NGI

FINAL PROJECT REPORT

SUWASO: Sustainable and complete waste management solutions for rural and semi-urban environments in Uganda and Mali

PROJECT PERIOD: JUNE 2021 – DECEMBER 2024

REV.NO. 0 / 2025-29-01

Project partners:

NGI
StrømmeFoundation FIGHTING POVERTY
INGENIØRER UTEN GRENSER
Norwegian Retailers' Environment Fund

Local implementing partners:

Rural Enterprise Development Solutions
APSM
ASSOCIATION MALIENNE AMSS POUR LA SURVIE AU SAHEL

NORWEGIAN GEOTECHNICAL INSTITUTE
NGI.NO

Project

Project title:	SUWASO: Sustainable and complete waste management solutions for rural and semi-urban environments
Document title:	Final project report
Document no.:	20210118-01
Date:	2025-01-29
Revision no. /rev. date:	0 / 2025-01-29

Client

Client:	Handelens Miljøfond / Norwegian Retailers' Environmental Fund
Client contact person:	Sjur Kvifte Nesheim

For NGI

Project manager:	Cathrine Eckbo
Prepared by:	Anna Østby Schippert, Gard Sviggum Saabye, Gerard Cornelissen
Mali chapters prepared by:	Tore Martin Herland, Anne-May Thompson, Abdramane Traore
Reviewed by:	Gerard Cornelissen

Summary

The Sustainable and Complete Waste Management Solutions for Rural and Semi-Urban Conditions (SUWASO) project, implemented from June 2021 to December 2024, was a collaborative effort involving the Norwegian Retailers' Environment Fund (NREF), Norwegian Geotechnical Institute (NGI), Stromme Foundation (SF), Engineers Without Borders Norway (IUG), and the local implementing organisations Rural Enterprise Development Services (REDS), Association Protestante de la Santé au Mali (APSM) and Association Malienne pour la survie au Sahel (AMSS). Building on the previous initiatives 'Green Jobs' in Mali and 'Trash into Cash' in Ethiopia, the **main goal** of SUWASO was to **enhance plastic waste management in rural and semi-urban areas** of the Global South by establishing sustainable businesses and inspiring innovative plastic recycling methods globally.

In Mityana, Uganda, the project tackled plastic waste management challenges in a municipality of about 100,000 people. The implementing consortium included NGI, REDS, Human Brights Engineering, and Schippert Consulting. Key steps involved conducting a Baseline Waste Audit in 2021, engaging local stakeholders, and **focusing on PET plastic**, which was identified as a plastic fraction not currently being collected for recycling in Mityana, but with a big potential to be recycled in Kampala. **Several plastic processing machines have been built** and sourced through the project, such as two locally produced shredders with self-developed reduction gears, one baler and a bottle preparation tool to ensure a robust business with the opportunity to process plastic into the required and wanted qualities.

Since April 2023, the Mityana facility has employed a manager, a technical engineer, and support staff. In June 2024, they **registered** their own company, **Ashimoki General Trading Company Limited**, to continue operations post-project. The facility operates two shredders and a baler with the **potential to process more than 40 tonnes of plastic monthly**. The business strategy focuses on increasing plastic collection from households and supporting other collectors by processing their plastic. Financial assessments **indicate profitability if machines operate at 40% capacity** or more. The project has established a scalable and transferable recycling model, empowering local employees and reducing plastic waste and emissions. Going forward, an **annual production of at least 100 tonnes of plastic is anticipated**, as the plastic processing company has received all necessary equipment and training to keep up a good plastic processing rate.

In Mali, the SUWASO project, implemented in San and Mountougoula, addressed waste management challenges and high youth unemployment rates. The project focuses on collecting and **recycling soft plastic waste to produce school benches and other plastic furniture,** reducing plastic contamination, emissions from open burning, and

contributing to climate change mitigation by replacing wood with recycled plastic. The project has **increased income for vulnerable women** in savings groups, who are paid for the plastic they collect. **Youth groups produce and sell** the benches, enhancing financial resilience.

To ensure sustainability, project participants have formed cooperatives to manage the production units. The project has also **focused on quality assurance and safety**, with technical assistance from the National Directorate for Pollution and Nuisance Control and Engineers Without Borders. Despite challenges, including security issues, the project has made significant progress in improving waste management and creating economic opportunities in Mali.

The SUWASO project in Mali has **conducted several workshops to engage local partners and stakeholders**, including communication and marketing sessions, project launches, and experience-sharing workshops. To strengthen market linkages, the project **developed a production and marketing plan**, recruited freelancers, and organized promotional tours. A business calculator was created to evaluate the financial sustainability of the production units, indicating potential profitability if there is sufficient demand for the products. **More than 150 tonnes of plastic** have been **processed** in Mali during the project, with an expected processing of **60 tonnes per year going forward**. The project has diversified its product portfolio to include furniture for offices, kindergartens, and churches to enhance economic viability.

The **lessons learned** from the projects in Mali and Uganda highlight the **importance of careful planning, adaptability, and local engagement**. Building **technical capacity** among local stakeholders ensures sustainability beyond the project period, while **involving local authorities and partners** from the outset provides valuable **support and cooperation**, increasing the likelihood of success. In the plastic waste industry, it is **crucial to consider the volatile market** for both plastic waste and plastic products. A **robust business model and diversified product offerings** are essential for long-term sustainability. Given the limited budget for our project, **securing fair prices for infrastructure** and machinery investments was vital. We found that this was most effectively achieved when our **local partner independently approached local businesses** without disclosing the donor-funded nature of the project.

As a last remark, focusing on the **business model** and planning for the project's **survival beyond the project period is crucial**. Both in Mali and Uganda a solid foundation has been laid. We recommend to carry out surveys a few years ahead, to evaluate long-term achievements and impacts. We want to use the opportunity to wish **good luck to the local businesses established** in the realm of the project, and express the hope to have paved the way for sustainable plastic collection and processing businesses, **helping to remove plastics from the streets for years to come**.

Contents

1 Introduction

The Sustainable and complete waste management solutions for rural and semi-urban conditions (SUWASO) project is a partnership project between the Norwegian Retailers' Environment Fund (NREF), the Norwegian Geotechnical Institute (NGI), Stromme Foundation (SF), Engineers Without Borders Norway (IUG) and the local implementing organisations Rural Enterprise Development Services (REDS), Association Protestante de la Santé au Mali (APSM) and Association Malienne pour la survie au Sahel (AMSS). It was implemented between June 2021 and December 2024.
The project is a continuation of two other projects, also implemented with funds from NREF, namely 'Green Jobs' which was implemented by SF in Mali, and 'Trash into Cash' which was implemented by NGI in Ethiopia.

The main purpose of the project was to expand horizons on plastic waste management in rural and semi-urban contexts in the Global South. In Mali, a complete waste management system has been developed. In both locations, sustainable businesses have been established based on local conditions and markets to ensure they can operate long after the project period, continuing to reduce the burning and littering of plastic and other waste, which ultimately ends up as microplastics. Our goal was that our experience through this project would lead to innovative approaches to plastic waste recycling worldwide. Even before the project concluded, we have received new funding to continue work on the pyrolysis unit developed through this initiative.
The following chapters will explain how we implemented the project components in Uganda and Mali, and the results we achieved.

2 Uganda

The SUWASO project in Uganda has been implemented in Mityana, approximately 70 km west of the capital city, Kampala. The municipality has a population of about 100,000 people, and waste management is a significant challenge due to the lack of proper collection systems or designated collection centers. While the exact amount of plastic waste generated is unknown, it is evident that a substantial amount is being produced, burned, or disposed of in uncontrolled ways.

To address these plastic waste issues, the project consortium in Uganda consisted of NGI, the project owner; REDS, the local project implementer; Human Brights Engineering, the technical lead responsible for designing and building all machines and tools not purchased from manufacturers; and Schippert Consulting, which provided project implementation support and co-led the project.

2.1 Step-by-step project implementation

A Baseline Waste Audit was conducted in 2021, with results which were used for the further implementation of the project.

Main results from 2021 Baseline waste audit:

- Poor waste management posts high incidences of littering, unhygienic conditions, blocked drainages, and air pollution.
- This report summarizes the findings of the baseline survey & waste audit conducted and presents the results obtained from a total of 318 households (Male =109, Female = 209) and 11 Plastic Waste Business Collectors (PWBC) interviewed on issues including type, quantity, management, and market for plastic waste.
- The estimated volume of plastic waste bottles accumulated in a month is 32 tonnes for the whole municipality. Only one out of 10 interviewed business collectors collected plastic bottles, the rest only aimed for plastic with higher value, such as broken jerricans, basins, buckets, tins, and worn-out utensils. It was estimated that the 10 collectors were collecting around 66 tonnes per month from Mityana and the areas around.
- The baseline found that the most generated plastic waste is the Polyethylene bags reported by 298 respondents (94%), followed by plastic bottles of mainly soft drinks and mineral water reported by 275 respondents (86%).
- Only 25% of the households reported that they do sort garbage; 43% of the households re-use Polyethylene bags; 32% reuse plastic bottles for repackaging other liquids like paraffin & agrochemicals and; 33% use the waste as fuel to light stoves.
- 90% of the respondents have not had any training in waste management and only 10% reported having received some form of training through different channels.
- There are no recycling initiatives or buyers of plastic waste within the municipality and Mityana District. Plastic waste collected is sold to buyers from the Greater Kampala Metropolitan Area who are attached to recyclers. A kilo of jerrycans delivered is bought between UGX 700 and UGX1400 (NOK 2-3) while a kg of basins/buckets is bought between UGX 300 and UGX900 (NOK 1-2).
- Landfill Assessment: Plastic bottles and Polyethylene bags are picked out for sale. 3 individual families scrape out a living from this waste and are not attached to the municipality. They can raise 1 tonne of plastic bottles in a month and simply wait for buyers who come directly to the site. The families have 3 main challenges while doing their work of sorting, (i) lack of protective gear (gumboots, gloves, and overalls) for protection against germs and diseases, (ii) lack of shelter at the landfill for protection against rain and sunshine, (iii) lack of toilet facilities.

In March/April 2022, the Norwegian team, along with participants from REDS, visited Mityana. We engaged with stakeholders we believed would be crucial for the continued project implementation, including members of a local waste collection cooperative, the landfill, radio stations, the municipality, local markets, a school, and the area identified for the facility construction. From the baseline report and discussions with key stakeholders, we concluded that our focus should be on PET plastic, as it was not being collected in significant quantities and was often discarded or burned.

Following this trip, our main priorities were constructing the facility, connecting it to electricity, and finding a suitable metal workshop to build a plastic shredder. We chose the Technical University in Kampala for this task. They were supposed to produce the shredder so that the team could visit the facility with it in April 2023 and start training the employees selected to run the facility. However, the University did not manage to finalize the shredder before this trip. When the team visited to check the status, they realized that significant assistance would be required to get a proper shredder up and running. Therefore, the field trip was primarily used to assist in the production of new shredder parts and to visit the facility building, with the facility workers participating in this process.

The shredder was sent to the facility and tested. However, it was observed that several times a day the reduction gear that would overheat. The grid was also very unstable, making it difficult to plan a stable production throughout the day. Additionally, the production capacity with a single-phase motor turned out to be too small to cover the costs of running the facility, so we had to seek ways to increase the production capacity. The motor would also be overloaded because of the low voltage and misalignments of the rotating parts in the shredder box.

Figure 1: The project team and employees standing proudly in front of the Mityana facility, radiating joy and dedication to the project's implementation.

A reduction gear was developed in Norway and constructed in Uganda to reduce the frequency of the shredder overheating. Two engineers travelled to Mityana in December 2023 to help construct the reduction gear and assist with other technical issues.
The facility workers, on their own initiative, used parts left from the production of the first shredder to build a second shredder for the facility. Since the grid was unstable and weak, they decided to procure a diesel motor for this shredder. To decrease emissions from the operations, as well as to allow for more machines to be run simultaneously and increase the shredder capacity of each machine, we decided to invest in a 3-phase grid connection. With the 3-phase connection, a baler could be operated simultaneously with the two shredders. Therefore, we decided to purchase a baler for the facility as well. This addition would further increase the processing capacity and enhance the business's robustness.

The Norwegian team visited Mityana one last time in June 2024, assisting in resolving any technical issues, as well as business case considerations. This work concluded that the biggest bottleneck for a business case break even was flow of volume of bottles. The necessary, current procedure for removing cap, ring and label (bottle preparation) was too slow.

To increase bottle preparation productivity, a bottle preparation tool (bottle cutter) was developed shortly after in Norway and sent to Uganda. The tool has since proved to reduce the bottle preparation time by up to 75 %, hence increasing the preparation rate by up to a factor of four.

In parallel with adjustments to the shredders and other equipment, the facility manager has been in continuous discussions with potential buyers of the shredded plastic, to ask for quality requirements and prepare for the day when larger quantities can be produced and sold. Since June, they have been actively working towards registering a business to seamlessly take over operations once the project implementation period concludes. This is a testament to their belief in this facility, from machinery to business model.
We have also continuously been cooperating with the NorGlobal biochar project, financed by Norad via the Research Council of Norway, and a collaboration between NMBU, NGI, Makerere University and REDS (implementing partner). This project has educated farmers in making biochar from agricultural organic waste, and 400 farmers have increased their harvest yield through the intervention from this project. Synergies between the projects have been realised by having the same implementing partner (REDS).

The closest collaboration with the current HMF project has been during the endline survey conducted by Makerere University and NGI in June 2024. In this survey questions were included about waste handling, and an increase in waste recycling compared to the baseline in 2021 was observed.
Another synergy was achieved by educating farmers in making biochar formulations by co-composting biochar with organic waste (animal manure and/or greenwaste). This also indirectly educated the people in Mityana that value can be obtained by successful recycling of materials previously considered as waste.

Figure 2: Bottles sorted and prepared for shredding. Shredder to the right.

2.2 Infrastructure and machines/tool innovations

Pyrolysis unit

In this project, the pyrolysis oven was designed as a safer alternative to open-pit burning of plastic waste. The process combust plastics anaerobically (without oxygen present), creating little residues, and reduces emissions of harmful gases. Where conventional pyrolysis processes often yield a form of char and/or oil, this process focuses solely on pyrolysis. The goal was to produce a unit that could pyrolyze waste with low value, while using the heat in the production of recycled plastic commodities. Two units were built and tested in Norway. The pictures below are from testing of prototypes Unit 1 (left) and Unit 2 (right). This section broadly summarizes the testing of the two units.

Figure 3: First (left) and second (right) pyrolysis unit being tested

The testing was performed with temperature measurement collected from various places inside the units, and emissions measurements from the chimney.

The results from testing of **Unit 1** showed controlled, complete pyrolysis of plastic/cardboard waste while measuring high, exploitable temperatures up to 360 degrees Celsius in the chamber. Emissions measurements revealed promising outcomes, with emissions levels lower than those from open burning/smouldering. However, the construction was concluded too rudimentary after a leakage of syn-gas from the reactor. The leakage was caused by damage to the sealing mechanism, which most likely happened during fitting of the reactor lid. Simple designs with high local replicability were, and are always, in focus, but in this case, amendments were necessary to ensure safer operations. The design and construction of a second prototype was concluded necessary.

Unit 2 was designed to be more robust, mobile, and efficient, incorporating new solutions for safer operations. One of these features was an emergency extinguishing system. It releases 215 litres of water into the system within 10 seconds, rapidly cooling it down. During **testing**, pyrolysis was achieved, and was in fact more powerful than anticipated, rendering the system under-dimensioned. This included the reactor safety pressure release mechanism. The extinguishing system proved very effective when tested. Still, post-extinguishing issues like syn-gas condensate and reactor water required more extensive restart measures than anticipated. This affected subsequent test runs.

We rented a state of the art high-tech gas emission measuring unit (GasMet FTIR) to quantify emissions from the constructed pyrolysis unit. These emissions were compared to literature numbers on the open burning and smouldering of cardboard/plastic waste (Wang, Xiaoliang, Hatef Firouzkouhi, Judith C. Chow, John G. Watson, Warren Carter, and Alexandra SM De Vos. "Characterization of gas and particle emissions from open burning of household solid waste from South Africa." Atmospheric Chemistry and Physics 23, no. 15 (2023): 8921-8937).

Table 1: Emission factors for the pyrolysis unit constructed in the present HMF project (Day 1 and day 2 of testing) and comparison with flame curtain kilns run on dry twigs (1), high-tech pyrolysis of wood chips and sewage sludge (2), as well as literature data (3)

- CO: carbon monoxide, a very toxic gas.
- CH4: methane, a strong greenhouse gas (30 times stronger than CO2)
- NOx: nitric oxides, causing acid rain
- SO2: sulphur dioxide, causing acid rain
- NMVOC: non-methane volatile organic matter – gases larger than methane
- TSP: total suspended particles= smoke = aerosols = health concern
- HCl, HF: hydrochloric acid, hydrofluoric acid
- NH3: ammonia, eutrofication
- N2O: nitrous oxide, laughing gas, a 300 times stronger GHG than CO2

	Emission factors (g/kg feedstock)							
	DAY 1		DAY 2		Dry twigs	Sewage sludge	Wood chips	Paper/Plastic bags open burning south africa
	average	stdev	average	stdev	Flame curtain	Biogreen	Biogreen	
CO2	2324		2230		1257	300	1200	2216
CO	27.76	18.87	61.54	22.36	25	0	0.07	142.55
CH4	1.18	1.19	1.16	1.21	1.3	0.1	0.1	not measured
NOx	3.03	2.14	2.19	0.67	3.2	1.5	1.5	10
SO2	0.52	0.34	0.39	0.09	0.14	0.3	0.2	0.345
NMVOC	2.51	0.46	8.55	0.38	0.32	0.2	2	not measured
TSP	2.59	3.46	7.43	1.48	14	0.005	0.01	52.315
HCl	0.13	0.04	0.2	0.03	0.25	0.01	0.02	not measured
HF	0	0	0	0	0	0	0	not measured
NH3	0.1	0.08	0	0.01	0.07	0.1	0.02	not measured
N2O	0.195	0.108	0.041	0.025	0.02	0	0.005	not measured

(1) Flame curtain kiln data: Cornelissen, Gerard, Erlend Sørmo, Ruy Korscha Anaya de la Rosa, and Brenton Ladd. "Flame curtain kilns produce biochar from dry biomass with minimal methane emissions." *Science of the Total Environment* 903 (2023): 166547.

(2) Biogreen high-tech data: Flatabø, Gudny Øyre, Gerard Cornelissen, Per Carlsson, Pål Jahre Nilsen, Dhruv Tapasvi, Wenche Hennie Bergland, and Erlend Sørmo. "Industrially relevant pyrolysis of diverse contaminated organic wastes: Gas compositions and emissions to air." *Journal of Cleaner Production* 423 (2023): 138777.

(3) Plastic/waste open burning/smouldering data: Wang, Xiaoliang, Hatef Firouzkouhi, Judith C. Chow, John G. Watson, Warren Carter, and Alexandra SM De Vos. "Characterization of gas and particle emissions from open burning of household solid waste from South Africa." *Atmospheric Chemistry and Physics* 23, no. 15 (2023): 8921-8937

Toxic CO emissions were 2-4 times lower than those for smouldering, and 1-2 times higher than for flame curtain kilns run on dry twigs. Methane emissions (a strong greenhouse gas) were low, and in the same order of magnitude as those for the preferred artisanal way of biochar making, flame curtain kilns. NOx and SO2 emissions, both contributing to acid rain, were also in the same order of magnitude as those of both high-tech pyrolysis and flame curtain kilns, and for NOx lower than those from waste smouldering. Emissions of TSP = Total Suspended Particles, aerosols or smoke, were much lower than those of smouldering, and even lower than those for flame curtain kilns, though higher than those of high-tech pyrolysis units. Slight emissions of acids HF and HCl were measured but nothing to be concerned about. The same was true for eutrofication-enhancing NH3 and the strong GHG N2O.

All in all, we can say that the emissions of toxic, acidifying and/or greenhouse gases were within reasonable boundaries for the pyrolysis unit constructed by the project.

Table 2: Emission factors for burning and smouldering of various types of waste (Source: Wang, Xiaoliang, Hatef Firouzkouhi, Judith C. Chow, John G. Watson, Warren Carter, and Alexandra SM De Vos. "Characterization of gas and particle emissions from open burning of household solid waste from South Africa." Atmospheric Chemistry and Physics 23, no. 15 (2023): 8921-8937)

Fuel	Burn type	Mean	Emission factor (g kg^{-1} fuel)							
		MCE	CO_2	CO	NO (as NO_2)	NO_2	NO_x (as NO_2)	SO_2	$PM_{2.5}$	PM_{10}
Paper	Flaming	0.96 ± 0.03	1530 ± 24	26.2 ± 6.9	0.58 ± 0.04	0.42 ± 0.15	1.00 ± 0.15	0.68 ± 0.58	12.05 ± 3.28	12.19 ± 3.70
	Smoldering	0.87 ± 0.04	1406 ± 22	101.2 ± 13.3	0.81 ± 0.51	0.86 ± 0.53	1.66 ± 1.00	0.33 ± 0.08	15.21 ± 6.96	15.16 ± 6.67
	Total	0.90 ± 0.02	1498 ± 7	44.9 ± 3.2	0.63 ± 0.16	0.52 ± 0.19	1.14 ± 0.31	0.57 ± 0.41	13.31 ± 0.77	13.42 ± 1.21
Rubber	Flaming					No flaming phase				
	Smoldering	0.92 ± 0.02	456 ± 41	28.1 ± 3.9	0.31 ± 0.15	2.75 ± 4.44	3.06 ± 4.59	0.16 ± 0.04	141.34 ± 23.01	153.19 ± 20.26
	Total	0.92 ± 0.02	456 ± 41	28.1 ± 3.9	0.31 ± 0.15	2.75 ± 4.44	3.06 ± 4.59	0.16 ± 0.04	141.34 ± 23.01	153.19 ± 20.26
Textiles	Flaming	0.97 ± 0.01	1540 ± 129	27.3 ± 8.9	9.53 ± 1.95	1.17 ± 0.19	10.70 ± 5.58	4.43 ± 2.12	37.20 ± 22.65	42.78 ± 31.32
	Smoldering	0.86 ± 0.03	1227 ± 59	149.5 ± 34.5	11.57 ± 8.73	1.19 ± 0.53	12.76 ± 9.87	1.68 ± 0.45	75.56 ± 15.33	87.55 ± 24.71
	Total	0.87 ± 0.03	1467 ± 104	54.9 ± 7.4	10.37 ± 3.72	1.21 ± 0.15	11.58 ± 6.57	3.72 ± 1.48	47.04 ± 16.83	53.95 ± 26.96
Plastic bottles	Flaming					No flaming phase				
	Smoldering	0.56 ± 0.05	182 ± 42	90.4 ± 10.6	0.22 ± 0.26	0.12 ± 0.08	0.35 ± 0.34	0.22 ± 0.02	651.00 ± 38.45	722.47 ± 17.98
	Total	0.56 ± 0.05	182 ± 42	90.4 ± 10.6	0.22 ± 0.26	0.12 ± 0.08	0.35 ± 0.34	0.22 ± 0.02	651.00 ± 38.45	722.47 ± 17.98
Plastic bags	Flaming	0.98 ± 0.00	2938 ± 26	21.0 ± 5.1	0.70 ± 0.17	0.72 ± 0.04	1.42 ± 0.14	0.08 ± 0.01	33.48 ± 9.22	36.01 ± 9.62
	Smoldering	0.89 ± 0.01	2506 ± 247	183.9 ± 13.7	3.74 ± 0.82	6.87 ± 2.62	10.61 ± 3.15	0.36 ± 0.17	85.75 ± 76.56	89.47 ± 76.47
	Total	0.94 ± 0.01	2934 ± 24	22.4 ± 5.4	0.72 ± 0.17	0.77 ± 0.06	1.50 ± 0.12	0.08 ± 0.01	34.00 ± 8.55	36.55 ± 8.88
Vegetation (0 % mc*)	Flaming	0.97 ± 0.01	1573 ± 11	21.0 ± 3.6	2.94 ± 0.42	0.40 ± 0.15	3.34 ± 0.21	0.72 ± 0.14	3.80 ± 1.07	3.60 ± 0.83
	Smoldering	0.84 ± 0.02	1366 ± 18	156.2 ± 13.6	1.87 ± 0.16	0.29 ± 0.03	2.17 ± 0.12	0.12 ± 0.02	1.70 ± 1.68	1.57 ± 1.48
	Total	0.88 ± 0.01	1515 ± 12	58.5 ± 4.8	2.64 ± 0.32	0.37 ± 0.12	3.01 ± 0.11	0.54 ± 0.08	3.20 ± 1.25	3.02 ± 1.01
Vegetation (20 % mc*)	Flaming	0.93 ± 0.04	1549 ± 14	34.7 ± 8.1	2.42 ± 0.13	0.74 ± 0.12	3.16 ± 0.24	0.76 ± 0.10	5.40 ± 1.00	5.56 ± 1.14
	Smoldering	0.87 ± 0.02	1390 ± 7	135.5 ± 15.2	1.43 ± 0.08	0.47 ± 0.09	1.90 ± 0.01	0.20 ± 0.08	5.88 ± 7.27	6.18 ± 7.68
	Total	0.91 ± 0.03	1505 ± 1	63.9 ± 3.3	2.17 ± 0.07	0.64 ± 0.07	2.82 ± 0.13	0.56 ± 0.07	4.80 ± 1.98	4.97 ± 2.16
Vegetation (50 % mc*)	Flaming					No flaming phase				
	Smoldering	0.79 ± 0.00	1124 ± 0	183.6 ± 0.7	1.64 ± 0.15	0.25 ± 0.04	1.88 ± 0.19	0.28 ± 0.05	87.57 ± 6.83	92.66 ± 7.24
	Total	0.79 ± 0.00	1124 ± 0	183.6 ± 0.7	1.64 ± 0.15	0.25 ± 0.04	1.88 ± 0.19	0.28 ± 0.05	87.57 ± 6.83	92.66 ± 7.24
Food	Flaming					No flaming phase				
	Smoldering	0.89 ± 0.01	955 ± 30	76.1 ± 7.6	1.71 ± 0.34	0.27 ± 0.01	1.98 ± 0.34	0.16 ± 0.02	82.97 ± 18.36	87.23 ± 20.76
	Total	0.89 ± 0.01	955 ± 30	76.1 ± 7.6	1.71 ± 0.34	0.27 ± 0.01	1.98 ± 0.34	0.16 ± 0.02	82.97 ± 18.36	87.23 ± 20.76
Combined	Flaming	0.98 ± 0.00	1443 ± 8	14.9 ± 0.7	1.66 ± 0.14	0.63 ± 0.03	2.29 ± 0.16	1.13 ± 0.15	6.94 ± 2.32	7.34 ± 2.36
	Smoldering	0.88 ± 0.02	1302 ± 28	105.1 ± 11.0	2.40 ± 0.19	0.55 ± 0.09	2.95 ± 0.26	0.17 ± 0.06	6.55 ± 3.01	6.95 ± 3.22
	Total	0.91 ± 0.01	1417 ± 8	31.6 ± 1.8	1.80 ± 0.11	0.61 ± 0.00	2.41 ± 0.11	0.95 ± 0.13	6.86 ± 2.08	7.26 ± 2.12

Considering both the operational and emissions tests, our **assessment concludes** that an appropriately dimensioned system would have given even better results than hoped. The uncovered safety issues can be mitigated. The temperatures achieved were deemed too high for controlled melting of recycled plastics. The potential for a locally deployable, robust pyrolysis system is validated by these results. In addition, the potential impact of such a unit is significant. So much so that another project already has been granted, solely for the purpose of developing a functional unit.

Deviating from the initial project objectives, the unit was not deployed. This was, partially and as previously mentioned, due to pandemic travel restrictions. In addition, the test results showed that further development of the unit was necessary before deployment. High pressures and temperatures, and harmful, flammable syngas are important safety aspects and must be treated as such if we are to live up to our safety standards.

Shredders

The project's first shredder was built by the Technical University in Kampala, with significant support from Engineers Without Borders Norway, and the facility workers.

Initially, we wanted to commission a local business to produce a Precious Plastic Shredder Pro. The construction and material requirements for this machine (in addition to what we believe to be opportunist pricing for an international project) rendered the total cost of the shredder several hundred percent too expensive. In response to this, we redesigned the shredder to be easier and cheaper to produce.

From here, we worked with Nakawa Vocational Training Institute in Kampala who provided materials, labour, expertise, machines and facilities. The result was a functioning, robust, less complicated shredder. As far as we know, the first to be entirely produced in Uganda only. The complete shredder assembly with motor, gear, and shredder box with hopper is shown in Figure 4 below.

Figure 4: Complete assembly of first shredder. Motor (blue), reduction gear (green), coupling (red), shredder box (black) and hopper (black top) make up the total assembly, mounted to a frame.

The parts we initially received were of poor quality. A considerable amount of time was spent adjusting parts so they would fit in the final assembly. This was partially successful as the shredder had significant internal friction, diminishing its function.

After the first shredder had had some time in use in Mityana, we returned to Nakawa where the shredder had been brought. The shredder had significant wear on rotating parts and production stops had been frequent. We proceeded by getting new parts for a second shredder, while discarding the first. Stabilizing design changes were made. The delivered parts required quite a bit of adjustments still. After this we were left with a much better functioning shredder. Due to other critical technical issues needing attention, we were unable to finish the entire shredder before departure. Our colleagues at Nakawa finished the assembly, now being intimately familiar with the shredder design.

On our return to Nakawa a few months later, we discovered that they had, unbeknownst to us, built a third shredder, from rejected parts. The blades, however, had been made from a different, much more wear resistant material. The Norwegian partners had not been able to source this, but the Ugandan ones eventually were. The third shredder now functions the best of all. This shows how well our approach on capacity building for technical sustainability has worked. New blades of even higher material quality have been sourced for the second shredder. Our local partners have located a provider in Kenya, from which they have imported them.

Figure 5: Complete set-up of second (right) and third (left) shredder. The reduction gear (green box) has been replaced on the second shredder.

The shredders are now operating nicely at the facility in Mityana. A network of workshops, people and suppliers has been established along with intimate knowledge of the machine. This lays the foundation for the shredders to operate for years to come. As was one of the core intentions of this project. Maintenance, repair and procurement of more is easily accomplished without our intervention. With 3 phase power at 380 Volts being available at the facility since November, new, more powerful motors (10 and 15 HP) have been purchased to significantly increase the torque and capacity of the shredders. The shredders have been designed to bear the loads of such high power use. With this, the shredders are expected to individually shred 40 kg/hour of PET bottles. This number could theoretically be higher, something operation of the new set-up will determine.

The drawings developed through the project aimed to make a design that could be easily built locally by a manufacturing company, even without advanced processing tools or previous experience in building shredders. When a company has produced this machine for us, they can also construct this same machine for others wanting to start a plastic processing business. It is also a big advantage that it is built locally if it had to be sent for repairs.

Reduction Gear

For context: *a reduction gear is used when a motor rotates faster than we would like the machine it is running to rotate. In our case, the motor rotates about 50 times faster than we would like the shredder blades to rotate. The gear does this reduction for us. The speed is reduced, and consequently (from mechanical equilibrium) the torque ("force of rotation") goes up.*

When the first shredder was received for inspection at Nakawa, the reduction gear had several issues. It had a history of overheating during operation, oil was leaking and cracking was observed. The gear was initially sourced in Kampala after significant efforts from our colleague and purchased at a high price. The gear that was used was probably around 20 years old (best guess from condition of paint) and likely rated for lower loads than our operations require. Reduction gear is shown in Figure 6.

Figure 6: Image shows the initial reduction gear.

Our assessments concluded that the gear needed to be replaced. Since gears were expensive and hard to find, a simple and robust gear was developed through the project. The new reduction gear was made from readily available motorcycle parts and components either produced at Nakawa or purchased in Kampala. We arranged and connected three chain-drives with shafts made at Nakawa. From scrap steel we made frames with industrial bearings, holding the shafts. From the required gear ratio (1:54), we could calculate the necessary number of teeth for all sprockets. Assembling the sequence of connected chain drives completed the reduction gear missing only a safety cover as shown in Figure 7 below.

Figure 7: Finished reduction gear is being welded to the frame for function testing. The coupling to the motor was made at Nakawa to fit the shaft dimension.

The gear cost a fraction of the initial one in materials. It is highly robust due to its large dimensions. Motorcycle parts (sprockets and chains) are readily available around the world, with the bearings available in most likely every capital city. The remaining parts can be made with basic steel profiles, bolts and nuts, a lathe, a drill and basic welding equipment. It is easy, cheap and intuitive to repair, and no special gear oils are required. By variations of one to three chain drives and various sizes of motorcycle sprockets, any gear ratio, theoretically, up to 1:260 can be set. The gear is still running nicely at the facility in Mityana, and a second one is being made for one of the new motors.

Manual baler co-developed with RIPL project

The manual waste baler, "The Bale-Out", is a transformative tool designed to empower individuals and small businesses in low- and medium income countries by making plastic waste into compact, manageable bales. With its cost-effective, electricity-free operation, this baler is particularly suited for remote or resource-limited areas. It was designed to be possible to construct with very basic tools and materials. Structurally, the design has aimed for the highest strength-to-weight ratio to make it as light as possible. With the transport wheels, the baler can be manually moved by one person. The compressive force is produced by a garage jack, that is inserted underneath, without needing modification. The jack moves a piston inside the chamber with the required compressive force. When using a jack with 2.5 tonnes of force, the surface pressure of the baler is approximately half of what the large, industrial balers produce. Sequential filling of waste through the top lid and compression produces the bale. Slits have been made to make room for strings used to tie off the bale before ejection. The weight of the baler frame is 64 kg, the piston weighs 10 kg, giving a total weight of the baler of 74 kg. A garage jack of 2 to 3 tonnes normally weighs 20-30 kg, giving the total assembly weight of 94 to 104 kg.

Developed as part of the SUWASO project, as well as the Preventing plastic in Nepal rivers by strengthening the informal sector (RIPL) project, the baler's drawings have been shared with the facility. Since adequate electrical power was made available at the facility, an electric, more powerful baler was procured. The facility has the option to construct or purchase a "Bale-Out" using the provided drawings at a later time if they find it beneficial in addition to the electric baler. The manual baler is also possible to set up as at collection points to ease the transport of bottles to the facility.

Figure 8: First baler prototype and testing

A prototype was constructed in Oslo for testing and proof of concept. The testing was done using cardboard as baling material. Ideally, we would have tested with PET bottles, but due to the Norwegian deposit system, we could not collect enough bottles to test. We used cardboard as it was readily available and is an equally tough fraction to compact.

Test 1 of the initial version gave proof of concept on the first run. The baler successfully compacted the cardboard. However, due to expansion of the compacted material, high friction occurred between the material and baler chamber wall. The material was tough to remove from the baler when finally baled. Still, a bale of six kilograms of cardboard was successfully produced.

The friction issues forced a redesign of the baler frame and function. The new design incorporated two doors, rotating on a vertical axis. As opposed to the single door with a horizontal axis rotation on the initial design. The two doors are connected with a heavy-duty toggle latch, allowing for pressure release when opened while still connected. The lid has also been fitted with a toggle latch that holds up to three tonnes of force. The baler was retrofitted to test the new design.

Test 2 was carried out in the same way as Test 1. A volume of cardboard was compressed by sequentially filling the chamber and compressing. The two-door mechanism proved highly effective in removing the frictional forces. Re filling after every compression was very easy. After 6 repetitions a bale of eleven kilograms was produced.

Figure 9: "The Bale-out" Prototype 2

Our assessment concludes that “The Bale-Out” is a practical and effective tool for compression of waste. It provides opportunity for waste compression and baling in remote areas. Its relatively light weight makes it possible to move over some distance by 1-2 people without means of transportation. It can compress the volume of waste 5-10 times. That means reducing the required number of trips to a recycler by the same rate, consequently **reducing emissions from- and cost of transport by 80 – 90 % pr kg of waste compressed.**

The "Bale-Out" technical specifications are:

- **Outer dimensions:** H: 1050 mm, W: 460 mm, D: 460 mm
- **Chamber dimensions:** H: 800 mm, W: 400 mm, D: 400 mm
- **Weight:** 73 kg

Hydraulic electric baler

A hydraulic baler was purchased for the facility. It is a single-phase power 10 tonne baler. This was produced after our own specifications. This baler is relatively small compared to industry standards, but very practical for smaller operations, such as ours. It can process close to 3 bales per hour, given 6 cycles per bale, and each 1 minute pressing cycles. With each bale weighing approximately 30 kg, the processing potential is hence approximately 90 kg per hour for PET bottles. This is likely to be substantially higher for baling HDPE or HDPE.
Should the 3-phase grid fail, it would still be possible to run this baler. Were the shredders to stop for maintenance, production could continue. This production redundance further solidifies the facility business model.

Bottle preparation tool / bottle cutter

The bottle preparation tool was developed as part of this project to significantly increase the number of bottles prepared for shredding and/or baling. This tool reduces the preparation time for a single bottle from 10-15 seconds down to 2-5 seconds. It features a set of knives that remove the cap and ring around the bottleneck in the first step, and a second knife that cuts the label for quick removal in the subsequent step.

Due to time constraints, the tool prototype was constructed in Norway and sent to Uganda. It was designed using tools and materials for easy replication there. The tool was assembled over video call with our technical lead supporting the staff at the facility directly.

This tool has very high transferability to other contexts and can cheaply increase production of pure PET fractions for collectors. This improved their business model in three ways: better pay for pure PET fractions, much higher volumes and income from separated HDPE (cap and ring).

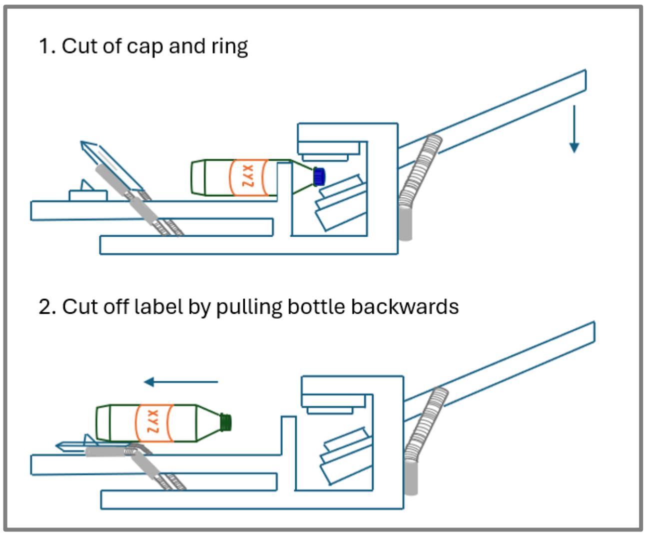

Figure 10: Illustration of bottle cutter

Figure 11: Bottle cutter testing

Facility building with 1- and 3 phase power:
The facility was constructed on land owned by the Municipality, with an agreement to lend the land for the duration of the project. The building includes space for the machines, a sorting area, and a storage area. Initially, the plan was to set up the processing machines in a rented facility, but we were unable to find a suitable location near Mityana. The search for an appropriate facility, along with the design and construction phases of the facility we ended up with, caused significant delays and required budgetary reprioritizations.

Figure 12: Processing facility in Mityana

Figure 13: Construction of 3-phase electric power at for the facility in Mityana

Shed and toilet at the landfill:
A shed and toilet have been installed at the Municipal Landfill to offer a higher level of comfort for the informal workers who collect plastic for recycling (i.e., not the ones having set up their own business around plastic recycling). This initiative was undertaken after the project team identified the need during their visit to the landfill in April 2022. Additionally, the informal workers have been provided with some safety equipment. However, since this was not part of the original project plan, we have not been able to follow up on this regularly.

Figure 14: Picture of the toilet at the Landfill

2.3 Business establishment and operation

Since April 2023, the facility in Mityana has employed one manager, one technical engineer, and one support staff member. These employees have been actively involved in all facility-related activities since then. Inclusion and true agency in the development, construction and operations of tools and machines, and the development of the business model has built strong ownership. In June 2024, the employees decided to register their own company (Ashimoki General Trading Company Limited) to take over operations after the SUWASO project concludes.

The facility currently operates two shredders with processing capacities of 75 kg and 55 kg of PET bottles per hour, respectively, along with a baler that can process approximately 100 kg per hour. The shredders were tested with PET bottles which were cut open with the bottle preparation tool. With around 190 operating hours each month, the facility can process over 40 tonnes of plastic monthly. This high production potential from three different machines ensures resilience against power outages and machine breakdowns, while also allowing for the production of various products based on market quality and price fluctuations.

Figure 15: Shredded plastic sample, unwashed and washed. This sample is from before upgrading the shredders with new motors.

The primary bottleneck of the material flow remains the preparation of bottles. Using the bottle cutter, preparation now takes 2-5 seconds per bottle, compared to 10-15 seconds manually. With an average PET bottle weight of 26 grams, and assuming 2-5 seconds per bottle, it is estimated that one employee can process between 18 and 46 kg (avg. 32 kg) of PET bottles per hour using the bottle preparation tool. The facility engineer plans to construct more of these tools to increase preparation capacity. To match the aggregate production rate of shredder bottles (130 kg/h), 3-7 of these tools would need to be operational. If adding the hydraulic at 90 kg/h, the number would be 5- 12 tools.

The business, Ashimoki, has engaged with several plastic recycling companies in Kampala to evaluate quality requirements and potential sales prices. It is important to note that competition in the processed plastic market is intensifying, with increasingly larger players entering the field. This surge leads to higher quality standards. However, we are confident that our facility's machinery can meet these demands, especially with the expertise of our technical engineer, who can make necessary adjustments to the equipment.

Processing the plastic at the Mityana facility adds value to the plastic and reduces transport costs, especially for plastic bottles, which would otherwise need to be transported 70 km with its full volume or crushed by hand.
The business strategy moving forward has two main focus areas:

1. Increasing the amount of plastic bottles (and potentially other fractions) collected from households in Mityana.
2. Supporting other collectors and aggregators in and around Mityana to make their businesses more profitable through processing their plastic in our facility, thereby encouraging more plastic collection.

To boost plastic bottle collection in Mityana, the business will distribute bags to households and institutions, asking them to fill the bags and call for collection when full. They will be paid per kilogram upon collection. The collection price will be adjusted based on transport and processing costs, as well as the income from selling the plastic in Kampala. This plastic will need to be sorted and prepared at the recycling facility.

Additionally, the facility can offer processing services to other collectors and aggregators, allowing them to bring their plastic for baling or shredding. The cost of this service should cover electricity, shredder wear and tear, and a portion of the workers' salaries. The electricity costs are up to 140 UGX (0.04 USD) per kilogram for shredding of PET and 12 UGX (0.003 USD) per kilogram for baling of PET. The salary costs to be covered will depend significantly on whether the facility workers are expected to prepare the bottles with the bottle cutters and sort the plastic into fractions, or if the collectors/aggregators have already prepared the plastic themselves. If facility workers need to prepare the bottles, one worker can handle approximately 30 kg of bottles per hour. This results in a cost of approximately 70 UGX (0.02 USD) per kg if this task is performed by support staff. Additionally, the salary for the machine operation personnel needs to be covered, which will likely range between 20 and 40 UGX (0.55 to 1.1 US cents), depending on the machine used. If facility employees are only required to shred or bale the bottles, the cost per kg of shredded or baled plastic will need to cover only the salary of the machine operator, along with the costs for electricity and wear and tear.

When combining the two business strategies, it is evident that if one covers a higher fraction of the salary costs and wear and tear, the other strategy can cover slightly less, vice versa. This will need to be sorted out during the testing phase, gathering more information about machine operation hours, actual collection costs, transport costs, and the quality of output from the different machines. Some adjustments might be necessary to improve quality. However, with high-quality PET shredding, we can achieve an income of around 1,300 UGX (0.35 USD) per kilogram. This should be sufficient to cover collection/purchase costs (estimated at 750 UGX (0.20 USD) per kilogram of PET), processing, employment, and transport costs (estimated at 10-100 UGX (0.0027-0.027 USD) per kilogram of PET), as long as more than approximately 80 kg high enough volumes can be collected and prepared. These assumptions and results are presented in detail below.

It is expected that as operations begin, it will become clear that more employees are needed to manage all processing-related tasks at such a large facility. This will be determined after assessing the balance between in-house collection and processing plastic for other collectors/aggregators, and evaluating the workload for each strategy.

We believe there is not enough PET waste in Mityana and the surrounding area to maintain production capacity with only this waste fraction. In the baseline assessment, it was estimated that approximately 32 tonnes of PET bottle waste accumulate in Mityana each month. This amount would utilize less than 15% of the machine's capacity. Even if assuming that we can find the equal amount of PET in the surrounding area, it would still utilize less than 30% of the capacity. Therefore, the facility will also process HDPE and other plastic waste fractions as needed by other collectors/aggregators. Through inquiries, we have estimated that a minimum of 2-3 tonnes of PET bottles and 2-3 tonnes of HDPE are collected daily by these collectors/aggregators. This can potentially fill the processing capacity at the facility if a significant number of these collectors see the benefit of such a cooperation.

Figure 16: Shredded plastic bottles, stored before transport ready for transport to Kampala

Since very little is known about delivering processing services at the facility, we have not outlined potential costs and profits for this business strategy. However, we have more information regarding the collection, processing, and sale of PET bottles, and based on this, we will present some potential operational results below, assuming the business focuses solely on this.

Table 3: Assumptions in business case without selling processing as a service

	25% machine operation	50% machine operation	75% machine operation
Kg shredded	6 tonnes/month	12 tonnes/month	19 tonnes/month
Kg baled	4 tonnes/month	9 tonnes/month	13 tonnes/month
Monthly Electricity costs shredders	876 000 UGX (239 USD)	1 752 000 UGX (477 USD)	2 629 000 UGX (716 USD)
Monthly Electricity cost baler	53 000 UGX (14 USD)	106 000 UGX (29 USD)	159 000 UGX (43 USD)
Number of employees	5	8	10
Monthly employment cost	2 850 000 UGX (776 USD)	3 750 000 UGX (1022 UGX)	4 350 000 UGX (1 185 USD)
Plastic collection/purchase price	750 UGX/kg (0.2 USD/kg)		
Monthly maintenance and other unforeseen costs	400 000 UGX (109 USD)		
Transportation costs	100 UGX/kg (0.03 USD)		
Income shredded PET	1300 UGX/kg (0.35 USD)		
Income baled PET	1000 UGX/kg (0.27 USD)		

The tables below shows a simplified overview of the resulting costs per kg processed plastic for the shredding and baling, given that the two processes are equally time consuming and requires equal maintenance and other unforeseen costs.

*Table 4: Costs per kg **shredded** plastic, given equal employment and maintenance costs for shredding and baling. Sales price for shredded plastic is 1 300 UGX/kg (0.35 USD). The costs for baled plastic are the same as for shredded, except for electricity cost which is 128 UGX (3.8 USc) lower for baling. The sales price for baled plastic is 1 000 UGX/kg (27 USc/kg). Baled plastic is cheaper than shredded plastic, as the baled plastic is not pre-shredded.*

	Emplo-yee costs	Plastic purch ase	Electr-icity	Transport-ation	Maint-enance	SUM
25% oper-ations	270 UGX 7 USc	750 UGX 20 USc	140 UGX 4 USc	100 UGX 3 USc	38 UGX 1 USc	**1 298 UGX 35 USc**
50% oper-ations	178 UGX 5 USc	750 UGX 20 USc	140 UGX 4 USc	100 UGX 3 USc	19 UGX 0.5USc	**1 187 UGX 32 USc**
75% oper-ations	137 UGX 4 USc	750 UGX 20 USc	140 UGX 4 USc	100 UGX 3 USc	13 UGX 0.3 USc	**1 140 UGX 31 USc**

Considering that shredded plastic can be sold for 1,300 UGX (0.5 USD) per kilogram, Table 4 indicates that shredding plastic generates a profit as long as more than 25% of the production capacity is utilized. Conversely, baling plastic does not seem profitable, given the selling price of only 1,000 UGX/kg (27 USc/kg), unless more than 75% of the production capacity is utilized. However, it may not be accurate to equally distribute employment and maintenance costs between the two production methods. Ashimoki is encouraged to conduct updated financial assessments after observing the actual workload for both operations, as well as maintenance and unforeseen costs, over a period of time.

Assuming 25%, 50%, and 75% production capacities for baling and shredding, the monthly costs and revenues are illustrated in the figure below. The graph shows that the business becomes profitable overall if the machines operate at approximately 40% capacity (90 kg/hour) or more. At 50% machine operation, the monthly profit would be almost 1 million UGX (272 USD), while at 75% operation, the monthly profit would be almost 3 million UGX (817 USD). It is unlikely that this volume of PET bottles can be collected solely within or around Mityana, as other collectors and aggregators are also sourcing from this area. However, the results indicate significant profit potential if plastic is collected from the area and processed before selling. We believe this is applicable for other plastic types (HDPE) as well. While there are many uncertainties in these figures, they do suggest that there is potential in this recycling business based on the current market information.

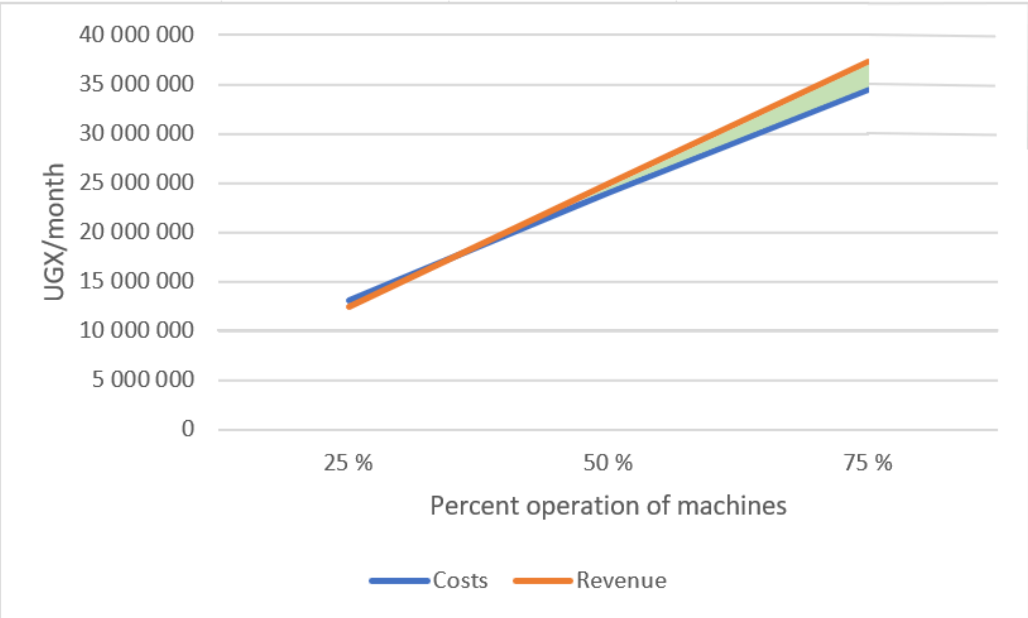

Figure 17: Assumed monthly costs and revenue given 25%, 50% and 75% operation of the machines. Green area marks the profit, which goes from -120 000 if operating the machines 25% of the time, up to almost 4 000 000 UGX if operating the machines 75% of the time

The figure below illustrates the monthly costs and revenue, assuming a cost increase of 50 UGX (0.014 USD) per kg processed plastic. It shows that given this cost increase, the production would only be profitable with more than approximately 60% operation of the machines. This scenario is particularly relevant in the event of plastic price fluctuations or if the estimated costs for transport, employment, maintenance, or unforeseen expenses prove to be too low. This highlights the importance of maintaining a focus on cost control and establishing a savings account for challenging times.

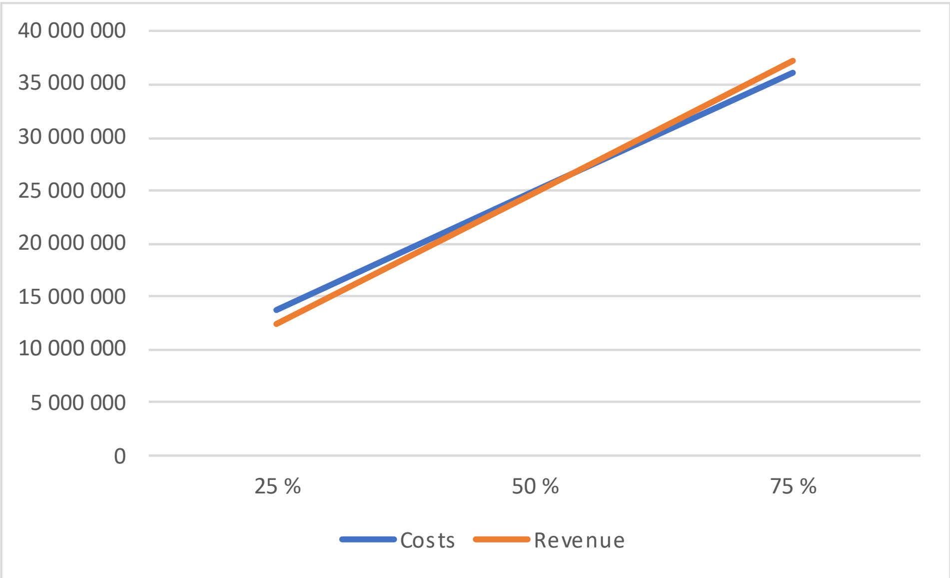

Figure 18: Sensitivity scenario showing 100 UGX/kg higher costs.

Conclusive remarks on the business model

With these results in mind, we can conclude that this project has successfully established a recycling facility with significant potential to clean up plastic waste from the surrounding area. It incentivizes households to recycle their plastic instead of burning or dumping it, while also empowering local employees to choose their own business strategies and direction. This initiative can increase profits for other collectors and aggregators, while also reducing emissions from transporting plastic from Mityana to Kampala for recycling.

The scalability and transferability of this project to other contexts are significant. While exact costs and revenues will vary from area to area, the technical solutions used in the facility—such as the easy-to-build shredder, the reduction gear, and the bottle cutter tool—provide a solid foundation for potentially profitable business models in other regions.

It is important to highlight the interplay between local technology development and business model evolution, which creates opportunities for long-term success. This process has identified and addressed bottlenecks, allowing for the direct development of technology and business models based on local needs. Initially, the plan was to produce a specific product, but market research indicated that this could be challenging and that there was a market for shredded plastic. This decision helped avoid significant costs associated with unnecessary machinery and allowed professional recycling actors to take on this task.

Lastly, the importance and value of the market research conducted cannot be overstated. It was a crucial factor in guiding the project's direction and ensuring its viability. With the facility now fully equipped and connected, we are ready to witness the full potential of its production capabilities. Although the annual production during the last year of project implementation was only 1.5 tonnes of plastic, we believe that the annual production going forward will be between 100 and 350 tonnes, as we anticipate the machines will operate between 25% and 75% capacity, see Figure 19.

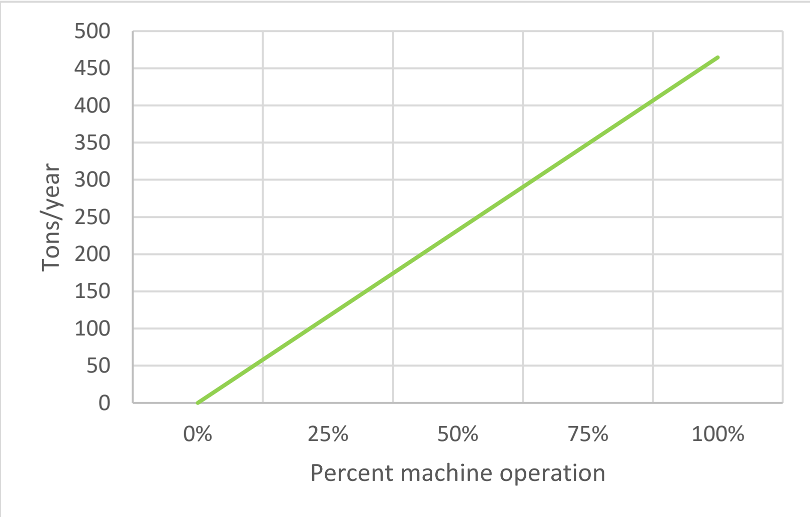

Figure 19: Annual production given 0-100% machine operation

3 Mali

The SUWASO project in Mali is implemented in San and Mountougoula. San is a city in the Segou region, 344 km from the capital Bamako, with a population of approximately 110.000. The town is situated central north-east in Mali, in a region that lately has been the scene of several violent strikes by non-state armed groups. Mountougoula, the second site, is situated in the suburbs approximately 30 km south east of Bamako in the Koulikourou region.

Both locations are experiencing challenges relating to waste management, with plastic and regular waste being deposed both in urban settings as well as in the nature.

This project is a continuation of the Green Jobs Programme, received with funding from HMF. This project period lasted from 01.01.2020 to 31.03.2023 and consisted primarily of setting up the two production units with additional components, and establishing the organisational infrastructure consisting of community-managed savings groups (CMSGs) and the youth-led production teams. [1]
The project consortium consisted in San region by the local implementing partner organization APSM and in the Bamako region AMSS. Technical resource partner, having a long experience in setting up similar plastic recycling units was Yamba-D, based in Ouagadougou, Burkina Faso. In addition, Engineers without Borders in Norway provided technical guidance and assistance.

This project responds to the combined challenges of waste management, including widespread plastic waste and high youth unemployment rates. The focus is on collecting and recycling soft plastic waste (plastic bags) collected by CMSGs producing school benches/tables and promoting environmental protection. Later in the program, the product portfolio was diversified into regular desks, stools and other plastic furniture.
Collection of plastic has contributed to reduced plastic contamination of nature, reducing lethal exposure of plastic to wildlife and domestic animals. It is assumed that the combined effects of the collection of plastic waste, and the sorting of waste into three fractions of waste - plastic, organic and residual – also have contributed to reducing emissions stemming from open pit burning. Further, replacing wood with recycled plastic in production of school benches contributes to reduced logging, and deforestation and thus contributes to reducing the effects of climate change.

The project has also contributed to a diversified and increased income for vulnerable women organized in savings groups. The women are paid 100 FCFA (0.16 USD) per kilo of plastic sold to the production units. The youth group sells the benches for approximately 37.000 FCFA (57.5 USD), and in principle, there is a small margin of profit. These activities thus enhance the financial resilience of the households.

In the following, a short recap will be done of the main milestones of the project:

[1] The first pilot project started with establishing production units in San in 2020 and continued with a 2nd production unit being established in Mountougoula outside Bamako. (01.01.2020-31.03. 2022, Recycling plastic waste through green jobs in Mali, funded by HMF)

3.1 Assessment of plastic waste and market opportunities

In January 2022, a report on the plastic waste market in Mali was finalized, laying the basis for further project implementation. The report involved data collection from various stakeholders, including the municipality, Economic Interest Groups (EIGs), GIZ (German International Cooperation, and other relevant stakeholders in the waste management sector in Mali. The report provides an in-depth analysis of the waste management practices within the municipality. The most important conclusion in this report is that the proliferation of plastic waste in Mali poses significant environmental, health, and economic challenges. Despite various initiatives and laws aimed at managing plastic waste, such as the 2014 law prohibiting non-biodegradable plastic bags, the problem persists due to factors like low public awareness, lack of enforcement, and the entrenched use of plastic bags. Recycling efforts, while beneficial, are insufficient to address the scale of the issue. Comprehensive strategies involving increased awareness, stricter enforcement, and the promotion of alternatives to plastic bags are necessary to effectively manage plastic waste in Mali.

3.2 Employment, Machine and infrastructure, Testing and Training

From the onset of establishing the production sites, the local municipalities have been engaged and involved. Construction has been carried out while ensuring collaboration with local and regional authorities as well as civil society to promote ownership and compliance.

Production was set to start in June 2022 with the test phases.

Committed and Trained Youth: 10 youth, 2 girls and 8 boys, have been engaged in the Mountougoula unit whereas in San 9 youth, 2 girls and 7 boys, are engaged. The youth have a service contract with the units and work on a piece-rate basis and the level of remuneration depends on the production during the month. The local youth were recruited based on applications and interviews and travelled to Burkina Faso to acquire the techniques of melting plastic bags into school benches.

3.3 Sorting of household waste, compost, production of biochar and fuel briquettes

The waste management part of the project started in July 2023 with awareness training and sensitization of municipalities, households of the savings groups and the youth from the production units. Installation of waste bins at household level, monitoring of activities, implementation of compost and biochar making as well as the youth mobilisation for the experimentation of products in demonstration garden plots followed.

The selection and acquisition of bins for waste sorting for each household: After a survey on the availability of bins and corresponding prices, half barrels with covers were selected, and altogether 400 bins were distributed - two for each household - with 200 in San and 200 in Mountougoula for organic and residual waste, covering 100 households in each location.

Number of households formed & Equipped: 200 Ongoing Awareness Training Creation of household waste depots for composting: we received some depot, we discussed with GIE to continue to provide household organic waste. In San the process is ongoing with training and awareness training	

Test production of biochar and fuel briquettes:

12 youth and 240 members of saving groups were trained in biochar and fuel briquettes production. The test production was carried out in small scale and for own consumption.	  
Number of Women sensitized in biochar production and in the making of briquettes 240. Household sensitization: 35 savings group,	
Household sensitization: 35 savings group	 
Compost production by youth in Mountougoula: this compost is used in market gardening inside the production unit.	 

Market gardening - to enhance resilience Market gardening in Mountougoula Cultivation: European eggplant and okra The area used is 340 m² transplanting date: 27/05/2024 900 European eggplant plants are planted.	  
Testing out soilless market gardening inside the production unit in San – using tires, bags and containers to cultivate in which is a good alternative in urban to semi-urban settings	  
Technical training for female participants of the Community Managed Savings Groups (CMSGs) applying biochar / compost , They were trained in making boards, composting techniques, Setting up and running a nursery, Zaï's techniques, and transplanting techniques, crop fertilization and spraying Techniques, crop care, Crop observations (identification of deficiencies, diseases and crop attack) and control methods	 

12 youth and 93 women from the saving groups were trained in biochar and compost production. Further 200 households with 1.909 members and 90 municipality representatives were trained and equipped on waste sorting techniques and environmental protection issues. Nineteen youths, including seven girls, were trained in plastic melting. Following the training, 426 women from the CMSGs collected a total of 156 517 kilos of plastic waste.

3.4 Ensuring sustainable operation at the units

For a more sustainable and long-term project management, the project participants in each municipality have been organized into cooperatives.

The association “Jeya ni Saniya Gestion des Déchets” (AJSGDS)has been set up and legally registered as a “GIE” (Income-generating legal entity) for the management of the San production unit. Similarly, NOUGOUDJI was created as a legal entity for the management of the Mountougoula production unit.

The young workers are engaged through a service contract with the unit and operate on a piece-work basis. Their earnings depend on the monthly production levels. Women are compensated at a rate of 100 FCFA (0.16 USD) per kilogram of collected plastic. Each unit's daily production capacity is 14 school benches with each bench requiring approximately 25 kilograms of plastic for manufacturing. The total production details are summarised in the table below:

Table 5: Collection and production summary

			
	San	**Mountougoula**	**Total**
Plastic collected 2020 (kilos)	7,464	0	7,464
Plastic collected 2021(kilos)	22,802	0	22,802
Plastic collected 2022 (kilos)	58,004	12,390	70,394
Plastic collected 2023 (kilos)	21,073	8,583	29,656
Plastic collected 2024 (kilos)	14,636	11,565	26,201
Accumulated (kilos)	**123,979**	**32,538**	**156,517**
Bench tables product 2020	324	-	324
Bench tables product 2021	456	-	456
Bench tables product 2022	605	313	918
Bench tables product 2023	524	392	916
Bench tables product 2024	880	525	1,405
Accumulated	**2,789**	**1,230**	**4,019**
Semi-produced plastic boards produced 2020-2024 not mounted	688	132	820
Other product(diversification)	**40**	**112**	**152**

Note: It should be noted that the plastic bags are weighted with sand, hence the actual weight of collected plastic might be slightly lower than reported.

3.5 Quality assurance / Safety

In order to secure quality and safety assurance, the project benefits from the technical assistance of the government through the regional structures of the National Directorate for Pollution and Nuisance Control (DNACPN) and Engineers Without Borders (EWB).

At the onset of the project in each zone, the DNACPN conducted an environmental and social impact study before issuing an authorisation for the implementation of the project. The DNACPN mission has issued recommendations that the production units adhere to.

Further, Stromme Foundation has entered into a partnership with EWB Norway with the objective of improving the manufacturing process and securing health and safety of workers. Both units received training on the implementation of the LEAN production process, quality assurance of finished products as well as a complete HSE plan (Health, Safety and Environment).

EWB has worked on improving temperature control and ventilation. A mission with EwB was planned for in 2024, however, due to the insecurity situation, the engineers were prevented from travelling to do direct project follow up. Thus, a remote follow-up was undertaken with SF and the local partner teams. As a result, expected quality improvements took longer than expected.

3.6 Partner Workshops / milestones

Working with locally based partners is the footprint of Strømme Foundation in its approach to creating ownership, activities adapted to context and sustainable development.

The following workshops have been conducted as part of the project implementation:
- A communication and marketing session in Bamako in March 2021 bringing together together approximately hundred participants (national NGOs, international NGOs, international organization, companies, municipal authorities, representatives of the State)
- Project launch in San, November 2021
- Project launch ceremony in Mountougoula , December 2022
- Altogether three workshops for reflection and sharing of experience on the challenges and issues of the SUWASO / Green Job project. The first workshop was organized in December 2022 in Bamako, the second in April 2023 with participants composed of approximately 20 representatives from government, partner NGOs, implementing NGOs, companies, as well as the local municipalities. The Third workshop, under the chairmanship of the Technical Advisor, brought together the Major of Mountougoula and his staff, partners AMSS and APSM, National and Regional Directorates of Sanitation and Control

of Pollution and Nuisances of Koulikoro, companies operating in green employment, as well as representatives of youth and women members of CMSG's.

3.7 Market Linkages

To strengthen market linkages and enhance the visibility of the products, several strategic initiatives were undertaken:

- Development of a production and marketing plan to boost sales, with the objective of contacting prospective customers, including private schools, NGOs, international institutions, private companies. The media and communication channels have been diversified to reach as many people as possible. Separate workshops were carried out throughout a week with partners, stakeholders, staff and authorities to improve sales and enhance the sustainability of the project.
- Recruitment and training of freelancers: to boost sales
- Caravan tour to Promote table benches in private schools, NGOs, institutions, municipalities and public squares

3.8 Evaluation of business case and profitability

To monitor and evaluate the financial sustainability of the production units, a business calculator was developed in consultation with NGI. All estimated sales, incomes and expenses, such as salaries, production and maintenance costs, are entered into the calculator. Initial calculations indicate, provided there is a demand for the products, that the production units can be profitable. As long as Strømme Foundation and its partners provide speed school programmes in Mali, there will be a demand for school benches that will contribute to the economic viability of the production units. The following paragraphs will present the inputs, the recycling process as well as the results from the assessments.
The model is fairly simple, and calculates costs for one school bench, assuming 8 benches can be produced per day. Based on experience, approximately 25 kilos of soft plastic is needed to produce 1 bench, down from approximately 40 kilos in the initial stages of the project. The collection and salary costs include paying FCFA 100 (0.16 USD) per kilogram to the savings groups for the collection of the soft plastic. Additionally, workers receive a salary of FCFA 1,200 (1.9 USD) per bench produced, while the head of the unit is compensated with FCFA 1,300 (2.0 USD).

The plastic is melted using gas, and placed into moulds, forming plastic boards. When the boards have dried, the metal frame is welded, and the boards are assembled in the metal frames. Purchase of iron constitutes the most significant cost with FCFA 15.000 (23.2 USD) per bench.

The total calculated costs to produce one school bench in this model adds up to FCFA 33.475 (53.0 USD), and with a sales price of FCFA 40.000 (63.3 USD), the calculated surplus is FCFA 6.525 (10.3 USD).

Cost type	Unit cost / salary cost per hour	Units / hours	bench / number of staff	Total cost budget
Assumptions:				
Normal daily production rate= plastic for 8 benches, assume two staff				
1.Purchase of plastic				
Plastic purchased from CMSG members, fixed price, 100 FCFA pr kilo	100,00	pr kilo	25	2 500
2. Melting of plastic, plastic into moulds.				
3 boards per table				
2.1. Payment per table produced / Salaire par table banc produit (FCFA 6100 per table bench, four persons, including welder, 5 personnes; per person FCFA 1.200, Head of Unit FCFA 1.300	1	par table banc	6 100	6 100
2.2. Gas used for heating pots	1 050	Kg	2	2 100
3. Production of frames for benches				
3.1. Purchase of iron	6 000	Unit cost per kilo of iron	2,50	15 000
3.2. Electrictiy for welding	850	Unit cost for production of on	1,50	1 275
3.3. Welding material for 1 bench	500		1	500
4. Mounting and finishing of benches				
Manpower for mounting and painting 1 bench	-		-	-
Paint for 1 bench	2 500	Peinture pour table-banc	1	2 500
5. Transport of benches to purchasers				
Transport, added to sales price	-	transport inclus	-	-
6. Depreciation of purchased material and equipment	2 500	par table banc	1	2 500
7. Miscellaneous	1 000	par table banc	1	1 000
Total costs per table				33 475
Sales price pr bench:				40 000
Result / Surplus:				6 525

Figure 20: School Bench Production Costs and Revenues

Although each school bank is profitable to produce, the production units cannot run solely on this production, as the school bench demand is lower than the production capacities. Therefore, in order to enhance the economic viability of the production units, several measures have been implemented. The most significant of these are the reduction of staff in each of the production units, down from 10 to 5, in addition, to potentially reach new customers and markets, the production units have diversified their product portfolio to also include furniture for offices, kindergartens and churches.

3.9 Advocacy, engagement of local authorities

The local and regional authorities of San and Mountougoula have expressed great interest in the units and the job opportunities they provide for youths and women. To underline their engagement in supporting the units, the Council of San has purchased 200 school benches of the municipality of Mountougoula has purchased 100 school benches. In addition, the town hall of Mountougoula offered free of charge a plot of land with an area of 2000m² for the construction of the unit.

Although there was extensive communication and collaboration with the Ministry of Environment, the planned advocacy towards the Government to ban the use of plastic bags was not implemented. This was due to already extensive workloads in project implementation.

3.10 Challenges and mitigation

The main challenge from the onset was how to establish market links for the production units. We assumed there would be a high demand for school benches. However, the Ministries of Education and Environment, Sanitation and Sustainable Development do not have funding available to finance the purchases needed. Low local and national demand for school benches impacts the sustainability of the units. However, regular procurement from the speed school programmes of SF partners, will mitigate the risks and lack of national and local demands.

In order to create sustainable market-oriented production without the "artificial demand" from SF, a communication and marketing plan has been developed to create additional market linkages and thus boost sales.

Another challenge is the fairly long time needed for the final products to dry. A drying time of 1 month is needed, according to EWB in order to ensure VOC gases have evaporated. This factor is being addressed by ensuring sufficient drying time for the final products before sale.

The plastic collectors have also experienced that less plastic is available for collection in the locations around where the activity initially started. Different solutions will be looked into where the plastic collectors identify new geographic areas with plastic available for collecting, In the long term, laws in the country might also be revised, in order to reduce and prevent the use of plastic bags. If these laws are enforced, the production units will have to completely revise their mode of operation.

See reports from phase 1-4 of the project here:

- Fra plastavfall til skolepulter: Fase 1
- Fra plastavfall til skolepulter: Fase 2
- Fra plastavfall til skolepulter: Fase 3
- Fra plastavfall til skolepulter: Fase 4

Kontroll- og referanseside/ Review and reference page

Dokumentinformasjon/*Document information*		
Dokumenttittel/*Document title* Final project report Sustainable and complete waste management solutions for rural and semi-urban environments (SUWASO)		**Dokumentnr./*Document no.*** 20210118-01
Dokumenttype/*Type of document* Rapport / Report	**Oppdragsgiver/*Client*** Handelens Miljøfond / Norwegian Retailers' Environmental Fund	**Dato/*Date*** 2025-29-01
Rettigheter til dokumentet iht kontrakt/ *Proprietary rights to the document according to contract* NGI		**Rev.nr.&dato/*Rev.no.&date*** 0 /
Distribusjon/*Distribution* Åpen: Legges ut på nett / Open: To be posted online		
Emneord/*Keywords*		

Stedfesting/*Geographical information*	
Land, fylke/*Country* Uganda, Mali	**Havområde/*Offshore area***
Kommune/*Municipality*	**Feltnavn/*Field name***
Sted/*Location* Mityana, San and Mountougoula	**Sted/*Location***
Kartblad/*Map*	**Felt, blokknr./*Field, Block No.***
UTM-koordinater/*UTM-coordinates* **Zone: East: North:**	**Koordinater/*Coordinates*** **Projection, datum: East: North:**

Dokumentkontroll/*Document control*

Kvalitetssikring i henhold til/*Quality assurance according to NS-EN ISO9001*

Rev/ *Rev.*	Revisjonsgrunnlag/*Reason for revision*	Egenkontroll av/ *Self review by:*	Sidemanns-kontroll av/ *Colleague review by:*	Uavhengig kontroll av/ *Independent review by:*	Tverrfaglig kontroll av/ *Interdisciplinary review by:*
0	Original document	2025-01-14 Anna Schippert	2025-01-14 Gerard Cornelissen		

Dokument godkjent for utsendelse/ *Document approved for release*	Dato/*Date*	Stedfortredende Prosjektleder/ Deputy *Project Manager*
	29 January 2025	Gerard Cornelissen

2015-10-16, 043 n/e, rev.03

NGI (Norwegian Geotechnical Institute) is a leading international centre for research and consulting within the geosciences. NGI develops optimum solutions for society and offers expertise on the behaviour of soil, rock and snow and their interaction with the natural and built environment.

NGI works within the following sectors: Geotechnics and Environment – Offshore energy – Natural Hazards – GeoData and Technology

NGI is a private foundation with office and laboratories in Oslo, a branch office in Trondheim and daughter companies in Houston, Texas, USA and in Perth, Western Australia

www.ngi.no

NGI (Norges Geotekniske Institutt) er et internasjonalt ledende senter for forskning og rådgivning innen ingeniørrelaterte geofag. Vi tilbyr ekspertise om jord, berg og snø og deres påvirkning på miljøet, konstruksjoner og anlegg, og hvordan jord og berg kan benyttes som byggegrunn og byggemateriale.

Vi arbeider i følgende markeder: GeoMiljø – Offshore energi – Naturfare – GeoData og teknologi.

NGI er en privat næringsdrivende stiftelse med kontor og laboratorier i Oslo, avdelingskontor i Trondheim og datterselskaper i Houston, Texas, USA og i Perth, Western Australia.

www.ngi.no

OSLO
TRONDHEIM
HOUSTON
PERTH

NORWEGIAN GEOTECHNICAL INSTITUTE
NGI.NO

Main office
PO Box 3930 Ullevaal St.
NO-0806 Oslo
Norway

Trondheim office
PO Box 5687 Torgarden
NO-7485 Trondheim
Norway

T (+47)22 02 30 00
NGI@ngi.no

BIC NO. DNBANOKK
IBAN NO26 5096 0501 281
ORGANISATION NO.
958 254 318MVA

ISO 9001/14001
CERTIFIED BY BSI
FS 32989/EMS 612006