and five out of the eight installations done are in schools. However, a complicating factor with schools is that they close for extended periods for holidays and summer break. The HomeBiogas units cannot be fed when the schools are closed, and this could result in the anaerobic process shutting down, and requiring that the units be reactivated, which could be quite a complex process. To avoid this situation during the monitoring phase, the Consultant fed the units at the schools over the Christmas period with organic waste brought from elsewhere. On shorter breaks like over Christmas, alternative arrangements such as this can be made, but it remains to be seen what can be put in place over the summer when schools are closed for extended periods.

3.2 Installation

No major constraints or problems were encountered in the installation of the units. The installation of the units was relatively straightforward. However, this was due to having the assistance from the HomeBiogas team onsite to teach the proper method of installing the units. Installation would have been much more complicated and challenging without having HomeBiogas onsite to provide training. Thanks to this training, the WNL Local Coordinator has learned how to install the units and can now train others in the procedures.

A major challenge of the installations related to the need to activate the units with fresh manure. There is apparently a relatively high demand for fresh manure in Monrovia and a limited supply, making the fresh manure difficult to obtain and also expensive. It also required travelling out of town to purchase the manure. If a larger scale installation programme is undertaken, arrangements will need to be made in advance for larger quantities of manure, and the lack of availability will need to be taken into consideration in overall scheduling and costing of the programme.

Although it is indicated above that the installation process was relatively straightforward, with no major constraints or problems, it must be understood that the installation was done under "idealised" circumstances. The procurement and installations were done by WNL utilising staff with extensive prior experience in procurement and small-scale installations, with the necessary financial and logistical resources in place to carry out this work uninterrupted. Additionally, there was a very high level of cooperation and support from HomeBiogas due to their interest in establishing their product in the West African market. Without the direct involvement of WNL or HomeBiogas in the installation of additional units after this initial testing stage, it is expected that there will be significant challenges. This will depend on the arrangements that are made for the execution of the work. Special attention should be drawn to the following:

1. The intent is that after the testing phase, ongoing monitoring and future installations would be done by counterpart staff from MCC/PCC. However, as stated below, and mentioned elsewhere in this report, the level of participation of MCC/PCC counterparts in the site selection process and the installation process was low, despite repeated efforts by the Consultant to involve them in the process. As a result, the counterpart personnel did not develop the desired capacity through the project. This will limit their ability to adequately perform

future site selection activities, install the units, and provide follow-up training and support. There are three HomeBiogas units remaining to be installed at the time of writing this report (two new installations plus one replacement installation). The Consultant ***highly recommends*** that the counterpart staff ***must*** take the lead role in the final selection of these sites and in the installation of the units in order to develop the capacity they will need to take on any future installations. The Consultant is prepared to provide guidance to the counterpart staff based on the knowledge gained during the site selection and installation process and can also link them with HomeBiogas for telephone or email consultations. However, the Consultant should not do this work; to build capacity, the counterpart staff need to be involved in a hands-on basis.

2. Installation crews must have the required resources to carry out the installations, including vehicles, labor crews (skilled and unskilled), tools, plumbing parts, communications, etc. Not all items of the installations can be planned in advance, and situations will come up in the field requiring purchase of small parts and/or tools. Therefore, it is necessary that installation crews have a cash float to respond quickly to these situations. Cash payments will also most likely be required for purchase of water to fill the units and manure to activate the units. If the counterpart personnel cannot have these resources at their disposal, including a cash float, then it will result in significant challenges and delays to the installation process. If this is the case, it will be better to hire a contractor to do the installations under the direction of the counterpart personnel, such that the contractor can use his own resources (as WNL did).

3. It is recommended that Cities Alliance procure any additional units directly from HomeBiogas. If this cannot be done due to procurement procedure restrictions, then a contractor could procure the units, but it must be a contractor with experience and systems in place to transact international procurements effectively. It will of course increase the cost if procurement of the units is done by a contractor. Costs presented in this report are direct actual costs, without any markup.

4. Regardless of whatever arrangements are made, without coordination from the Consultant and support from HomeBiogas, Cities Alliance will have a much larger role to play in oversight and coordination and will need to dedicate significant staff time to the effort.

5. It is ***highly recommended*** that if additional units are being installed, only units from HomeBiogas be considered. Their product is good, and works as claimed, and their ability to process and ship orders quickly and provide a high level of after-sales support is very good. As well, their pricing is good. If other vendors are brought into the picture in order to comply with procurement restrictions, then there could be several unknowns and complicating factors, and they would not be able to take full advantage of the lessons learned from the initial installations.

6. Fencing needs to be incorporated into the installation plans from the beginning, with fences put up immediately after installation of the units to avoid any tampering.

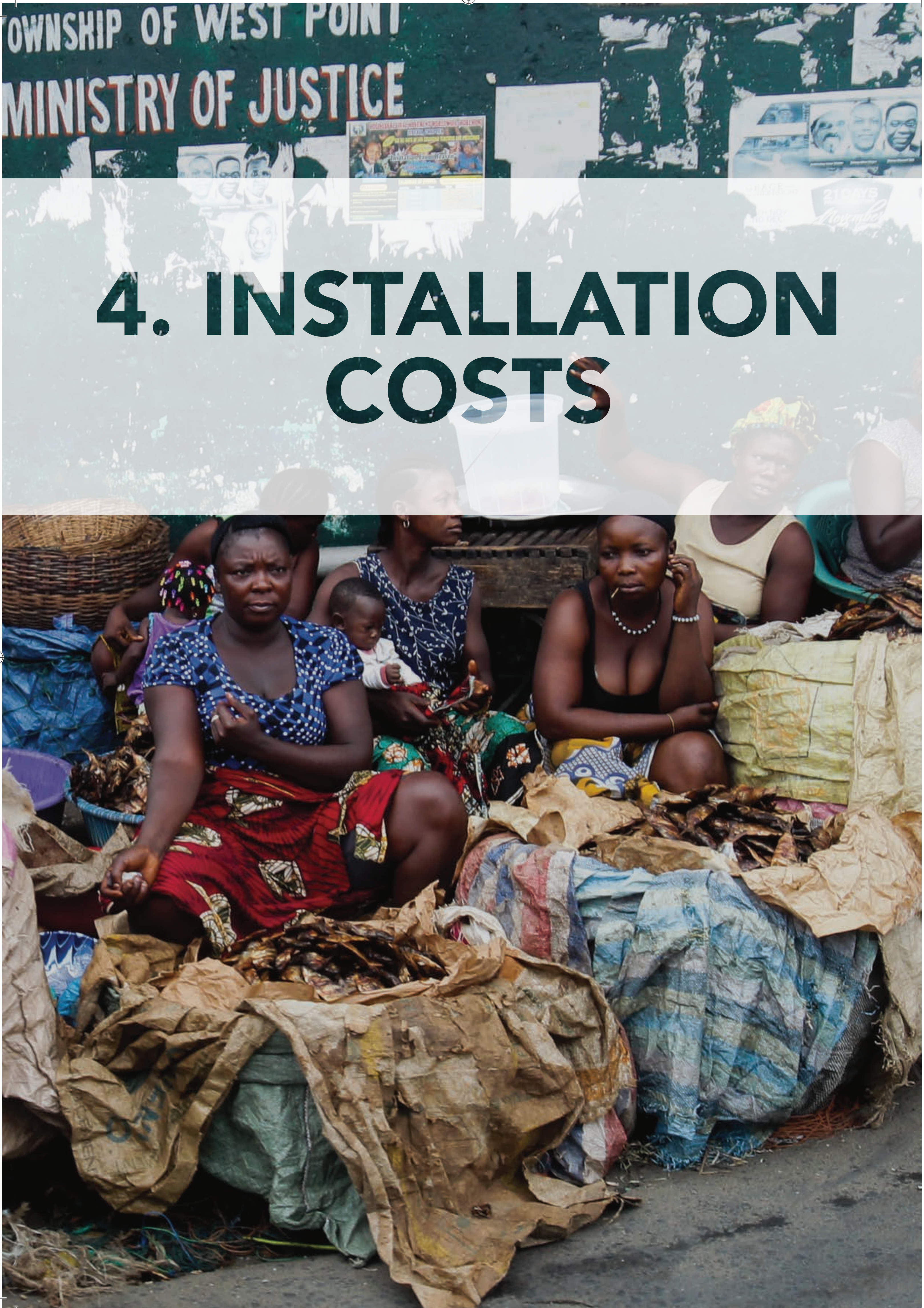
7. Schedules, timeframe expectations, and costs must be established realistically from the start, based on the results of the initial testing phase, but taking into consideration capacities of those proposed to carry out the work. Although there were a few minor setbacks in the site selection and installation process, overall, the process went quite smoothly. This was due to WNL having a full-time, dedicated Local Coordinator assigned to the project, with backup from WNL's

head office; the financial and logistical resources to move the work forward without interruption; and prior experience in this type of work, combined with support from HomeBiogas. This will not necessarily be the case for the next set of installations, depending on what arrangements are put in place for the installations, and needs to be considered in planning out the project so that expectations are realistic.

3.3 Counterpart participation

The level of participation from counterpart staff from MCC and PCC was low. As stated earlier in the report, the level of participation in the site selection process was very limited. Counterpart staff from PCC did participate in the installations to a limited extent, but there was less participation from MCC. This resulted in increased costs to the Consultant for the installations, as we had to hire additional personnel to assist with the installation process so that the majority of the installations could be accomplished while the HomeBiogas personnel and the WNL/SW60 Biomass Engineer were on site. Otherwise, the installation schedule would have been delayed significantly. It also resulted in the counterpart staff not developing the intended capacity as part of the project. Consequences of this for future implementation of the project are discussed elsewhere in the report.

4. INSTALLATION COSTS



In the revised project work plan prepared by the Consultant on 2 August 2019 and which was approved on 6 August 2019, the Consultant committed to spending a maximum of US $15,000 for the procurement and installation of the HomeBiogas units, including the cost of bringing the manufacturer's representative to Monrovia for the installation of the units. Actual costs incurred up to the end of the 2nd activation of the HomeBiogas units on November 13th, 2019 were as follows:

1.	Purchase of HomeBiogas Units:	US $7,591.00
2.	Cost of HomeBiogas trip to Liberia (one person only):	US $4,481.00
3.	Installation (materials, labor, allowances, vehicle rental):	US $2,950.44
		Total: US $15,022.44

These costs are summarised in the table presented in Appendix VI. Receipts for all expenditures can be provided upon request from the Client.

It should be noted that the installation costs were higher than expected, primarily due to higher than anticipated costs for water and manure to activate the units, as well as the need to hire more site staff for the installations than originally anticipated (due to lack of input from MCC/PCC counterpart staff).

Due to the costs incurred, it was not possible to install security fencing around the units, and this is highly recommended for the project. Tampering of some units took place very soon after the installations. Cities Alliance installed the fencing through a local contract.

As well, these costs have been incurred for the installation of eight units. At the time of writing this report, sites for the additional two units that were purchased have not been confirmed yet.

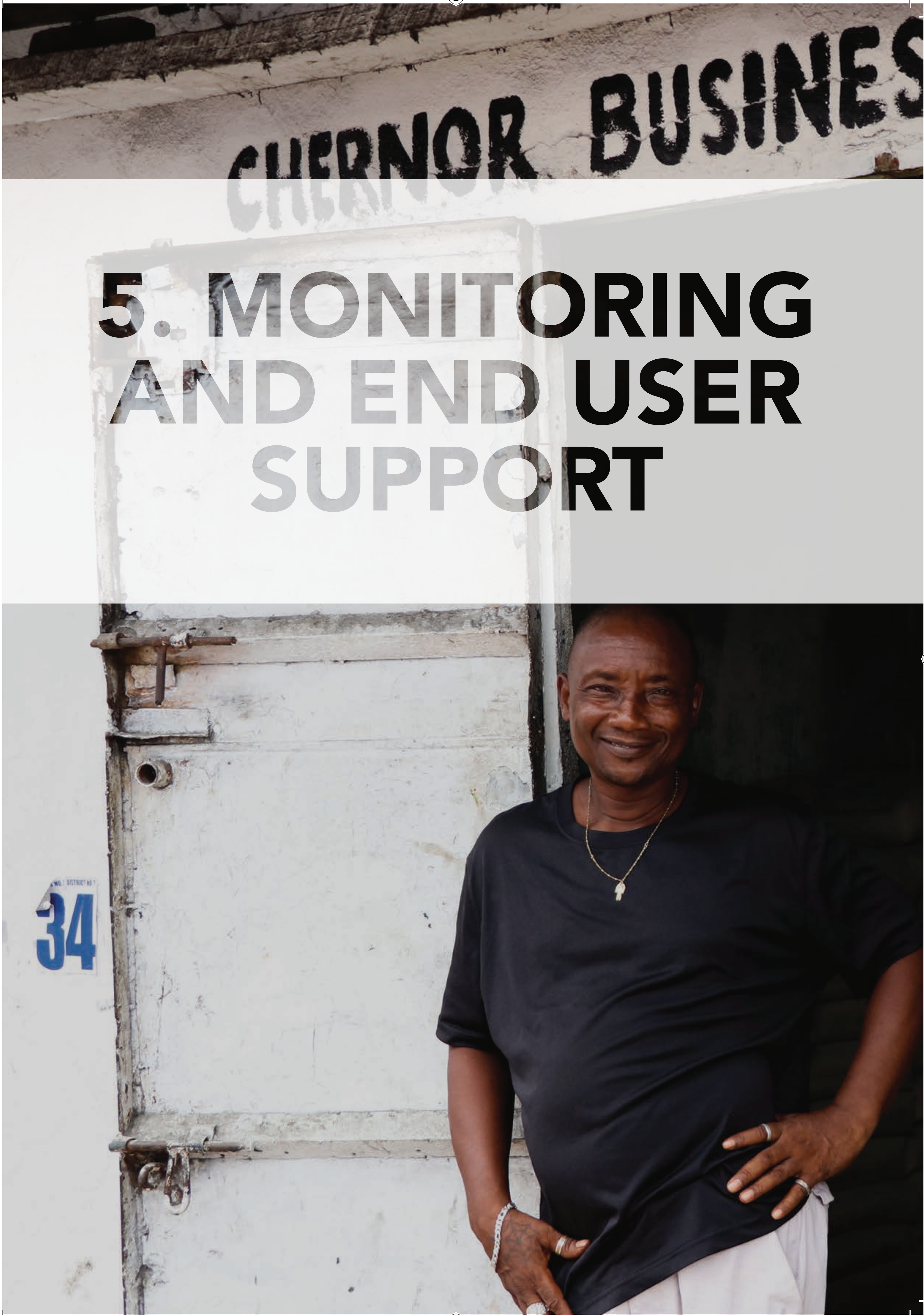
The following additional points also apply to the costs:

1. HomeBiogas provided the two larger units at no additional cost for this pilot test, but most likely will not provide the same discount on future orders.
2. HomeBiogas provided the toilet and also paid for the toilet enclosure at their cost.
3. HomeBiogas covered the cost of the 2nd representative to come to Monrovia.
4. Transportation costs for HomeBiogas personnel (other than to and from the airport) during the week they were in Monrovia are not included in the costs presented above and were covered by the Consultant.
5. Some additional costs were incurred by the Consultant to connect the water supply for the HomeBiogas toilet at Isaac A. Davies School. These costs are not reflected in the above summary.

Including the above items, the true costs incurred are closer to US $20,000 – the US $5,000 difference being absorbed by HomeBiogas and the Consultant.

As the maximum contribution from the Consultant has been exceeded, the cost of installing security fencing around the already installed units is being borne by Cities Alliance. Two units remain to be installed and a third unit needs to be replaced due to damage. The Consultant will provide the services of our Local Coordinator to provide guidance and advice to do these installations, but as stated earlier, the bulk of the work for these installations should be done by MCC/PCC counterpart staff so that they can build capacity for future additional installations. The cost of materials, labor, transportation, water, manure, etc. will need to be provided by Cities Alliance.

5. MONITORING AND END USER SUPPORT



The revised work plan includes a one-month period to monitor the operation of the units and to provide ongoing support to the recipients. Forms for monitoring were developed and approved by the Client. Copies of the forms are included in Appendix VII. Training on how to fill in the monitoring forms was provided to each recipient by the Consultant.

Monitoring commenced on 4 December. Due to the Christmas holidays, monitoring is planned to continue until 12 January 2020. Information from the monitoring phase will then be summarised and presented in a report, and monitoring will then be handed over to MCC/PCC. Results so far show that the units are being used, but that ongoing support is required.

WNL Local Coordinator providing training in how to fill in the monitoring forms

6. CONCLUSION

The project work plan was revised in early August 2019 to incorporate the Small-Scale Biogas Testing Phase as Phase III of the project. The revised work plan for Phase III includes 16 items as per Table 1 presented in the report. This report is submitted in fulfilment of deliverables #1-12 for Phase III of the project and serves as a payment milestone for the site selection, procurement, and installation of the HomeBiogas units, end user training, and a capacity building workshop, all of which have been successfully completed.

This report provides an update on the status of the project at the completion of the site selection and installation of the HomeBiogas units, including end user training and handover of the unit to the recipients; the capacity building workshop that took place on 1 November 2019; and plans for the upcoming monitoring and end user support activities. The report also describes constraints encountered in the site selection, procurement and installation process, commentary on lessons learned, and considerations for subsequent installations of additional units.

Site selection, procurement, and installation of the home biogas units has been accomplished according to the objectives of the work plan. Ten units have been procured and eight units installed to date. The exercise took a bit longer than anticipated, mainly due to the site selection process taking longer than expected, but overall, it has been successful with no major setbacks. The capacity building workshop exposed the topic of waste-to-energy and specifics of the project to a large and diverse audience and is viewed as a success, with many positive comments received.

The following provides commentary on the key activities and takeaways of the project testing phase to date:

- The HomeBiogas units have been successfully installed in eight locations. Ten (10) units were purchased, but there were challenges to find more locations that met the criteria for the project. This includes:
  - Finding recipients who were willing to participate in the project.
  - Finding locations that produce sufficient food waste to operate the units.
  - Finding locations that satisfy the physical conditions necessary for installation of the units, including a secure location within 20m of where the gas will be utilised, level ground, ability to utilise the effluent, etc.
- The units were installed from late October to mid-November.
- Activation of the units took place from mid-November to the first week of December, when the units were put into use.
- The HomeBiogas units work as claimed by the manufacturer and as hoped for by the project. Technically, the product is very good; it is designed and works well, the cost is reasonable, and the support offered by HomeBiogas is good. If additional units are to be installed, the Consultant recommends only considering products from HomeBiogas company.
- Training has been provided to all the recipients in the proper operation and maintenance of the units, and all recipients have signed off that they are prepared to accept the responsibilities of operation and maintenance of the units.
- Installation of the units was relatively straightforward due to having the manufacturer's representative on site and an experienced team from WNL coordinating the installations, with the necessary resources at their disposal.

- The cost of installation of the units was somewhat higher than anticipated mainly due to higher-than-expected costs for water and manure to activate the units, as well as for labor for the installations (due to low participation from counterpart staff). To activate the units, 100 liters of manure mixture is required for the smaller units (HomeBiogas 2.0) and 300 litres is required for the larger units (HomeBiogas 7.0). In an effort to speed up the activation process, two activations were done. Obtaining this volume of fresh manure was an unanticipated challenge, as there is limited supply and a relatively high demand for the manure, making it costly. This needs to be taken into consideration in planning for future installations.
- Installation of the units requires vehicles, tools, plumbing parts, labor, and coordination. It is also necessary that the installation team have a cash float to deal with unexpected situations and to purchase tools, materials, etc. as required for the installations under a fast turnaround.
- There is a high level of interest and enthusiasm about the units.
- Monitoring and end user support systems have been put in place by the Consultant, and this will continue until mid-January, when a report on lessons learned will be provided, followed by handover of the ongoing monitoring and support activities to MCC/PCC.
- So far, the exercise has been successful. However, there are concerns about having enough food waste at some of the sites and having waste that has enough energy content to generate a useful amount of biogas.
- Participation from MCC/PCC to date has been quite low. This impacted negatively on the site selection process by not having official representation and it increased the cost of the installations. Staff from MCC/PCC did not gain the capacity that was desired due to their low level of participation, and the Consultant has serious concerns about their interest and ability to take over the monitoring and support at the conclusion of the Consultant's contract. There are also concerns about their ability to take on future installations, as their knowledge and capabilities in waste treatment, engineering and general construction are very low. The Consultant highly recommends that the MCC/PCC counterpart staff be fully involved in the site selection and installation of the two remaining units, and the replacement of one unit that was damaged.

The revised project plan of August 2019 was that 10 of the HomeBiogas units would be procured, installed, and tested during Phase III of the Waste-to-Energy Feasibility Study, with the plan to rollout 100 units in 2020 if the initial installations were successful. Observations from this initial testing phase that need to be considered in planning the next stage of the overall project are as follows:

1. The technology works and the units produce useful amounts of biogas as expected. The HomeBiogas product is very good – it is relatively inexpensive, relatively easy to install, operate and maintain, and the company provides excellent after sales service. If additional units are being installed, the Consultant recommends dealing with HomeBiogas company on an exclusive basis.
2. It was a challenge to identify 10 suitable locations that met the criteria for the initial installations. Some of these were external and can be dealt with in the next project phase. The real issue is finding locations that have enough food waste (with sufficient energy content) that also satisfy the other criteria relating to usage of the gas, usage of the effluent, and physical site requirements. The Consultant believes that based on the experience of the initial testing, it will be very difficult to find 100 sites within Greater Monrovia that are suitable for

installation of the units. The Consultant recommends planning on a maximum of 20 additional sites for the next phase of the project. If proceeding on this basis, 20 units should be purchased in advance to reduce dropout from interested recipients due to long timeframes. Units can be installed in parallel with the site selection process. If possible, the units should be procured directly by Cities Alliance. A project promotional campaign also needs to be undertaken to raise awareness and increase the likelihood of finding 20 suitable sites. Additional sites could be done thereafter if the 20 sites can be concluded successfully.

3. The installation process was relatively straightforward and without any major constraints or issues. However, this was because it was done under somewhat "idealised" conditions of having the support of HomeBiogas and also taking advantage of the Consultant's prior experience in this type of work, business systems in place, and ability to provide for all resources and logistics throughout the process. Without the support and involvement of HomeBiogas and WNL, the installation process can be expected to be much more challenging to implement. Recommendations on this are given within the report. In any case, it will require significant additional inputs and oversight by Cities Alliance.

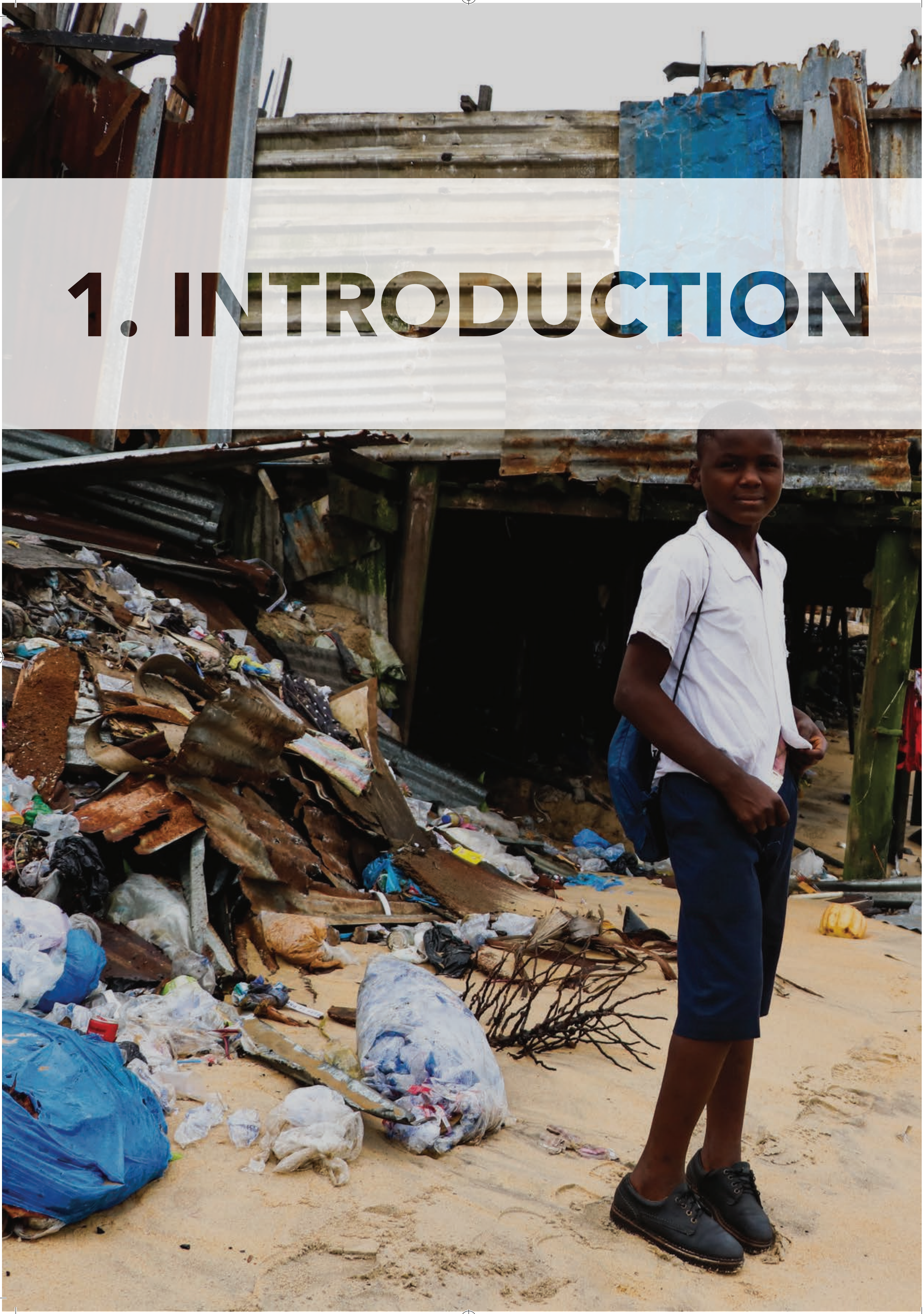
4. Costs and implementation schedules experienced in the initial stage were also under an "idealised" scenario and not reflective of the costs and timelines that will be incurred for future installations. Future planning needs to be based on realistic cost and schedule assumptions, depending on how Cities Alliance will choose to implement the project.

5. The involvement and level of interest/commitment to the project from MCC/PCC has been low to date. There was minimal active participation in the site selection and installation process, and as mentioned elsewhere in the report, MCC is supposed to select two additional sites for installation of the remaining units, and this still has not been concluded. Expected capacity gains to MCC/PCC from the project have not been achieved. There is also very limited capacity in other government organisations. The Consultant sees very large risks in proceeding with future installations if relying on MCC/PCC. The Consultant recommends that MCC/PCC take the leading role in identifying the last two sites, and in the installation of the last two units (plus the third replacement unit). The Consultant can offer guidance and knowledge transfer, but the work needs to be done by MCC/PCC to develop the capacity. It is also recommended that MCC/PCC staff who may be involved in future activities under the project be incentivised to participate through the provision of allowances or other salary supplements. It has been the Consultant's experience in many projects and different countries in Africa that this is necessary to get the required level of participation and interest from counterpart staff.

6. The above concerns the site selection, procurement, and installation of the units only. The monitoring phase of the project is currently underway and will be concluded shortly. Results of this activity will determine the level of usage of the HomeBiogas units from recipients, and any issues encountered by recipients in the ongoing operation and maintenance of the units. The information from the monitoring phase will be critical in determining the final recommendations for the next stage of the project.

HOME BIOGAS UNIT MONITORING AND LESSONS LEARNED

1. INTRODUCTION



Background

The Feasibility Study on Waste-to-Energy (W2E) Options in Monrovia, Paynesville, and Surrounding Townships in Liberia (W2E Feasibility Study) is a component of the EU-funded UNOPS Cities Alliance Programme. The project is one of numerous ongoing activities related to improving solid waste management in Monrovia, funded by various organisations and donors including Cities Alliance, EU, World Bank, and others. The Client for this project is the Cities Alliance Liberia Country Team.

The overall objective of the study is to identify small-scale, community-based W2E initiatives that can be piloted in the project area by Cities Alliance, with implementation to proceed as soon as possible after completion of the Feasibility Study Project.

WNL Development Solutions Ltd. (WNL) in association with Soft White 60 Corporation (SW60), hereinafter referred to as the Consultants, submitted a proposal to carry out the W2E Feasibility Study in November 2018. Negotiation meetings were held 7 December 2018 as well as on 5 and 7 February 2019, and WNL/SW60 subsequently entered into a Contract for the assignment with UNOPS on 12 February 2019. Project activities commenced mid-February 2019.

Scope of Work and Work Plan

The initial project scope and work plan included three phases as follows:

- Phase I: Project Inception and Inception Report
- Phase II: Feasibility Study
- Phase III: Detailed Design and Action Plan

In July and August 2019, subsequent to the findings of the Consultant's project study tour in Europe and Africa and after extensive consultations and consensus with project stakeholders, Phase III of the project was changed to comprise the installation and testing of up to 10 micro-scale biogas units (HomeBiogas units) in various locations in Greater Monrovia. As such, Phase III of the project became the **Small-Scale Biogas Testing Phase.**

A revised project work plan to incorporate the Small-Scale Biogas Testing Phase into the project was submitted to the Client on 2 August 2019, with a project completion date of 31 December 2019, and was approved through Contract Amendment #2, signed on 6 August 2019.

For various reasons, primarily related to complications of completing the site selection process and installing and activating the HomeBiogas units in the field, the schedule slipped by approximately one month. The project completion date was extended to 31 January 2020 through Contract Amendment #3, approved on 9 December 2019. The final project deliverable schedule as per Contract Amendment #3 is as follows:

No.	Milestone	Target date
1	Project Kick-off Meeting	5 March 2019

No.	Milestone	Target date
2	Inception Report	20 March 2019
3	Feasibility Study Report	31 August 2019
4	Installation of ten (10) Units of Home Biogas, Workshop, End User Training and Submission of Installation Report	13 December 2019
5	Handover of Monitoring and Project Documentation, Final Report	15 January 2020
	CONTRACT END DATE	**31 January 2020**

Milestones 1 – 4 have been completed, with the procurement, installation, commissioning, training, and handover of the home biogas units to recipients taking place from mid-October to 8 December 2019. Details of the installation of the home biogas units are included in the Home Biogas Unit Installation and End User Training Report, previously submitted to the Client.

Report Content

This report is the **Home Biogas Monitoring and Lessons Learned** and is in fulfillment of project Milestone #5. The report is the final deliverable of Phase III of the project.

The intent of the report is to provide information on the following concerning the Small-Scale Biogas Testing Phase of the project (HomeBiogas unit installations):

- Review of installation and handover process
- Monitoring activities carried out by the Consultant in December 2019 and January 2020
- Weekly progress updates and lessons learned
- Actual costs incurred for installation of the units
- Lessons learned from the installation and monitoring phase of the HomeBiogas units and recommendations for future installations and monitoring for the pilot project rollout
- Conclusions and recommendations for pilot project

The intent is that the information of this report can be used by the Client to plan the subsequent implementation stage of the pilot project. This report also serves as the final deliverable by the Consultant on the contract for the Feasibility Study on Waste-to-Energy Options in Monrovia, Paynesville, and Surrounding Townships in Liberia. Upon finalisation and acceptance of this report, the Consultant will hand over any documentation or other items in the Consultant's possession to the Client and submit the final invoice for the project to formally end the services under the contract.

2. REVIEW OF INSTALLATION AND HANDOVER

As described in the previously issued "Home Biogas Unit Installation and End User Training Report," the units were installed from 28 October to 6 November 2019. The installations were done by WNL/SW60 with assistance from HomeBiogas, who had two personnel on site from 27 October to 3 November 2019 to provide guidance and training in the installation, commissioning, operation, and maintenance of the systems.

Starting with a list of nine confirmed sites (which was intended to be eight smaller units plus one larger unit – equivalent to a total of 10 smaller units total as originally planned), two were dropped during the installation process due to the inability to find a suitable location for the units on these sites, and one new site was added for a total of eight installations. The locations and the size of units installed are as shown in the table below. For the size of the unit, the following applies:

- Small: HomeBiogas 2.0 unit, single burner, capacity 2 kg waste/day
- Large: HomeBiogas 7.0 unit, double burner, capacity 6 kg waste/day

Summary of HomeBiogas Units Installed

S/No.	Name/Location	Jurisdiction*	Type of Facility	Size of Unit
1	Aware International School	PCC	School	small
2	Isaac A. Davies School	PCC	School	small
3	WVS Tubman High School	MCC	School	small
4	John Lewis Methodist School	PCC	School	small
5	Mother Pattern College	MCC	School	small
6	RLJ Kenedja Resort	PCC	Hotel/Restaurant	large
7	Corina Hotel	MCC	Hotel/Restaurant	large
8	Tropicana Resort	PCC	Hotel/Restaurant	small
PENDING				
9	Bella Casa Hotel	MCC	Hotel/Restaurant	small
10	GSA Complex	MCC	Government office	small

**MCC = Monrovia City Council, PCC = Paynesville City Council*

It is noted that five of the installed sites are schools while three are hotels, with five in PCC and three in MCC. The cost of the procurement and installation of the units, as well as bringing HomeBiogas personnel to Liberia for assistance with the installations, was donated to the project by WNL/SW60 as agreed in the revised work plan of August 2019.

Ten HomeBiogas units were procured, so there are two units that remain to be installed. These are indicated as PENDING in the table above. It is intended that these units be installed at Bella Casa Hotel and the GSA Department of the Government. Additional information regarding these last two installations is given in the latter sections of this report. If the two additional units are installed, there will be five in MCC and five in PCC.

Additionally, at Isaac A. Davies School, a HomeBiogas toilet unit was installed. HomeBiogas donated the toilet to the project and paid for a small building to be constructed to house the toilet and a sink. WNL also donated the cost of connecting the water supply piping to the toilet building.

The installation process included activating the units with fresh manure, and then a second activation, as recommended by HomeBiogas to speed up the activation process, was completed from 8 to 13 November. Following the second activation, the units were tested for gas production and the ability to produce flames from the burners, and this was completed for all eight units on 26 November. Some of the units were producing a lower level of gas, so it was decided to give the activation another few days.

Starting from 2 December, the units were put into operation. Plastic buckets of the appropriate size were provided to the recipients and feeding of the units with food waste commenced. Field training for end users was also provided at this time. The field training was through hands-on demonstrations and discussions with the users to show them how to feed the units, the type of food waste that could and could not be used, operation of the gas valves, operation of the cooker, effluent removal, and maintenance requirements. Some sites were visited on multiple locations to carry out this field training.

After the field training, final training was provided, and the units were then officially handed over to the recipients. The final training consisted of a review of the field training and providing hard copies of the HomeBiogas unit Owner's Manuals. The owner's manual was reviewed to ensure that all recipients fully understood the operation and maintenance requirements of the units and were familiar with the contents. At most sites, multiple personnel were trained.

The units were then formally handed over to the recipients who were requested to sign the "HomeBiogas System Installation Attestation Form" that was specifically prepared for this purpose and clearly outlined the responsibilities of the recipient with respect to the units after the handover. The form and the responsibilities of the recipient were reviewed prior to signing. The formal handover of the units took place from 2 to 8 December 2019. The forms were then signed by Cities Alliance on 10 December 2019. Copies of the forms signed by the recipients, the Consultant and Cities Alliance were delivered to the recipients. Copies of the forms are included in the Appendices of the "HomeBiogas Units Installation and End User Training Report."

Security fencing around the units was installed by Cities Alliance from 23 December to mid-January. This was considered essential, as some of the units had already been tampered with. The cost of the fencing was covered by Cities Alliance due to the allocated procurement and installation budget of US $15,000 provided by WNL being fully utilised on the installation of the eight units. The cost of the installations was higher than expected primarily due to higher costs for water and manure required for the activation process.

As part of the installation process, a capacity building workshop was also held on 1 November 2019 at the Corina Hotel. Presentations were given by WNL and HomeBiogas providing a general overview of waste-to-energy topics, anaerobic digestion, and the work carried out on the project, as well as details on the HomeBiogas units and products. The workshop was very well attended by a wide group of stakeholders from government, NGOs, the private sector, and all recipients. The workshop was well received and was believed to have achieved its goals of transfer of knowledge and capacity building on waste-to-energy topics to the stakeholder audience.

An official project launch event was held at Isaac A. Davies school on 5 December and was viewed as very successful.

Please refer to the "HomeBiogas Units Installation and End User Training Report" for additional information concerning the procurement, installation, training, and handover of the units. Constraints encountered in the site selection, procurement, and installation process as well as commentary on lessons learned and considerations for subsequent installations of additional units is provided within the Installation and End User Training Report. Information from that report is also repeated in the latter sections of this report.

A few photos of the installed units are shown below.

HomeBiogas 7.0 (larger unit) installed at RLJ Kenedja Resort

HomeBiogas unit and toilet facility prepared for the launch event at Isaac A. Davies School

Testing of one of the double burner units for presence of flames

Field training on feeding of the units

Signing the Attestation Forms for handover

Example of fencing installed around the unit

3. MONITORING ACTIVITIES

3.1 Planned handover and monitoring schedule

The final revised work plan approved in August 2019 included a one-month period after the official handover of the HomeBiogas units to the recipients, to monitor the operation of the units and provide ongoing support to the recipients. Forms for monitoring were developed and approved by the Client, and training on how to fill in the monitoring forms was provided to each recipient by the Consultant.

Homebiogas Unit Handover and Monitoring Schedule - Planned

H official handover and they need to start feeding the units
M monitoring visit

Date	Day	Remarks	PCC		
			Aware International School	RLJ Kenedja Hotel	
2-Dec-19	Mon		H		
3-Dec-19	Tues	all units handed over by Tues Dec 3		H	
4-Dec-19	Wed		M	M	
5-Dec-19	Thur	official launch at Isaac A. Davies School. All sites handed over and one monitoring visit by Thurs			
6-Dec-19	Fri		M		
7-Dec-19	Sat	weekend - schools closed		M	
8-Dec-19	Sun	weekend - schools closed			
9-Dec-19	Mon		M		
10-Dec-19	Tues			M	
11-Dec-19	Wed				
12-Dec-19	Thur		M		
13-Dec-19	Fri			M	
14-Dec-19	Sat	weekend - schools closed			
15-Dec-19	Sun	weekend - schools closed		M	
16-Dec-19	Mon		M		

A proposed handover and monitoring schedule were submitted to the Client at the end of November. This schedule showed handover of all units by 3 December, with a total of 13 monitoring visits at each site, to ensure that each site was visited every few days. The monitoring period was originally intended to be one month according to the revised work plan, but it had to be extended due to the monitoring occurring over the December Christmas break period, and as such became approximately 5 ½ weeks from 4 December to 11 January.

The planned Handover and Monitoring Schedule is shown below.

			MCC			
	Isaac A. Davies School	**Tropicana Hotel**	**Corina Hotel**	**WVS Tubman High School**	**John Lewis Methodist School**	**Mother Pattern College**
	H			H	H	
		H	H			H
	M	M	M	M	M	
	M					M
				M	M	M
		M	M			
	M			M	M	M
		M	M			
	M			M	M	M
		M	M			
		M	M			
	M			M	M	M

Date	Day	Remarks	PCC	
			Aware International School	RLJ Kenedja Hotel
17-Dec-19	Tues			
18-Dec-19	Wed			M
19-Dec-19	Thur		M	
20-Dec-19	Fri			
21-Dec-19	Sat	weekend - schools closed		M
22-Dec-19	Sun	weekend - schools closed		
23-Dec-19	Mon		M	
24-Dec-19	Tues	**Christmas Break - no activities**		
25-Dec-19	Wed	**Christmas Break - no activities**		
26-Dec-19	Thur	**Christmas Break - no activities**		
27-Dec-19	Fri	schools probably closed	M	
28-Dec-19	Sat	weekend - schools closed		M
29-Dec-19	Sun	weekend - schools closed		
30-Dec-19	Mon	schools probably closed	M	
31-Dec-19	Tues	schools probably closed	M	M
1-Jan-20	Wed	**New Years Day - no activities**		
2-Jan-20	Thur	schools probably closed	M	
3-Jan-20	Fri	schools probably closed		
4-Jan-20	Sat	weekend - schools closed		M
5-Jan-20	Sun	weekend - schools closed		
6-Jan-20	Mon		M	
7-Jan-20	Tues			M
8-Jan-20	Wed		M	

			MCC			
	Isaac A. Davies School	Tropicana Hotel	Corina Hotel	WVS Tubman High School	John Lewis Methodist School	Mother Pattern College
		M	M			
	M			M	M	M
		M	M			
	M			M	M	M
	M			M	M	M
		M	M			
	M			M	M	M
		M	M			
	M			M	M	M
		M	M			
	M			M	M	M
		M	M			
	M			M	M	M

Date	Day	Remarks	PCC		
			Aware International School	RLJ Kenedja Hotel	
9-Jan-20	Thur			M	
10-Jan-20	Fri		M		
11-Jan-20	Sat	weekend - schools closed		M	
12-Jan-20	Sun	weekend - schools closed			
13-Jan-20	Mon				
14-Jan-20	Tues				
15-Jan-20	Wed				
	Thur				
	Fri				
Total Number of Monitoring Visits			13	13	

	MCC					
	Isaac A. Davies School	**Tropicana Hotel**	**Corina Hotel**	**WVS Tubman High School**	**John Lewis Methodist School**	**Mother Pattern College**
		M	M			
	M			M	M	M
		M	M			
	13	13	13	13	13	13

3.2 Actual schedule

The actual schedule for handover and monitoring was generally in accordance with the planned schedule, but ran longer than planned for the following reasons:

1. Handover of the units to the recipients was planned for completion by 3 December. This task took longer than anticipated due to necessity to confirm availability of recipients for training and filling in of paperwork, and also due to assisting with preparations for the official project launch at Isaac A. Davies School on 5 December. Handover therefore occurred from 2-8 December, with the HomeBiogas System Installation Attestation Forms signed by Cities Alliance on 10 December 2019. The final training and handover process are described more thoroughly in the previously submitted "HomeBiogas Unit Installation and End User Training Report" and the signed forms are included in the Appendices of that report.
2. Monitoring commenced one day early, on 3 December, and was extended one extra week to 20 January 2020.
3. During the monitoring period, due to schools being closed over Christmas, it was necessary for the Consultant to feed the units with food waste brought from elsewhere. This was

Homebiogas Unit Handover and Monitoring Schedule - Actual

H official handover and they need to start feeding the units
M monitoring visit

Date	Day	Remarks	PCC		
			Aware International School	RLJ Kenedja Hotel	
2-Dec-19	Mon			H	
3-Dec-19	Tues	all units handed over by Tues Dec 3		M	
4-Dec-19	Wed				
5-Dec-19	Thur	official launch at Isaac A. Davies School. All sites handed over and one monitoring visit by Thurs			
6-Dec-19	Fri			M	
7-Dec-19	Sat	weekend - schools closed			
8-Dec-19	Sun	weekend - schools closed			
9-Dec-19	Mon		H		
10-Dec-19	Tues		M	M	
11-Dec-19	Wed				

considered essential to keep the anaerobic digestion (AD) process going and avoid having to reactivate the units with manure if the AD process stopped due to lack of feedstock.

4. The number of visits at the various sites ranged from 12 to 17 compared to the planned 13 visits at each site.
5. From approximately mid-December to mid-January, the Consultant also provided some inspections and oversight on the security fencing installations that were arranged by Cities Alliance.
6. At RLJ Kenedja Hotel, as a result of an accident while doing the fencing work, the HomeBiogas 7.0 unit was punctured by a pipe that fell on the unit, necessitating taking the unit out of service. HomeBiogas company graciously agreed to provide a replacement unit under warranty, and the unit was shipped to Liberia in early January. The replacement unit has not been installed yet, and the Consultant has recommended that this be done by the MCC/PCC counterpart staff under the guidance of the Consultant, to acquire better hands-on experience with respect to installation, training and operation of the units – a necessity for them to take on the responsibility of ongoing project monitoring.

The actual handover and monitoring schedule are shown in the next table.

			MCC			
	Isaac A. Davies School	**Tropicana Hotel**	**Corina Hotel**	**WVS Tubman High School**	**John Lewis Methodist School**	**Mother Pattern College**
	H	H				
	M	M				
						H
	M	M			H	
			H			
			M	H	M	M
	M	M				
			M	M	M	M

Date	Day	Remarks	PCC		
			Aware International School	RLJ Kenedja Hotel	
12-Dec-19	Thur		M	M	
13-Dec-19	Fri				
14-Dec-19	Sat	weekend - schools closed	M	M	
15-Dec-19	Sun	weekend - schools closed			
16-Dec-19	Mon		M	M	
17-Dec-19	Tues				
18-Dec-19	Wed		M	M	
19-Dec-19	Thur				
20-Dec-19	Fri		M	M	
21-Dec-19	Sat	weekend - schools closed			
22-Dec-19	Sun	weekend - schools closed			
23-Dec-19	Mon		M	M	
24-Dec-19	Tues	**Christmas Break - no activities**			
25-Dec-19	Wed	**Christmas Break - no activities**			
26-Dec-19	Thur	**Christmas Break - no activities**			
27-Dec-19	Fri	schools probably closed	M	M	
28-Dec-19	Sat	weekend - schools closed			
29-Dec-19	Sun	weekend - schools closed			
30-Dec-19	Mon	schools probably closed	M	M	
31-Dec-19	Tues	schools probably closed	Equipment Damaged		
1-Jan-20	Wed	**New Years Day - no activities**			
2-Jan-20	Thur	schools probably closed			
3-Jan-20	Fri	schools probably closed	M		

			MCC			
	Isaac A. Davies School	**Tropicana Hotel**	**Corina Hotel**	**WVS Tubman High School**	**John Lewis Methodist School**	**Mother Pattern College**
	M	M				
			M	M	M	M
		M				
	M	M	M	M	M	M
	M	M				
			M	M	M	M
		M				
	M		M	M		M
	M	M				
			M	M		
	M				M	M
			M	M		
	M		M	M		

Date	Day	Remarks	PCC		
			Aware International School	RLJ Kenedja Hotel	
4-Jan-20	Sat	weekend - schools closed			
5-Jan-20	Sun	weekend - schools closed			
6-Jan-20	Mon		M		
7-Jan-20	Tues				
8-Jan-20	Wed		M		
9-Jan-20	Thur				
10-Jan-20	Fri		M		
11-Jan-20	Sat	weekend - schools closed			
12-Jan-20	Sun	weekend - schools closed			
13-Jan-20	Mon		M		
14-Jan-20	Tues				
15-Jan-20	Wed		M		
16-Jan-20	Thur				
17-Jan-20	Fri		M		
18-Jan-20	Sat				
19-Jan-20	Sun				
20-Jan-20	Mon		M		
Total Number of Monitoring Visits			17	11	

			MCC			
	Isaac A. Davies School	Tropicana Hotel	Corina Hotel	WVS Tubman High School	John Lewis Methodist School	Mother Pattern College
		M				
	M	M				
	M		M	M	M	
						M
						M
	M	M	M	M	M	
	M	M	M		M	M
				M		
	M	M	M	M	M	M
			M			
	M	M		M	M	
	M	M	M	M	M	M
	17	16	15	14	12	12

It should be noted that the workload of the WNL Local Coordinator during the monitoring period was much higher and longer than originally anticipated. The monitoring period was initially planned as a one-month period, with support from MCC/PCC counterpart staff, but was extended to almost six weeks to account for the Christmas break and additional tasks that the Project Coordinator had to take on during this period as follows:

- There was no support from MCC/PCC counterpart staff during the period despite several efforts by the Consultant to involve them in the process, resulting in the local coordinator needing to take on all the monitoring activities on his own.
- With people on holidays before and after the Christmas period, it was difficult to meet with recipient staff to review the operation of the units.
- The local coordinator had to feed the units at the schools over this period to keep the units operational, including sourcing of waste. This took a considerable amount of time that was not originally planned for.
- The local coordinator was requested to provide inspections and oversight of the fencing work being implemented by Cities Alliance, commencing from 23 December to mid-January.
- The HomeBiogas unit at RLJ Kenedja was damaged as a result of the fencing installation work, requiring considerable input from the local coordinator to assess the damage, review possible solutions with HomeBiogas, and collect the replacement unit from customs, etc. It should be noted that the support provided by HomeBiogas during this incident was excellent, and they agreed to provide a replacement unit at no cost and dealt with the situation very promptly.
- The local coordinator was requested to attend meetings with MCC and potential recipients and provide support and information to them concerning the selection of the sites for the two additional units remaining to be installed. This was despite repeated efforts for MCC to deal with this issue in November and December.
- The number of monitoring visits was higher than planned with an average of 14 visits per site, representing eight additional visits from what was originally planned

These additional activities reduced the ability to focus on ensuring that monitoring forms were being correctly filled in so that accurate data was being gathered. Nonetheless, the monitoring activities were successfully concluded on 20 January 2020, and the information and observations of the monitoring period have been used to prepare this report. One of the lessons learned regarding monitoring on subsequent installations is that a longer period should be planned to account for unknowns and additional activities that may also need to take place during the monitoring period. As well, all site selection and site installation activities need to be concluded prior to the monitoring stage.

3.3 Monitoring forms

Monitoring forms were provided to all recipients with the intent that these forms be filled out on a daily basis to record:

- Volumes and times of food waste addition to the units
- Utilisation of the units for cooking
- Utilisation of the effluent from the units
- Problems experienced in the operation of the units

Training was provided to the recipients on how to fill in the forms as part of the handover exercise. The completed monitoring forms are included in Appendix I.

3.3.1 OBSERVATIONS AND LESSONS LEARNED

Responses to filling in the forms were less than desired or anticipated, despite the Consultant providing training to all recipients on how to fill in the forms and stressing the importance of completing the forms during the training and subsequent visits to enable us to do proper monitoring of the systems. Some observations include:

- The monitoring form from Aware International School could not be retrieved. It is apparently locked in the principal's office, and he has travelled out of the country.
- Data is entered inconsistently on most forms and much data is missing.
- Some sites recorded data for December, while others recorded data mainly for January after being prompted to use the forms.
- Most recorded cooking usage but not all.
- None recorded usage of effluent.

Due to the inaccuracy of the records, this data cannot be relied upon to establish any quantitative values (to any degree of confidence) for total monthly amount or average daily amount of waste loaded in units or hours of use. It was hoped that these values could be established from the monitoring forms to give an idea of the amount of waste diverted from landfills, amount of gas generation and utilisation, and greenhouse gas offsets.

However, the following insights can be derived from the monitoring forms (and supported through verbal discussions with the recipients):

- It appears that the units are being well used, and waste is being added every 1 – 3 days.
- It appears that waste is generally being added according to the instructions provided, using the waste buckets provided, and mixing the waste with water as intended. Some locations may be adding more waste than intended, but this does not appear to be a problem. Given the warm climate in Liberia, particularly at this time of year, the rate of anaerobic digestion will be very high, enabling larger volumes of waste to be decomposed.
- Cooking utilisation is in the range of 30 minutes to 4 hours per day, although there are a lot of discrepancies in the data.

The lesson learned is that the monitoring forms may be too complex for the level of literacy of the personnel involved in the operation of the units. As well, some of the units are operated by multiple people, so no single person may want to take responsibility for filling in the form. And people may have simply been too busy with their regular responsibilities to bother with filling in the forms. To have these forms filled in correctly by all recipients would have required a lot of dedicated oversight by the local coordinator, who – with many other tasks required during the monitoring period – was not able to provide the level of support required in this regard.

For subsequent installations, a more simplified form should be developed.

3.4 Recipient interviews

Given that the response to filling in the Monitoring Forms was less than desirable, with inconsistent information that makes it difficult to form opinions on the success or otherwise of the installations, the Consultant determined that recipient Interviews should be carried out in an attempt to get more useful information as the basis for recommendations going forward. This was not originally planned but was considered essential. The approach was discussed and agreed with Cities Alliance. A standardised questionnaire was developed, consisting of 26 questions, and one-on-one interviews were held with the recipients from 27 to 29 January 2020. All recipients were interviewed except for RLJ Kendeja Resort, as it was believed that an interview with them would not yield useful information given that their unit was damaged and had to be taken out of service at the end of December. However, it is known from the monitoring activities that they were using the unit regularly up until when it was damaged, and they had the same concern as others with respect to the small size of the burner.

In total, seven interviews were conducted, and the completed interview forms are included in Appendix II.

The results of the interviews were very **useful, interesting, and valuable,** and results were **very consistent** across the board. Results of the recipient interviews are as follows:

1. The HomeBiogas units ARE being used. Three of seven use the unit regularly, while four use it sometimes. None responded that they are not using the unit.
    - The key observation concerning usage is that the burner is too small for the size of pots that are normally used for cooking at the recipient facilities. Because of this, the usage is not as high as it otherwise could be. Five out of seven recipients indicated that they would use the unit more if it had a larger burner so that they could use their larger pots. Two recipients indicated they would prefer (and likely use more) a double burner as opposed to a single burner (note that six out of eight recipients receive the smaller HomeBiogas units that have a relatively small single burner). Two recipients indicated that the burner is slow and it takes time to cook with the unit.
    - This observation makes sense. The HomeBiogas units are designed for residential use, but due to low waste volumes in Monrovia, the units needed to be located at commercial and institutional settings, where higher volumes of cooking are undertaken compared to a residential setting.

2. There does not appear to be any issue with odor/smell from the unit. There were no recipients indicating they are not using the unit due to bad odors. Only one recipient indicated any presence of odor/smell but this is believed to be due to leaving the gas valve open.
3. The units are used for cooking throughout the day, but mainly in the morning. This is likely due to most units being located in schools, where they would cook in the morning to prepare lunch. Most use the unit for 1 hour or more at a time.
4. The units are being used for all kinds of cooking, including boiling water, soups, and all cooking such as rice, eggs, oats, etc.
5. The total usage per day is 1 hour or more. Four recipients indicated 1 hour of use, two use it 1-2 hours, and one for 2-3 hours.
6. When asked if the unit would be used more if it produced more gas, six of seven recipients indicated yes. The answer to this question was also consistent with other answers that they would use it more if they could use bigger pots or if they had a double burner.
7. Most recipients are feeding the unit one time per day, but some feed two times per day or every second day. Food waste is fairly consistent, comprising rice, meat, beans, vegetables and greens, eggs, leftover soup, and stew, etc. Units are fed with waste morning, afternoon, and evening, depending on circumstances.
8. All recipients are mixing the food waste with water as intended and all are using the bucket provided to them for this purpose. One bucket of waste is used for each feeding of the unit.
9. When asked how much food waste per day, most recipients indicated two. This question was intended to mean the amount of waste loaded in the unit per day, but judging from the answers given, may have been misinterpreted as the total amount of waste produced at the site per day. Two recipients indicated they produce up to three buckets a day of food waste.
10. All recipients indicated that the food waste comes from on-site operations, except for Isaac A. Davies School, which obtains waste both onsite and offsite. This was already known for this school that they would need to supplement their waste from outside.
11. All recipients indicated that it was EASY to collect and load the food waste.
12. Regarding problems with the unit, five recipients had NO problems, and two had MINOR PROBLEMS that were quickly resolved by the Consultant.
13. When recipients were asked how they would describe the HomeBiogas unit overall, the response was overwhelmingly positive. None indicated they did not like it. Comments received are summarised below:

Location	Comment
Aware International School	Working perfectly well
Corina Hotel	Very efficient even though we are not frequently using it because of the size of the burner. Will continue to use it for small meal preparation, but will recommend a bigger burner

Location	Comment
Isaac A. Davies School	The HomeBiogas unit is OK, but I think a little improvement on the burner to accommodate big pots will make it much (more) useful
John Lewis United Methodist School	Find it very efficient, useful
Mother Pattern College	The system is working well for us but we would prefer a double burner
Tropicana Resort	Fantastic but I would prefer a double burner and a bigger unit
WVS Tubman High School	Like the unit but will prefer a little modification on the burner (larger)

14. When asked if they will continue to use the HomeBiogas unit, all recipients indicated YES.
15. When asked if they would recommend a HomeBiogas unit to others all recipients answered YES.
16. When asked if government or donors should provide more HomeBiogas units, all recipients answered YES. Some useful comments in this regard included:
    - *Government/donors should provide more of these units to home and businesses to reduce the usage of charcoal and help reduce the huge stockpile of garbage collected daily.*
    - *The donor should distribute more of these units to homes and provide the education to use it.*
    - *Yes, it will reduce the cutting of trees for burning charcoal.*
    - *Donor and government should invest more into such technologies and carry out more awareness.*
17. When recipients were asked if they would pay the full cost of a unit (US $1,000), three indicated YES and four indicated NO. Comments to go along with this were as follows:
    - *As an individual I would not mind paying up to US $500 considering the value.*
    - *The cost will be too high considering the type of business (cafeteria).*
    - *I would pay around US $500 if I could get a double burner.*
    - *I would not mind US $500 or US $600, but US $1,000 for a single burner plus the unit is expensive.*
18. When asked if recipients should receive the units for free or pay a token amount, the responses were that a token amount should be paid. None indicated that the units should be given for free. Out of six responses received, five indicated that recipients should pay US $200-US $300 and one indicated US $50-US $100. Comments included:
    - *Recipient should pay a little fee in order to add more value to the unit instead of having it for free.*

- *Should not be free but should be affordable.*
- *Recipient should pay a little amount as an appreciation.*
- *People should pay in order to value it and use it more.*

Comments mentioned in item 17 above are also related to this. It should be kept in mind that the recipients now have the units, like them, use them, and see a value to them. Their indicated willingness to pay might be different if they had not yet received the units.

19. When asked about climate change responses were as follows:
    - *All recipients knew what climate change was.*
    - *All recipients thought that the weather was changing.*
    - *All recipients indicated that they were very concerned about climate change.*
20. When recipients were asked if they know what greenhouse gases are, three indicated NO and four indicated YES.
21. When recipients were asked if they thought that burning wood or charcoal contributes to climate change, all answered YES.
22. When asked if they thought converting food waste to energy was a good idea, all recipients answered YES.
23. When asked if they thought the HomeBiogas units would reduce climate change, all that answered the question said YES. Verbal comments received included:
    - *It will help reduce the burning of trees and usage of charcoal if they are affordable.*
    - *The HomeBiogas unit will reduce climate change by stopping the cutting of trees for burning of charcoal and also stop garbage pollution (burning garbage).*
    - *Will help to reduce climate change if more people start to understand the value and start utilising it.*

At the conclusion of the in-person interviews, it was realised that the interview forms had missed a few questions of interest regarding the units, and so the following additional inquiries were made via telephone:

1. Are they using the effluent and if so, what are they doing with it? Do they find the fertiliser to be good? Responses were very encouraging, as follows:
    a. *Tropicana Resort: Yes, they are using the effluent on their flowers and other plants around the resort. I was told that the fertiliser has been very useful to the growth of their plants. Some of staff have taken the fertiliser home.*
    b. *RLJ Hotel: The effluent was also used as fertiliser for their flower garden and the results were fantastic.*
    c. *Corina Hotel: Due to the absence of plant or flower garden staff collect the effluent in container and take it home for use on their small garden. I was told that is has been very helpful to the fast growth.*
    d. *Aware International School: The effluent is used as fertiliser on their flowers, and the administrator takes some of the fertiliser home for use on his personal garden. According the administrator, the result has been so amazing.*

e. *John Lewis Methodist: There is no garden or plants on campus, the recipient takes the effluent home for use on her personal garden. According to her, the results are good.*

f. *Tubman High School: The effluent is used on a small vegetable garden and some are taken home by the recipient for use on her personal garden. Good results as well.*

g. *Mother Pattern College: The effluent is used for flower garden and the result has been very good according to the recipient.*

Note: At Isaac A. Davies school, where the HomeBiogas toilet was provided, the effluent cannot be used as fertiliser due to the possibility of pathogens in the effluent. This is unfortunate as the school has a very large vegetable garden where they grow produce that is used by the school and would like to use the fertiliser for their garden. On future initiatives, it is not recommended to utilise a toilet as it complicates and increases the cost of the installation and prevents use of the effluent as a fertiliser.

2. For schools, are they involving the students in waste collection and feeding of the units, and are they teaching the students about climate change/renewable energy/waste management issues as a result of having the HomeBiogas units on site?

   At Isaac Davies, Aware International, John Lewis and Tubman High, the students are partially involved with the waste collection and feeding. The units are operated mainly by the kitchen or cafeteria staff. The unit at Mother Pattern is being run and fed by the Catholic nuns and administrative staff.

   All the schools run a science programme as part of their curriculum that teaches about the cause and effect of climate change, and how renewable energy is an alternative to reduced global warming. Isaac Davies and Tubman High run an environmental campus-based programme that teaches about climate change and renewable energy. The students use the Home Biogas units as demonstration for their programme.

3. For the hotels, are their staff learning about climate change/waste to energy/waste management issues?

   WNL Local Coordinator: With reference to my recent interviews and past engagement with the recipients, I can confirm that most of the recipients along with their colleagues/staff are fully aware of climate change and are very concerned about what we can do to raise awareness to tackle some of the issues associated with it. The introduction of technology like the HomeBiogas unit has provided them with knowledge of how climate change can be minimised using some simple techniques.

The information collected from the interviews is very encouraging for subsequent stages of the project.

Key takeaways from the recipient interviews are as follows:

a. The technology works well and the HomeBiogas units perform as per the manufacturer’s claims.

b. Recipients like the units and use them for all kinds of cooking, but the usage is being limited by the small size of the burner and in some cases the small size of the units. If larger units with double burners were provided and/ or burners that can accommodate larger pots, the level of usage would be higher.

c. Recipients appear to have enough waste, and in the case of the larger hotels, more than enough. Collecting the waste and loading the units is not an issue.

d. Very few problems have been experienced with the units.

e. Recipients will continue to use the units, but again stressed the issue of the size of the burners.

f. Recipients are using the effluent as fertiliser and are very pleased with it.

g. Recipients are familiar with climate change and are very concerned about it, and believe that converting waste to energy with a HomeBiogas unit is good for the environment, will reduce cutting of trees and burning of charcoal, and will reduce greenhouse gases and climate change.

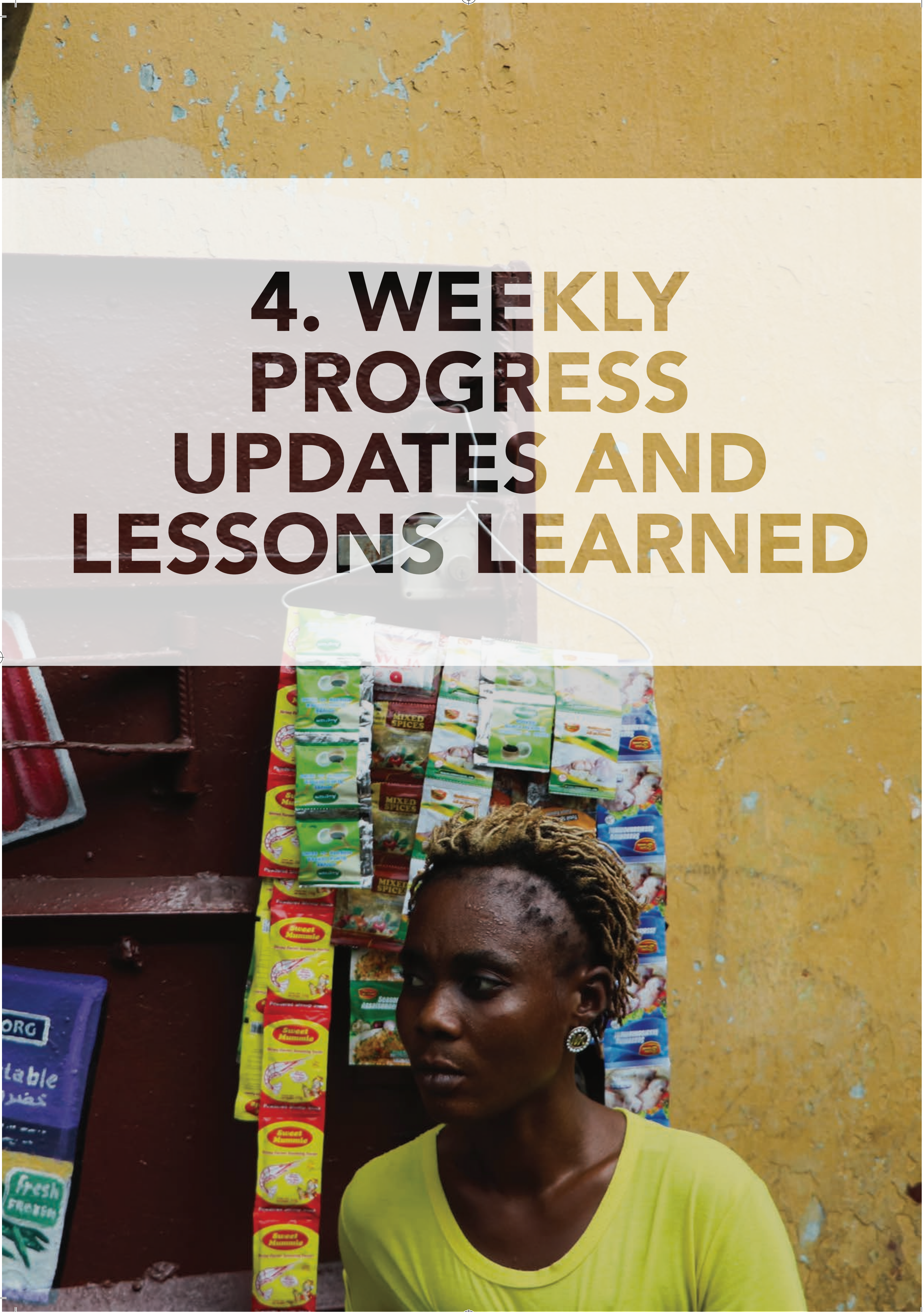
h. Schools are using the HomeBiogas units for teaching about climate change, global warming, renewable energy topics.

i. Recipients would recommend the HomeBiogas units to others.

j. Recipients recommend that donors and government provide more HomeBiogas units along with raising awareness, but should provide larger units and charge a token fee for the units.

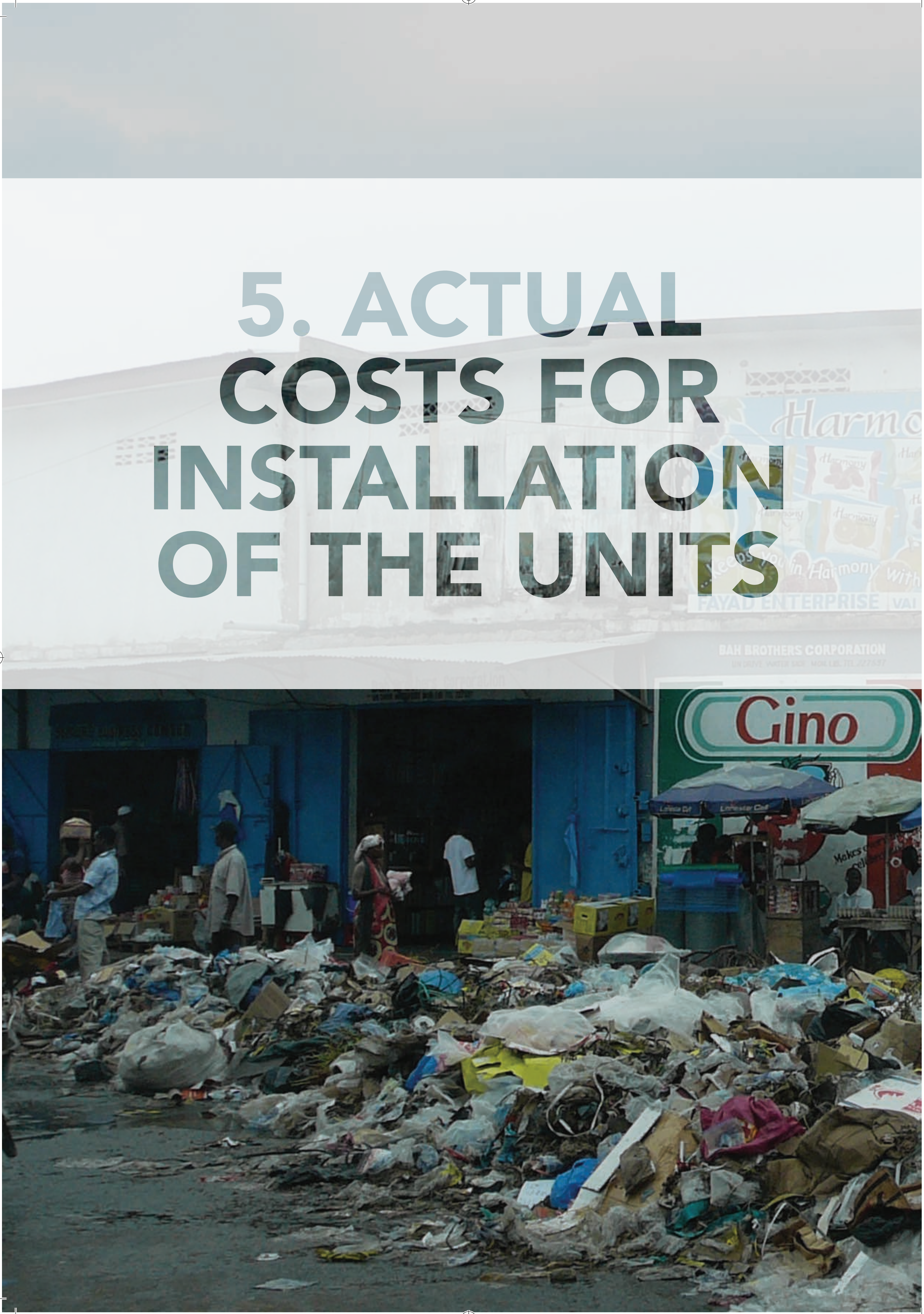
The monitoring phase of the project was completed with the conclusion of the interviews.

4. WEEKLY PROGRESS UPDATES AND LESSONS LEARNED



The Consultant has prepared Weekly Progress Updates and Lessons Learned for Phase III of the project, commencing from the week ending 18 August 2019, and these are included in Appendix II. The weekly updates summarise the activities carried out during the week, challenges encountered, lessons learned, and the planned activities for the following week, as well as photos of the activities during the week. These updates provide a running record of the work of Phase III of the project. Unfortunately, not all of these updates were sent to the Client on a regular basis, but the Client was kept abreast of activities and constraints through constant communications and the project chat group set up on WhatsApp. The weekly reports do serve as a good running record though of all activities.

5. ACTUAL COSTS FOR INSTALLATION OF THE UNITS



5.1 Actual costs incurred

Costs incurred by the Consultant for the supply and installation of the HomeBiogas units were reported on in the Installation and End User Training Report. The cost for installation of the fencing around the units and importation/port clearance costs were provided by Cities Alliance, which organised and paid for these elements of the work. Actual costs incurred are as summarised in the table below.

These are direct costs only and do not include costs for Consultant's services in relation to installation, training and monitoring of the units, or administrative costs incurred by Cities Alliance.

Summary of Actual Costs Incurred

Description	Total Cost (USD)	No. of Units	Unit Cost (USD)	Remarks
Costs Covered by Consultant				
Purchase of HomeBiogas units including transportation to Monrovia	$7,591	10	$759	Includes 2 larger units that were provided at same cost as smaller units.
Manufacturer's representative costs (trip plus labor)	$4,481	8	$560	8 units only installed
Installation cost (materials, labor and allowances, vehicle usage)	$2,950	8	$369	8 units only installed
Subtotal Consultant Costs	**$15,022**	**10/8**	**$1,502 /$1,878**	**10 units purchased, 8 units installed**
Costs Covered by Cities Alliance				
Importation of units	$1,962	10	$196	Port clearing, etc.
Installation of fencing around units	$4,366	10	$437	Price provided by Cities Alliance. (8 installed to date)
Subtotal Cities Alliance Costs	**$6,328**	**10**	**$633**	
TOTAL COST	**$21,350**	**10/8**	**$2,135 /$2,668**	**For purchase of 10 units and installation of 8**

Note: Values in table may not add up exactly due to rounding

5.2 Projected cost for additional installations

The costs for additional units will not necessarily be the same as for the 10 units initially purchased due to the following factors:

1. HomeBiogas provided a discounted price for the larger units (HBG 7.0 unit) and did not charge for some additional components ordered.
2. If additional units are installed, it likely will not be necessary to have the manufacturer's representative onsite, as the learning curve for the installation of the units has been accomplished during the first trip from the manufacturer's representative.

We therefore propose the following costs as a basis for the installation of additional units.

Proposed Cost for Additional Units

Description	Unit Cost (Smaller Unit HBG 2.0) (USD)	Unit Cost (Larger Unit HBG 7.0) (USD)	Remarks
Purchase of HomeBiogas units and accessories excluding transportation to Liberia	530	930	Includes yearly gas filter kit, extra gas hose, and extra gas valve
Shipping to Liberia (air freight)	240	240	Based on min. order of 10 units
Clearance through port	196	196	Based on costs provided by Cities Alliance
Installation cost	369	369	Based on costs above from Consultant
Security fencing	437	437	Based on costs provided by Cities Alliance
TOTAL COST	**$1,772**	**$2,172**	
CONTINGENCY @ 10%	**$177**	**$217**	
ROUNDED TOTAL COST	**$1,950**	**$2400**	

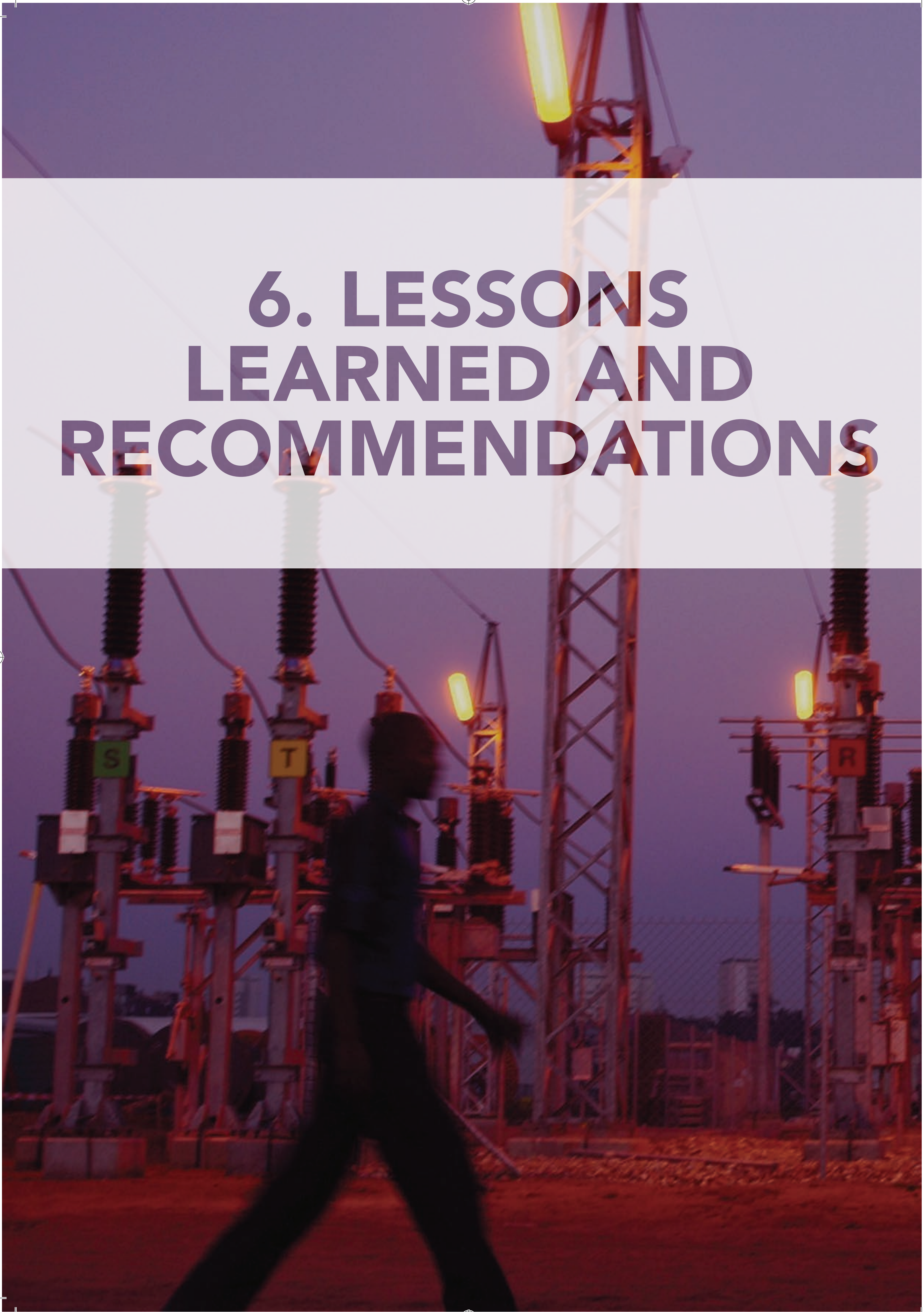
As above, for budgeting and planning purposes, if additional units are to be installed in the immediate future, the Consultant recommends using a cost of **US $1,950 for the smaller units and US $2,400 for the larger units.** Costs may increase if units are installed at a later date.

These are direct costs only for procurement of the units and direct labor and materials for installation. These costs do not include the following:

- Executing agent (Cities Alliance) administrative costs
- Any costs for hiring of Consultants to oversee the installation (if necessary)
- Costs for ongoing end user training and monitoring of installations
- Cost of manufacturer's representative to come to Monrovia for installations

As well, it needs to be recognised that the installation cost of US $369 incurred by the Consultant for the initial installations only included wages for site laborers and small daily allowances for MCC/PCC counterpart staff. The cost of the Consultant Local Coordinator, who led the work of the installations, is not included, nor is any cost for management and/or overhead and profit. The costs presented are direct costs only. Depending on the arrangement for installation of additional units, which is unknown at this time, the costs will need to be adjusted to account for these items.

6. LESSONS LEARNED AND RECOMMENDATIONS



This section of the report summarises the lessons learned from the home biogas testing phase. This includes the various stages of the testing phase including:

- Site selection
- Procurement of HomeBiogas units
- Installation and end user training
- Monitoring and end user support

Under each of these categories, we have described the experience of the testing phase and lessons learned/recommendations for the pilot project phase. The intent is that this information can used for planning purposes for subsequent stages of the project. The reader is also advised to read the "HomeBiogas Installation and End User Training Report" for additional information concerning the experience and constraints encountered on site selection, procurement, installation of the HomeBiogas units, and end user training.

6.1 Site selection

6.1.1 EXPERIENCE DURING TESTING PHASE

The site selection activity took much longer than anticipated to complete. Reasons included the following:

1. Very little input and support to the process by MCC/PCC and Cities Alliance, leaving the Consultant to essentially complete this task on their own. Without official backing and representation from government or Cities Alliance, potential recipients were skeptical of the process.
2. Access to key decision makers in organisations took time.
3. Volume of food waste at many sites was too low to sustain operation of the units.
4. Difficulty in finding level ground conditions, proper security, etc.
5. Some potential recipients lost interest in the project due to long time frame in making commitment.
6. Changing from smaller units to large units at the last minute.

Additional details are provided in the "HomeBiogas Installation and End User Training Report."

6.1.2 LESSONS LEARNED/RECOMMENDATIONS

It was very challenging to identify 10 suitable locations for the HomeBiogas test units. Part of this was due to external factors, such as lack of support from MCC/PCC and lack of "official" project representation and awareness of the issues. It is believed these constraints can be better managed and alleviated through improved planning. However, the real issue is that there are simply not a lot of sites in the project area that have the necessary amount of food waste and physical site conditions to install a HomeBiogas unit, and that are interested in participating in the project.

Given the challenges of finding 10 suitable locations for the testing phase, the Consultant does not believe that it will be possible within the timeframe of the project to identify 100 sites, as was the intent. This objective should be scaled down to a more realistic target of say 20 units for the proposed pilot stage, at least initially, and then consider more if additional sites can be identified.

Recommendations include the following:

1. "Official" input from government and Cities Alliance is necessary when contacting potential recipients.
2. A proper project promotional effort/awareness campaign needs to be carried out before trying to identify recipients for additional units.
3. Better screening of food waste volumes and physical site conditions is required. These items were not that well understood prior to the installation of the units during the testing phase but are well known now that some units have been installed and put into use.
4. As part of the site selection process, if considering schools, it will need to be discussed and plans will need to be developed for how they will keep the units running during periods when schools are closed for holidays.
5. A quantity of HomeBiogas units should be purchased prior to identifying recipients and the units kept on hand so that they can be installed quickly for recipients showing interest in the programme. This would eliminate potential recipients losing interest in the programme due to drawn out timeframes.
6. The site selection exercise should take advantage of the already installed units, and potential recipients should visit existing installations and talk to existing recipients to physically see a unit in operation and hear opinions from recipients.
7. MCC/PCC need to be involved in all aspects of the site selection process in order to develop the capacity and understanding of the project.
8. The proposed plan of installing 100 units for the pilot stage is likely not achievable and should be reduced to a more reasonable target of say 20 units, at least initially.
9. Adequate time needs to be given for the site selection process. It is recommended that units be purchased in advance, and then site selection can continue while some units are being installed. Both things can be underway in parallel, and this will ensure that sufficient time is given to identify and screen and selection participants.
10. Finally, as per the outcome of the recipient interviews, it is recommended that recipients are requested to pay a token amount for the units rather than just being given them. This will ensure the recipients take a larger interest in the project and utilise the units once installed.

6.2 Procurement of Home Biogas units

6.2.1 EXPERIENCE DURING TESTING PHASE

The procurement process with the HomeBiogas company was very straightforward, and they provided a high level of support to the project. However, their level of interest and commitment was lower at the initial stages when dealing only with the Consultant, as they were not confident that the order would proceed or that the financial backing for the order was in place. After discussing the project directly with Cities Alliance to confirm what the Consultant had told them about the project, HomeBiogas developed a high level of confidence that the project was for real, and subsequently provided better cooperation and support, including price reductions. Once the order was placed and payment made, HomeBiogas was able to ship the units very quickly to Liberia, without any issues, due to their experience and having systems in place for shipping their product around the world on a regular basis.

In the Consultant's opinion and experience, it is unlikely that other vendors of similar equipment would provide the same level of technical support and be able to process orders as quickly and efficiently as HomeBiogas did.

Notwithstanding the cooperation from HomeBiogas, the procurement process also went smoothly and quickly due to the Consultant's prior experience in importing goods into Liberia and having systems in place to quickly process international payments.

6.2.2 LESSONS LEARNED/RECOMMENDATIONS

1. If future procurements are being done by an organisation other than Cities Alliance, "official" input from Cities Alliance should be provided at the beginning to officialise the procurement and provide a higher level of confidence to the vendor from the start.
2. If more small-scale biogas units are being procured, unless there is a specific requirement in the procurement process to go to other firms, the Consultant recommends procuring directly with HomeBiogas due to their professional approach, high level of support, good product, and ability to process and ship orders quickly. It is anticipated that it will be difficult to find this combination with other vendors.
3. It is recommended that Cities Alliance/UNOPS procure the units directly from HomeBiogas. This will take advantage of UNOPS procurement systems and will be the lowest cost to the project. However, if this cannot be done, and procurement needs to be done by others, ensure the firm doing the procurement has experience in international procurement and systems in place to process international payments so that procurement can be done quickly and efficiently.
4. Results of the interviews of the recipients are consistent that they would see more value in the larger units with double burners. It is therefore recommended that all units be procured with double burners, and that most units procured should be the larger HomeBiogas 7.0 unit. Also, the possibility of a larger burner that can accommodate large pots should be explored with HomeBiogas. If HomeBiogas cannot accommodate this, it may be necessary to purchase larger

burners elsewhere. Larger, more robust burners could possibly be purchased locally, and an adapter kit used to convert the burner to enable operating on methane instead of the normally used propane.

5. It is recommended to procure 20 units only for the pilot project (at least as a starting point).

6.3 Installation and end user training

6.3.1 EXPERIENCE DURING TESTING PHASE

Details of the installation and end user training are provided in the "HomeBiogas Installation and End User Training Report." The experience is summarised below.

1. Overall, the installation went very well without any major problems.

   HomeBiogas provided excellent support for the installation process during a one-week period on site. They also provided extensive training and knowledge transfer in the operation and maintenance of the units and continued to provide support after the installations via WhatsApp and email. The onsite and offsite support provided by HomeBiogas was viewed as essential. It is doubtful that the installations and end user training could have been done this successfully without their input.
2. Installation of the units is very simple. There is no requirement for a concrete pad under the unit (as initially thought). All that is required is a patch of level ground.
3. In some locations, it was a challenge to find a suitable location with level ground that was close enough to the location where the gas would be used and where the unit would be located in the sun. The knowledge gained will be useful in future sight selections.
4. Obtaining fresh manure for activation of the units proved very challenging and more costly than anticipated. There is a scarcity of supply of fresh manure available.
5. Purchasing of trucked-in water was more costly than anticipated.
6. The activation period was longer than anticipated. This should be taken into consideration in any future planning. On the advice of HomeBiogas, it was decided to do a second activation to speed up the process, and with that the activation period was reduced to two weeks.
7. Participation by MCC/PCC counterparts in the installation process was very minimal. Although they showed up for the installations, the level of interest was low, and it required that allowances be paid. When allowances were curtailed participation stopped. Due to the low level of interest and participation, it is doubtful that they will be able to install additional units on their own.
8. End user training went very well, and recipients were responsive to the training.
9. Although additional gas valves to be located inside of each building (at the stove) were provided with the units, HomeBiogas recommended not to install these. These valves should be installed, as there were instances of recipients not turning off the gas valves because it was located at the HomeBiogas unit rather than inside the building.

10. There were some instances of tampering with the units before the fencing was put up. Fencing around the units should be installed immediately after installing the unit.

6.3.2 LESSONS LEARNED/RECOMMENDATIONS

1. Based on the knowledge gained through the installations, better site selection is possible, with the location of the units determined in advance of arriving to the site. This will enable a more efficient installation process and will enable determining necessary parts (piping, etc.) in advance.
2. In planning, scheduling, and budgeting for additional units, the cost and availability of fresh manure for activation of the units needs to be considered. An advance payment to a supplier to secure manure in bulk may be necessary to ensure availability. Two rounds of activation as was done with the initial units is recommended to reduce the activation time to approximately two weeks.
3. Gas shut-off valves should be installed inside the building, close to the cooker.
4. Fencing should be installed immediately after the units are installed and activated. Extreme caution needs to be taken not to damage the units during installation of the fencing.
5. Proper signage should be provided around the units and mounted to the fence. This was not included in the initial units. The cost of this is not included in the budget numbers provided in section 3.
6. MCC/PCC counterparts and Cities Alliance staff need to get involved in the installation of the two remaining units and replacement of the unit at RLJ Kendeja, with direction and oversight by the Consultant in order to learn the installation details for future installations.
7. The installations and end user training went well, but it needs to be understood that this process was implemented with the assistance of HomeBiogas (which was critical) and utilising an experienced team from the Consultant along with financial and logistical resources, technical expertise and business systems of the Consultant in place to enable uninterrupted work on the installations and end user training. These are highly idealised conditions. It is unknown how Cities Alliance intends to implement the next phase of the work, but this "idealised" situation likely will not prevail. If HomeBiogas and the Consultant are not involved, it will be a much larger challenge to carry out the site selection, install the units and provide training and support to the end users. Unfortunately, MCC/PCC counterparts did not gain capacity and knowledge of the project due to their lack of participation in the project despite several attempts by the Consultant and Cities Alliance to involve them. The Consultant recommends that MCC/PCC counterparts take the lead role in the site selection, installation, and training of the two remaining units, plus replacement of the unit at RLJ Kendeja, under the direction of the Consultant to develop the necessary capacity. If this can be accomplished, then MCC/PCC staff could supervise installation crews to be hired or from MCC/PCC, but it will be essential to provide these crews with all necessary resources to continue the work uninterrupted, including a cash float. If MCC/PCC staff are to be involved, it is recommended that they should receive a financial incentive to secure their participation.
8. If MCC/PCC cannot develop the required capacity by getting thoroughly involved in the remaining work, then it is recommended to proceed without them. A local firm(s) could be hired to undertake the field work for site selection

and installation but would require training either from the Consultant or from HomeBiogas, and perhaps some oversight during the process. In either case, the level of involvement of Cities Alliance will need to increase, and Cities Alliance would need to ensure the local contractors have the necessary experience and resources in place to execute the work. Refer to the Installation and End User Training Report for additional details.

9. Schedules, timeframe expectations, and costs must be established realistically from the start based on the results of the initial testing phase, but taking into consideration the capacities of those proposed to carry out the work. As above, the implementation of the HomeBiogas testing phase as part of the Feasibility Study project was done under idealised conditions that likely will not prevail for the pilot phase. As well, WNL and HomeBiogas absorbed many costs and this is also unlikely not to be repeated. Higher costs, longer timeframes and more complications should be expected for future installations without the involvement of the Consultant or HomeBiogas, and this need to be considered in the project planning so that realistic expectations are established.

6.4 Monitoring and end user support

6.4.1 EXPERIENCE DURING TESTING PHASE

The experience of the monitoring and support is described in section 3 above.
The monitoring and end user support stage generally went well, but there was no participation from MCC/PCC, and the Consultant Local Coordinator was overtasked with other things during this period that prevented a higher focus on proper data collection on the operation of the units.

6.4.2 LESSONS LEARNED/RECOMMENDATIONS

1. The data collection forms were not filled in well for a variety of reasons, but the forms were probably too complex for the literacy level of the recipients. Simpler data collection forms are required.
2. The person carrying out the monitoring and end user support needs to be dedicated only to that task if good data is desired and cannot be tasked with other issues like site selection and construction. This is particularly true if installing more units covering a wide area of Greater Monrovia. The monitoring person will need to spend considerable time with the recipients to ensure that data collection forms are completed properly.
3. The recipient interviews went very well and were considered very useful. It is recommended that these interviews be incorporated into any future monitoring exercise.

7. CONCLUSIONS AND PILOT PROJECT RECOMMENDATIONS

7.1 Conclusions

7.1.1 BACKGROUND

As part of the Feasibility Study on Waste-to-Energy Options in Monrovia, Paynesville, and Surrounding Townships in Liberia, in August 2019 (based on research carried out by the Consultant and a series of meetings with project stakeholders), it was determined that Cities Alliance would implement a pilot project to install approximately 100 small-scale biogas units (home biogas units) in various locations in the Greater Monrovia area, to convert organic food waste to gas that would be used for cooking purposes. The units would be located primarily in educational, institutional, and commercial establishments. Residential installations were not proposed as their organic waste generation was too low to support the operation of the proposed biogas units.

The proposed pilot project would satisfy the objectives of the Feasibility Study, namely to identify small-scale, W2E initiatives that could be piloted in the project area that:

- Are community based
- Are replicable and scalable
- Will reduce greenhouse gases and landfill emissions
- Will contribute to environmental protection and building local resilience
- Will promote an integrated approach to municipal solid waste management
- Should consider gender inclusivity and mainstreaming
- Will build the capacity of communities, local and national governments to understand, design, and manage the Integrated Solid Waste Management System of Greater Monrovia
- Can be implemented within the timeframe and available budget of the Cities Alliance project

Prior to committing fully to this pilot project implementation option, Cities Alliance wanted to test approximately 10 of the home biogas units, to test the technology and provide lessons learned that could be incorporated into the design of the pilot project. Phase III of the Feasibility Study project was thus changed to the Small-Scale Biogas Unit Testing Phase and included the procurement, installation, training, monitoring and end user support for up to 10 home biogas units in the Greater Monrovia area.

The units were procured and installed by the Consultant with assistance from HomeBiogas from October to early December with training provided to end users. Work carried out by the Consultant for the procurement, installation, and training (including constraints encountered and recommendations for future installations) is detailed in the "HomeBiogas Installation and End User Training Report" previously submitted.

This report has described the implementation and results of the monitoring phase that was undertaken after the installations and training, as well as the resulting lessons learned and recommendations for moving forward with the planned pilot phase in 2020. The report fulfils Milestone #5 of the project and is the final deliverable of the Consultant under the Feasibility Study on Waste-to-Energy Options in Monrovia, Paynesville, and Surrounding Townships in Liberia.

7.1.2 RESULTS AND CONCLUSIONS OF MONITORING PHASE

HomeBiogas units were procured, installed and end user training was provided from late October to early December. Although some constraints were encountered in relation to site selection, the overall process went well. Details are provided in the "HomeBiogas Installation and End User Training Report" previously submitted.

Monitoring and end user support was carried out from 3 December 2019 to 20 January 2020 and culminated with in-person recipient interviews on 27-29 January 2020. The work carried out and lessons learned are provided within this report. In general, the monitoring and end user support went well and was very necessary and useful, with the following being noted:

1. The end user support was critical, and this component must be incorporated into any future implementations.
2. There was no participation from MCC/PCC counterpart staff in the process despite many attempts to involve them. There was also very little participation from MCC/PCC in the previous site selection and installation activities. To date, they have not developed the capacity to be involved in future initiatives under the project, and this needs to be taken into consideration in future planning.
3. Monitoring forms were not well completed by recipients, despite the Consultant providing training on how to fill in the forms and stressing their importance to recipients on several occasions. It is believed that the forms are too complex, and that simpler forms should be developed for future initiatives. As well, the person carrying out the monitoring and support needs to be focused solely on this task to provide time to work with recipients on filling out the forms accurately; this was not the case during the current monitoring exercise.
4. As a result of the monitoring forms not being well completed, no useful data could be extracted from them, and it became necessary to conduct personal interviews with the recipients regarding the usage and their experience/ opinions about the HomeBiogas units. The interviews were very useful, and it is recommended that they be incorporated into any future monitoring exercise at the end of the monitoring period. The Consultant also recommends carrying out a follow-up interview three months later to determine if situations have changed concerning usage of the units.
5. The duration of the monitoring period was about six weeks, but this included the Christmas period. This duration was about right. A one-month monitoring and support period is recommended for future endeavors, plus time for any holidays.

The results of the monitoring phase, and in particular the recipient interviews, are very encouraging. Key takeaways are as follows:

a. The technology works well and the HomeBiogas units perform as per the manufacturer's claims.

b. Recipients like the units and use them for all kinds of cooking, but usage is limited by the small size of the burner and, in some cases, the small size of the units. If larger units with double burners were provided and/or burners that can accommodate larger pots, the level of usage would be higher.

c. Recipients appear to have enough waste, and in the case of the larger hotels, more than enough. Collecting the waste and loading the units is not an issue.

d. Very few problems have been experienced with the units.

e. Recipients will continue to use the units, but again stressed the issue of the size of the burners

f. Recipients are using the effluent as fertiliser and are very pleased with it.

g. Recipients are familiar with climate change and are very concerned about it, and believe that converting waste to energy with a HomeBiogas unit is good for the environment and will reduce cutting of trees, burning of charcoal, greenhouse gases, and climate change.

h. Schools are using the HomeBiogas units to teach about climate change, global warming, and renewable energy topics.

i. Recipients would recommend the HomeBiogas units to others

j. Recipients recommend that donors and government provide more HomeBiogas units along with raising awareness but should provide larger units and charge a token fee for the units.

These results support installation of more small-scale biogas units during the pilot. However, as explained in section 6 of this report, there were challenges in identifying suitable sites during the testing phase, and as such it is recommended to only proceed with 20 sites under the pilot phase, as opposed to the 100 sites originally planned. This is discussed in more detail below where recommendations for the implementation of the pilot project are given.

7.2 Recommendations for implementation of pilot project

7.2.1 INSTALLATION OF HOME BIOGAS UNITS

As indicated above, the results of the small-scale biogas unit testing phase are encouraging and support the installation of more units during the pilot project. The small-scale biogas units satisfy all of the objectives originally outlined.

It was originally planned to install approximately 100 small-scale biogas units under the pilot project to be implemented in 2020. However, in implementing the testing phase for the installation of the 10 HomeBiogas units, it has been a challenge to identify sites that have sufficient organic waste generation (with reasonable energy content) even to operate these small units. The experience to date on the testing phase indicates that it likely will not be possible to confirm the planned 100 locations that will meet the criteria for the installation of the units. Locations and recipients must meet the following criteria as a minimum:

1. Generate enough organic food waste on a consistent basis to support the operation of the system. This is 2 kg/day for the smaller units and 6 kg/day for the larger units.
2. Have the ability to utilise the biogas produced by the system for purposes of cooking.
3. Be able to utilise the liquid effluent generated by the system as a liquid fertiliser.
4. Have a level and secure location to install the unit so that it can be installed correctly. The biogas unit will need to be located within 20m of the biogas stove and be in a location where sunlight reaches the unit.
5. Have access to water supply.
6. Recipients must be willing to accept the responsibility of utilising the system in accordance with the intent of the project, including having a designated person that will receive training and take responsibility for operation of the system. This is to avoid installing the system in a location where it will not be utilised as intended. The recipient must also be willing to participate in monitoring of the system by the project, sign a Right-of-Use Agreement, and accept the legal, financial, operation, and maintenance responsibilities and liabilities associated with the Agreement.

Although the procurement and installation of the HomeBiogas units was relatively straightforward, it was done under highly "idealised' conditions of having the manufacturer's representatives onsite during the installations combined with an experienced team and resources of the Consultant. These conditions are not expected to prevail for the installation of the pilot units, and as such, the Consultant foresees significant challenges to install 100 units during the timeframe of the Cities Alliance project, even if 100 suitable sites could be identified. This is further compounded by a lack of capacity within government organisations to take on the responsibilities of the project.

Taking these factors into consideration, it is recommended that the pilot project be based on the installation of 20 home biogas units only, at least to start with – additional sites could be added later if things go well. It is believed that 20 suitable locations can be identified, and by scaling down to 20 units, the prevailing challenges related to installation complexity and lack of capacity within government organisations can be overcome and managed with the right approaches.

Specific recommendations for the pilot project are as follows:

<u>A. Project Scope:</u>

1. Pilot project should be based on 20 biogas units only. However, flexibility should be incorporated into the project plan to do more if the implementation is going well and there is a demand for additional units.
2. At least half the units should be of larger capacity, and all with double burners. The possibility of larger burners to accept larger pots needs to be explored.
3. The project should focus on educational and institutional organisations, government offices, and private sector companies.

4. It is recommended that recipients pay a token amount to receive the units, as a means of increasing their level of commitment and usage of the units.
5. The project should be based on units from the HomeBiogas company.
6. Phases of the project should include:
   i. Planning and budgeting
   ii. Site Selection
   iii. Procurement
   iv. Installation
   v. Monitoring and End User Support

B. Site Selection:

1. "Official" input from government and Cities Alliance is necessary when contacting potential recipients.
2. A proper project promotional effort/awareness campaign needs to be carried out before trying to identify recipients.
3. Better screening of food waste volumes and physical site conditions is required. These items were not that well understood prior to the installation of the units during the testing phase, but they are well known now that some units have been installed and put into use.
4. It is not recommended to install the biogas toilet under the pilot project. This complicates and increases the cost of the installations, and prevents the use of the effluent for fertiliser, negating one of the major benefits of the system.
5. As part of the site selection process, if considering schools, it will need to be discussed and plans will need to be developed for how they will keep the units running during periods when schools are closed for holidays.
6. A quantity of HomeBiogas units should be purchased prior to identifying recipients and the units kept on hand so they can be installed quickly for recipients showing interest in the programme. This would eliminate potential recipients losing interest in the programme due to drawn out time frames.
7. The site selection exercise should take advantage of the already installed units, and potential recipients should visit existing installations and talk to existing recipients to physically see a unit in operation and hear opinions from recipients.
8. Adequate time needs to be given to do the site selection process properly. It is recommended that units be purchased in advance, and then site selection can continue while some units are being installed. Both things can be underway in parallel, and this will ensure that sufficient time is given to identify, screen, and select participants.
9. As per the outcome of the recipient interviews, it is recommended that recipients are requested to pay a token amount for the units rather than just giving them to them. This will ensure the recipients take a larger interest in the project and utilise the units once installed.
10. It is recommended to have meetings/small workshops with potential recipients before they commit to their participation to educate them on the project, the biogas units, their responsibilities, etc. and as part of this to visit an existing

installation. This will give potential recipients much more knowledge about the units and their responsibilities to aid in their decision to participate.

C. Procurement:

1. Unless there is a specific requirement in the procurement process to go to other vendors under open tendering, it is recommended to procure the biogas units directly from HomeBiogas due to their professional approach, high level of support, good product and ability to process and ship orders quickly. It is anticipated that it will be difficult to find this combination with other vendors. This will also make for consistency with the already installed units.
2. It is recommended that Cities Alliance/UNOPS procure the units directly from HomeBiogas. This will take advantage of UNOPS procurement systems and will be the lowest cost to the project. However, if this cannot be done, and procurement needs to be done by others, ensure the firm doing the procurement has experience in international procurement, and has systems in place to process international payments so that procurement can be done quickly and efficiently. If procurements are being done by an organisation other than Cities Alliance, "official" input from Cities Alliance should be provided at the beginning to officialise the procurement and provide a higher level of confidence to the vendor from the start.
3. Results of the interviews with recipients are consistent that they would see more value in the larger units with double burners. It is therefore recommended that all units be procured with double burners, and that most units procured should be the larger HomeBiogas 7.0 unit. As well, the possibility of a larger burner that can accommodate large pots should be explored with HomeBiogas. If HomeBiogas cannot accommodate this, it may be necessary to purchase larger burners elsewhere. Larger, more robust burners could possibly be purchased locally, and an adapter kit used to convert the burner to enable operating on methane instead of the normally used propane.
4. It is recommended to procure 20 units only for the pilot project (at least as a starting point).
5. Additional gas shut-off valves for installation inside the buildings should be procured with the units. Units should also be procured with extra lengths of gas piping and connector fittings, as well as some spare parts in case parts get lost or damaged during installation and for end user support.

D. Installation:

1. Based on the knowledge gained through the installations, better site selection is possible, and the specific location of the units should be determined in advance of arriving to the site. This will enable a more efficient installation process and will enable determining necessary parts (piping, etc.) in advance.
2. In planning, scheduling, and budgeting for additional units, the cost and availability of fresh manure for activation of the units needs to be considered. An advance payment to a supplier to secure manure in bulk may be necessary to ensure availability. Two rounds of activation, as was done with the initial units, is recommended to reduce the activation time to approximately two weeks.

3. Additional gas shut-off valves should be installed inside the building, close to the cooker.
4. Fencing should be provided for each unit and installed immediately after the units are installed and activated. Extreme caution needs to be taken not to damage the units during installation of the fencing.
5. Proper signage should be provided around the units and mounted to the fence. This was not included in the initial units. The cost of this is not included in the budget numbers presented within this report.

E. Monitoring and End-User Support:

1. Monitoring and end user support is an essential part of the project and must be incorporated into the project plan. A one-month monitoring and support period is recommended, plus any time for holidays within the period.
2. A single dedicated person is required to carry out the monitoring and end user support. To undertake this effectively and get good data, the person needs to focus solely on this task, and not be tasked with other issues such as site selection and construction. This is particularly true if installing units covering a wide area of Greater Monrovia. The monitoring person will need to spend considerable time with the recipients to ensure that data collection forms are completed properly.
3. Simpler data collection forms need to be developed that are easier for recipients to fill in.
4. Formalised in-person recipient interviews are recommended at the end of the monitoring period, with a follow-up interview after approximately three months.

F. Project Planning:

1. It is essential to do proper and thorough project planning prior to execution. This needs to include confirming scope, implementation arrangements (see more below about this), schedules and budgets.
2. It is viewed as essential to carry out a project promotional and awareness campaign prior to commencing with identifying potential recipients.
3. Information contained in this report can guide in developing project schedules and budgets. However, this will ultimately depend on the implementation arrangement selected. It needs to be understood that the implementation of the initial test units was done under highly idealised situations of having HomeBiogas on site and the installations, monitoring and support being arranged by the Consultant, who has extensive experience in this regard, as well as the financial resources and business systems in place to continue with the work efficiently and uninterrupted. As well, both WNL and HomeBiogas contributed financially. These situations most likely will not prevail for the pilot phase, and costs and implementation timeframes experienced in the testing phase should not be used verbatim for planning of the pilot stage. Rather, they should be used for initial guidance and then adjusted accordingly based on the selected implementation arrangements.

G. Implementation Arrangements:

1. It is assumed in this report and other project reports that MCC/PCC counterpart staff would take on the responsibilities of implementing the pilot project, under the direction of Cities Alliance, based on developing the capacity to do this through participation in the testing phase. This did not happen as planned and there was very little participation from the counterpart staff (see below). If MCC/PCC staff are not going to be involved directly in the installations and monitoring, other implementation arrangements will need to be considered in order to move forward with the pilot project.
2. Other implementation arrangements to consider if MCC/PCC are not to be involved include:
   - i. Cities Alliance undertakes all of the work of the project themselves and directly hires local labor to work under their direction.
   - ii. Cities Alliance procures the HomeBiogas units and hires a local contractor to install them. The local contractor could also be hired to carry out the monitoring and end user support, or one person could be hired to carry this out.
   - iii. Cities Alliance hires a Consultant to prepare the project plan, assist with procurement of the units, assist with procurement of a contractor, supervise the contractor, and prepare project reports. This would be a traditional Client-Consultant-Contractor arrangement, with the Consultant operating in the interest and on behalf of the Client.
   - iv. As above, but the Consultant accepts responsibility to hire direct labor to install the units and accept responsibility for the installations. The Consultant would be reimbursed for construction costs. This has the advantage of a single point of responsibility for the Client and can be implemented faster. This approach is similar to how the testing phase was done, but with cost reimbursement (or lump sum) for the installations.

   The selected arrangement will depend on internal procurement regulations and available staff and logistical resources within Cities Alliance. No matter the arrangement selected, including if MCC/PCC is involved, the important aspect is to ensure that whoever is implementing has the necessary logistical, financial and technical resources at their disposal to keep the work moving forward without interruption and to complete the work to a high degree of quality.

H. Involvement of Government Agencies:

1. As mentioned above, it has been assumed in this report, and other project reports, that MCC/PCC counterpart staff would take on the responsibilities of implementing the pilot project, under the direction of Cities Alliance. This would be the preferred arrangement in order to enhance the capacity of government agencies to take on future related projects. Unfortunately, the involvement of government counterparts has been minimal to date, and they have not developed the necessary capacity. But it is not too late. At the time of writing this report, there are still two HomeBiogas units to be installed and one to be replaced. If MCC/PCC counterpart staff get very involved in these installations by actually doing the work, under the direction of the Consultant, and then do the training and follow up monitoring on these units and others,

they can still develop a good understanding of the units to be able to take on the responsibilities of the pilot stage. The Consultant has offered to provide guidance and training for the installation of the remaining units after the expiration of our contract if the counterpart staff are prepared to take the work of the installations. However, if this does not happen, it is recommended that MCC/PCC staff are not involved in the pilot project, except perhaps in a cursory role, as it will be too risky to involve them in the implementation if they do not develop the necessary capacity immediately.

2. It is recommended to secure the participation and interest of the MCC/PCC counterpart staff that a financial incentive be provided. It has been the Consultant's experience on other projects in Liberia and elsewhere that this is necessary to achieve good levels of participation from government counterpart staff. Logistical resources such as transportation may also be required.

7.2.2 OTHER PILOT INITIATIVES

The original objective of the project was to identify small-scale, community-based W2E initiatives that could be piloted in the project area that:

- Are replicable and scalable
- Will reduce greenhouse gases and landfill emissions
- Will contribute to environmental protection and building local resilience
- Will promote and integrated approach to municipal solid waste management
- Should consider gender inclusivity and mainstreaming
- Will build the capacity of communities, local and national governments to understand, design and manage the Integrated Solid Waste Management System of Greater Monrovia
- Can be implemented within the timeframe and available budget of the Cities Alliance project

The initially proposed pilot project – to install up to 100 small-scale biogas units and utilise the biogas for purposes of cooking – satisfies all of these objectives. However, based on the results of the testing phase, it is recommended to only install 20 small-scale biogas units, at least initially. While this still meets the project objectives, it becomes a very small pilot project, and it is recommended that other pilot initiatives be considered to enlarge the project.

The Consultant provides the following discussion and recommendations in this regard. The text presented below is also included in the Final Version of the Feasibility Study Report.

The underlying challenge of the Feasibility Study project from the start has been the lack of available suitable organic waste that is clean and has a reasonable energy content. Given the local diets and local economic conditions in Monrovia, there is simply a lack of clean organic waste with reasonable energy content to serve as a basis for an effective waste-to-energy project, on the basis of a small-scale, community-based project. Also, except for at market locations, there are no mechanisms in place for source separation of organics, and it would be a very large challenge to introduce waste separation within the budgets and timeframe of the Cities Alliance project. Furthermore, waste separation is outside of the scope of the W2E Feasibility Study project.

The feasibility study has shown that there are small-scale waste-to-energy technologies available that could be implemented at market sites, because there is sufficient organic waste available that can be easily sorted. There are even some small-scale technologies available that could use mixed-waste from communities. However, in both of these cases, the capital costs are quite high. The projects would not be financially self-supporting and would require significant ongoing support to reach a point of continuous successful operation. The timeframe and budgets for these options are outside of what is available with the Cities Alliance project.

In short, the options for small-scale, community-based waste-to-energy projects that can be implemented within the short timeframe and low budget of the Cities Alliance project are very limited. This is due to a combination of factors, constraints, and challenges, including:

- Low level of organic waste generation and low quality of waste (low energy content). This increases the cost, size, and complexity of any system, because the available technologies are generally designed around higher energy content waste that is found in a developed country setting, or higher energy content agricultural waste.
- The above requires that any system that is installed to utilise low energy content municipal waste will need extensive testing and experimentation, and possibly equipment modification, to get the process to the point where it can operate continuously and effectively and produce a reasonable amount of energy output.
- There is a lack of capacity in the local environment in Monrovia to carry through on the testing and experimentation and for the longer-term operation. Extensive support will therefore be required, at costs that exceed the available budget.
- The project is focused on municipal solid waste. Despite extensive searching, our research has not identified any successful (sustainable) small-scale waste-to-energy projects based on municipal solid waste in developing countries. This is likely due to the same challenges/constraints identified herein. The Consultant believes that this is just a case of the technology not yet being well-developed. However, several initiatives are underway in many countries, and a few years down the road the landscape and options to consider will likely be different. This is similar to when solar power was in its infancy 20-30 years ago – the technology worked but was fairly complex and not financially viable. As we know, great strides have been made in solar power, and the solar technology that is available today is much less complex, does not require a lot of technical support, and is financially viable even at a very small scale. It is expected that the same thing will happen with waste-to-energy technology in the coming years, given the vast amount of research being done and new products coming to market. But for now, other than the micro-scale biogas units (which utilise higher energy value food waste and where the operation cost is covered by the recipient), to identify small-scale waste-to-energy options based on municipal solid waste that can be implemented relatively quickly and at low budget, and that do not require a lot of ongoing support, is a tall order that is not easily satisfied. There are however, many examples of successful implementations of simple, small-scale waste-to-energy projects in rural areas based on farm waste, and some urban projects based on treating sewage and wastewater. If the mandate of the project were expanded outside the scope of municipal solid waste only, then it would open up several other options to consider.

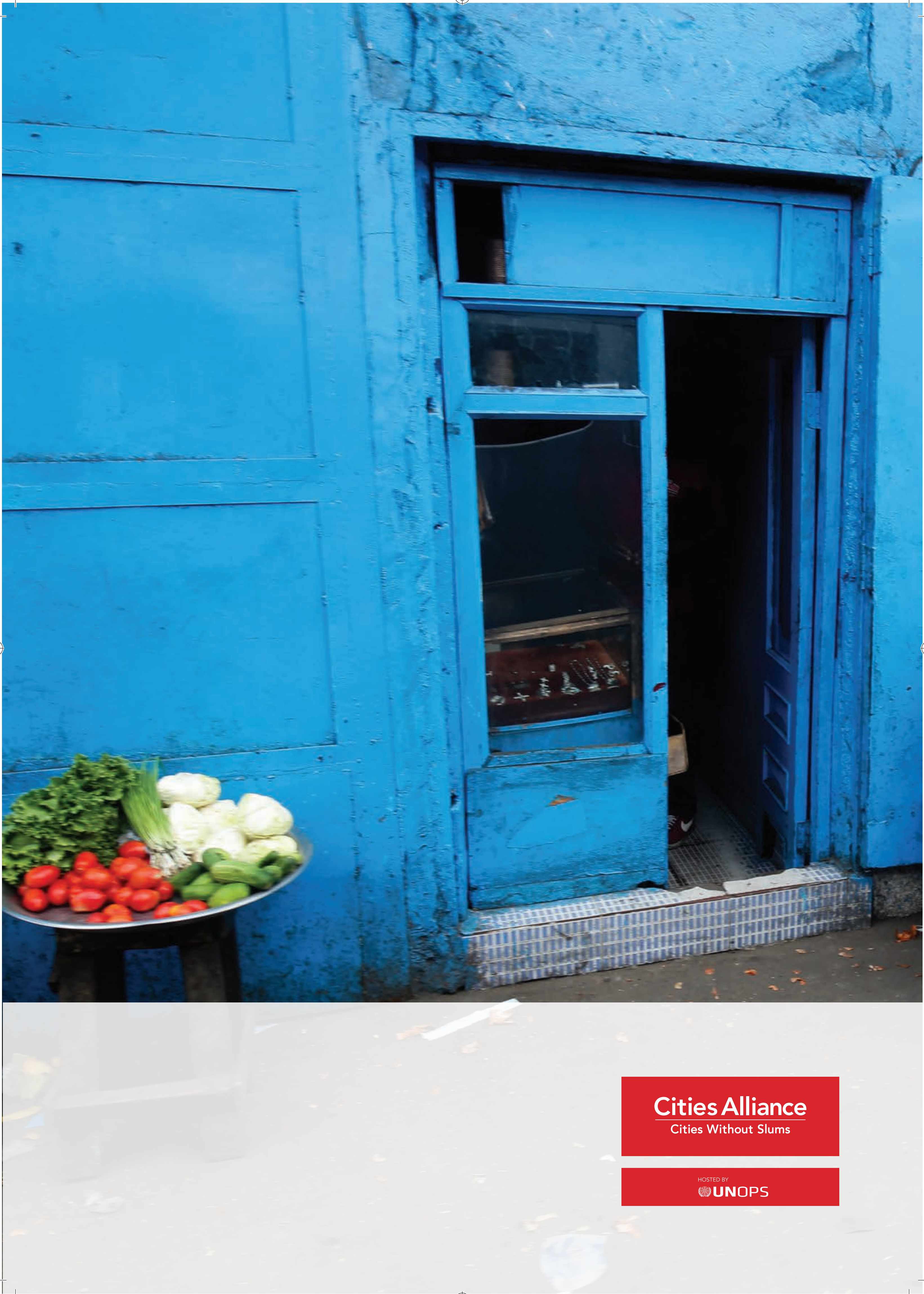
Given the above, without a longer project timeframe, and higher budgets to support the capital cost and to provide technical and operational support for the first few years of operation, there are very limited options to choose from for viable waste-to-energy options. Other options may be available if waste sorting were in place. Waste sorting at a household level would provide better waste streams for conversion to energy. But there is no waste separation in Monrovia, and it is outside of the scope of this project to introduce waste sorting.

In short, within the context of the current project, the small-scale biogas units appear to be the only viable alternative for a pilot project, hence why this was proposed. But it has been determined that the initial plan of installing up to 100 units of the small-scale biogas systems is also not feasible, again due to limited volumes of organic waste, and installation of approximately 20 units is more appropriate.

Installation of 20 micro-scale biogas systems, however, is a very small undertaking and will not provide much benefit to the citizens of Monrovia. As well it will not fully utilise the available project budget. The requirement to utilise municipal solid waste to generate useful forms of energy, in a small-scale community-based manner within the confines of Greater Monrovia, is too restrictive, and this mandate cannot be effectively accomplished within the timeframe and budget of the project. In order to reap more benefit from the project, the Consultant therefore recommends the following:

1. Increase the timeframe and budget of the project. Doing so would enable executing a pilot project along the lines of the Option 1 project identified in the Feasibility Study Report.
2. If timeframe and budgets cannot be increased to the required level as per the previous item, then the mandate of the project should be expanded to be less restrictive.
    a. If the mandate were changed from "waste-to-energy" to "renewable energy," this would then introduce other options that could be very beneficial, such as solar power. The pilot project could then be developed on the basis of some waste-to-energy (for example the 20 micro-scale biogas units) plus other forms of renewable energy initiatives involving solar power or solar water supply. At the community level, for example in a school, it may be possible to combine a HomeBiogas unit with solar electrical power for the school and a solar powered borehole for improved water supply. There also may be good renewable waste-to-energy options to consider from sewage (utilising anaerobic digestion), for example at public toilets or at the Monrovia sewage treatment plant (note this was not considered as an option to pursue in the current study as it was limited to "solid" waste only). Initiatives such as this could provide significant benefits to the community and could be accomplished within the project budget and timeframe. The environmental benefits that are desired would also be accomplished. Waste-to-energy is a subset of renewable energy, so this does not represent a huge change in the nature of the project, but would greatly enhance the ability of the project to come up with viable project options to achieve the goals of the project and Cities Alliance and benefit the population of Monrovia.

b. It is also recommended that consideration be given to expanding the project beyond the confines of the urban areas of Monrovia. While it is understood that the mandate of Cities Alliance is urban areas, if the mandate was expanded to include areas on the fringes of Monrovia where there is agricultural activity, then several options for waste-to-energy based on agricultural waste would emerge.



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