REPIC

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State Secretariat for Economic Affairs SECO

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Final Report:

Integrated dumpsite solution

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1. Summary

In this moment in Serbia there are more than 100 dumpsites where no solution for landfill gas or for landfill leachate exists. This poses risks to the local environment and population due to the pollution caused by the dumpsites. Each dumpsite is polluting the air, the soil and the surface and underground waters continuously.
A solution for these dumpsites is not easy to be found as many of them do not have access to electricity from the grid, consequently causing the inability to treat the Landfill gas or leachate. Financing for many smaller landfills is minimal and does not allow to connect the landfill to the electricity grid due to budget constraints.

The project described in this document solves these issues by implementing a 3 in 1 solution. The landfill gas is being extracted and burned in in a containerised solution. The burning takes place in an engine which has been optimised for landfills. Furthermore, the engine is equipped to run in island mode, allowing to generate electricity for local usage without any connection to the grid. The electricity generate is used to run the process itself, including the gas pump and control system, as well as the leachate treatment system that is housed in the same container.

Following the installation a subjective improvement in environmental conditions was noted such as reduced odour pollution from the landfill and its leachate.

The project was carried out in two main locations. Locally the landfill was prepared for the installation of the system by the local partner including following points:

- Installation of Gas wells
- Installation of dewatering Pipes in Landfill
- Installation of Piping from landfill to foreseen location of the treatment container built by Hofstetter Gastechnik AG
- Building of foundations needed for the treatment Container.

In Switzerland the project started out by finalising the Piping and Instrumentation Diagram (P&ID). Subsequently parts and services needed to produce the container were identified and suppliers were approached. After in depth discussions with manufacturing and the gas engine suppliers additional changes were made, following which purchasing and manufacturing started.

Due to issues with manufacturing, sourcing of parts in Switzerland delays were experienced. Further Delays were experienced as the process of approval with local authorities by the local partner in Serbia took longer than expected.

This project proved that an all-in-One system for landfill treatment can be a viable solution for smaller landfills. In a next step Hofstetter Gastechnik AG is approaching more landfills to install this solution. Furthermore, the installed design is being investigated to identify possible improvements for the next iteration of the system. The next iteration may include a Stirling engine to improve reliability and reduce maintenance needs.

2. Starting Point

During evaluation of various landfills worldwide it was realised that especially smaller to medium sized landfills which are not connected to the electric grid were not yet served with any treatment systems. According to HGT research often these landfills did also not try to install treatment systems as the costs associated with connecting the landfill to the electricity grid which was necessary for traditional setup was just too high.

Based upon this observation the idea was built to offer an all in one System that can run on its own generated electricity and treat the leachate and landfill gas at the same time. An initial engineering effort was then undertaken to create a basic P&ID with the most important devices on which a project could be built up on. Following this the project was further developed by contacting possible suppliers for components which were either not commonly used yet by HGT or parts that were completely unknown.

Based upon this information it was decided that project presented an economical viable product for the company with which an as of yet unaddressed corner of the market can now bee addressed.

The Cooperation with REPIC was shortly after sought out to further develop this idea.

3. Objectives

Hofstetter Gastechnik AG wants through this project to address and resolve a series of environmental problems at small to medium landfills/dumpsites. The problem addressed by Hofstetter is not easy to solve and is now rarely addressed by any local or international entities. Main reason of not addressing this issues is the fact that in most of the cases the landfill or dumpsite is not connected to the electrical grid. The investments required to connect to the grid are financially not viable for the parties involved, additionally the work and materials required to connect the landfill to the grid would also cause additional harm to the environment. At the same time if the problems addressed are solved the immediate consequence is an improvement of living conditions for the surrounding inhabitants. If these environmental problems can be solved using internal resources of a landfill/dumpsite through a renewable energy generation will create an more sustainable solution then traditional approaches, as environmental impacts such as logging for power lines and other impacts can be avoided.

Therefore for this project three main objectives were defined:

- Objective 1: Solve a big environmental problem.
- Objective 2: Improvement of living conditions.
- Objective 3: Use of landfill gas for renewable energy generation

It was calculated that for the specified dumpsite 4’000 litres of leachate can be treated per day and between 20-100 m^3/hour of landfill gas can be burned in the engine and flare. It is noted that with the calculated production of leachate of the landfill and the capacity targeted by the proposed solution more than 90% of leachate and gas production of this landfill can be treated.
The CO2 emission reduction calculation estimated for this project does only take into account direct emissions, the calculation is done against the original landfill conditions without any treatment. Implementing a new technological solution for landfill gas utilisation in leachate treatment. This new solution will be a very easy delivery and installation solution. All equipment will be installed in a container and will be prepared for a plug and play concept installation. Only average civil works will be needed on site (platforms and basins, pipes and wires).

To achieve this project following key project content were identified at the start of the project:

- Implementing a degassing system: drilling 3-5 wells and a network of landfill gas extraction
- Implementing a leachate collection system: in wells we will install a pump for leachate extraction
- Implementing a system for gas conditioning (cleaning and dewatering the gas)
- Install a UPS system to start the blower for gas extraction and start the gas engine
- Install a gas engine to produce energy
- Install a emergency flare to burn the landfill gas when the engine is not working
- Install a control system and a local distribution panel for electricity
- Install a landfill leachate treatment module
- Implement a total fluid management system(reinjecting 25% of initial treated leachate assuring constant quality and quantity of landfill gas)

4. Project Review

4.2 Project Implementation

Below can be seen the Initial 3D Design of the plant. While all major devices were already included in the design the placement and exact dimensions were not yet final at all. In some cases it was necessary to change suppliers due to various constraints. One such constraints was that the planned Engine, based upon the Stirling Engine principle, was not ready in its own development for landfill gas applications. For upcoming projects, it should be available to use.

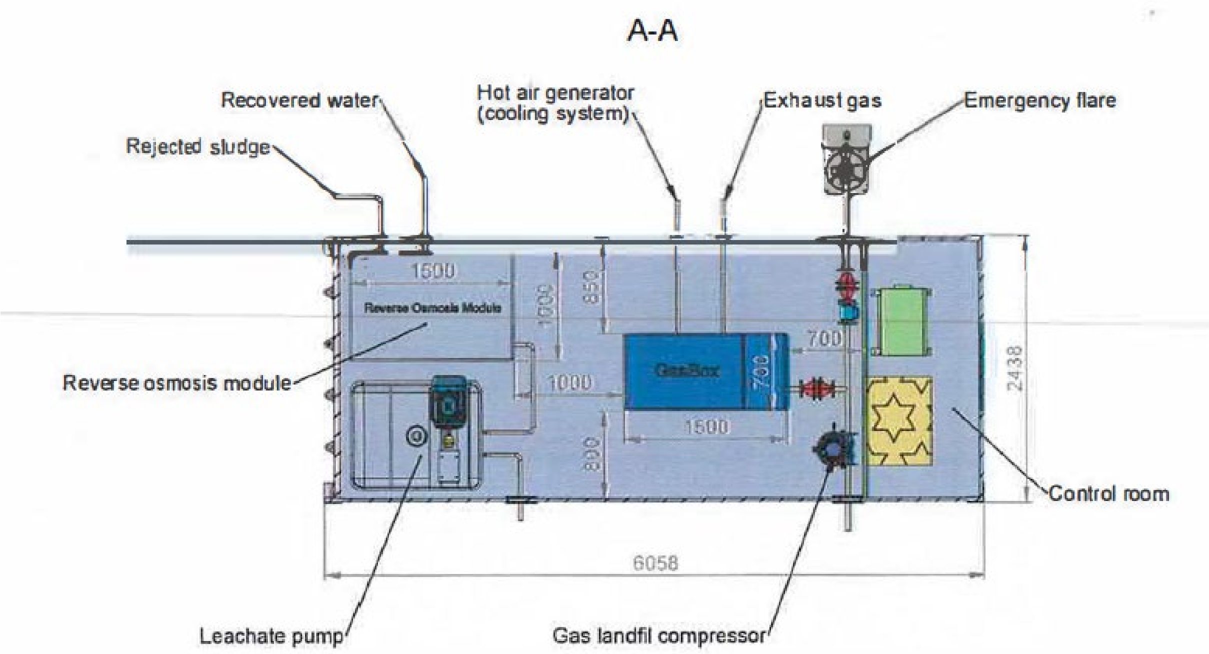

Figure 2: Initial Design

Furthermore, the placement of all devices was changed multiple times before a final design was settled. Optimizations included:

- interfaces to the rest of the project on end customer side to be all on the same side of the container
- Leachate Tank and RO unite became 1 unit
- Start up changed from purely by battery to
    - Start up of control system by battery
    - Starting engine with propane
    - Starting up remaining system, switching from Propane to landfill gas
- Placement in the container was changed so that no additional doors needed to be installed
- Placement of Forced Air Removal with ATEX certification
- Placement of Active Coal Container before the blower to treat the landfill gas before the engine to reduce harmful emissions and less accumulation of residues in the engine.

After all parts were installed extensive in-house testing was conducted with Propane for landfill gas part of the system and salt water on the leachate part of the system. This included initial adjustments on the engine.

Following the transport to the end customer site was organised. The system was then transported on site and initially placed for some days in storage at the end customer until all the foundations were ready. After placement of the container the installation was conducted by end customer with supervision of Hofstetter Gastechnik AG.

Training of local personnel as well as the Site Acceptance Test (SAT) were conducted with the local personnel.

During SAT also further adjustments needed to be made to the engine to account for the specific landfill gas found at the customer site.

Following the SAT the plant was handed over to the end customer for normal operation.

Local Authorities were invited to display this development project to them and an info Plate was installed which is used to inform further groups visiting the site to be informed about the project, be it local stakeholders or parties interested in installing a similar plant.

Figure 3: Plant on Site

4.3 Achievements of Objectives and Results

The plant is now being operated by the customer. The success criteria are being tracked and are used to measure the success of the plant. The presented Results are taken from the Dataset which covers following time period:

1st of June 2021 to 6th of December 2021

4.3.1 Operating Hours

The Measurement of the operating hours was always taken on Friday afternoon of the mentioned Calendar Week. All Hourly Values were rounded by personnel on site to the next hour. On the 1st of June 2021 the operating hours were reset to zero.

Table 1: Log of operating hours

Week	**Operating Hours**	**Total Operating hours**
22	35	35
23	81	116
24	76	192
25	93	285
26	97	382
27	122	504
28	100	604
29	130	734
30	112	846
31	117	963
32	131	1094
33	129	1223
34	124	1347
35	65	1412
36	133	1545
37	115	1660
38	120	1780
39	111	1891
40	118	2009
41	119	2128
42	133	2261
43	140	2401
44	127	2528
45	110	2638
46	126	2764
47	81	2845
48	65	2910

To better display the change in operating hours per week the following Graph has been created. As can be seen in the graph the operating hours per week are in a constant flux. At the start in week 22 the System started in the middle of the week, explaining the low number. Same can be said for week 48. The Dip in operating hours in week 35 and 47 can be explained by the maintenance conducted by the costumer on the system. The Trendline over the whole time period is positive showing that operating personnel on site is improving overall operation of the plant and down times are reduced with increased Knowledge of the plant.

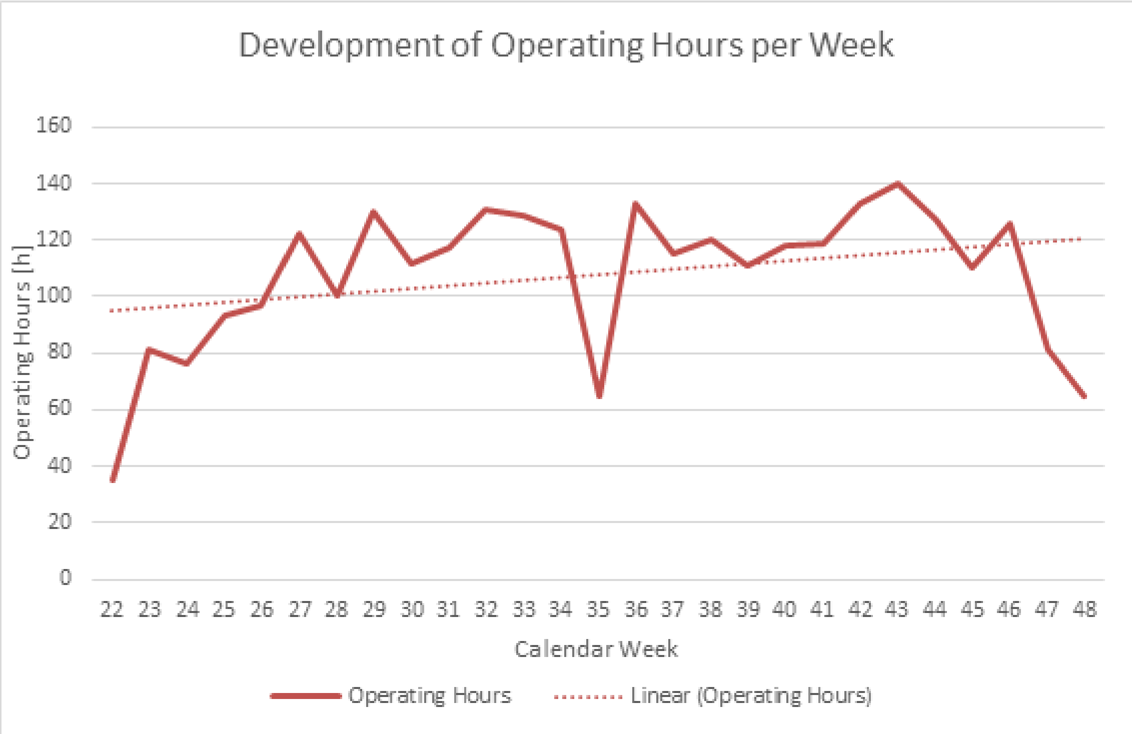

Figure 4: Operating Hours per Week

4.3.2 Maintenance & Consumables

This chapter describes in the tables below all the Consumables and Spare Parts that were installed/exchanged.

Table 2: List of Consumables used

Name of Item	Usage	Quantity
Cartridge filter	Used in RO-Unit	2
Gas Filter Insert	Used in Flare	1
Propane Bottles	Used for Startup of system	2

Table 3: List of Consumables to be used in the next 6 months

Name of Item	Usage	Quantity	Notes
Cartridge filter	Used in RO-Unit	2	
Gas Filter Insert	Used in Flare	1	Needs to be exchanged when dirty
Propane Bottles	Used for Startup of system		Depending on amounts of Start ups, always 1 spare bottle on stock
Membrane of Pressure Regulator	PR3008 and PR2000	2	Needs to be exchanged yearly
Active Coal Container	Used to clean gas before engine	1	Needs to be exchanged half yearly
Acid	Used in RO Unit	l	

4.3.3 Feedback of Customer

During the whole duration of the project the end customer was actively participating in the project giving HGT Inputs and Feedback. During the Training of Personnel the Papers and Presentation handed out to them received overall good marks but some points where not clearly enough written in the document which led to initial confusion. Following this Inputs adjustments to the Manual were made.
Customer also mentioned that the leachate treatment part of the plant needs a lot of time investment to adjust the system. They would wish for a more automatic approach for a future project.

4.3.4 Measurements of Gas Composition and Leachate Quality

Together with the Maintenances conducted in Calendar Week 35 and 47 measurements were taken of the gas as well as the leachate. The Gas Composition was measured in 4 places:

Figure 5: Measuring Point 1

Figure 6: Measuring Point 2

Figure 7: Measuring Point 3

The Measurements were taken with a mobile Gas Analyzer. The Measurements taken provide a snapshot of the gas composition, this can indicate the overall gas quality over a longer time frame of the gas burned. But these snapshot may also be misleading due to various environmental variables which may impact the gas composition, flow and quality.

Table 4: Measurements of Gas Quality in CW35

	Measuring Point 1	Measuring Point 2	Measuring Point 3	Measuring Point 4
CH_4 Content [Vol. %]	45.7	50.3	48.8	35.9
CO_2 Content [Vol. %]	10.3	5.9	7.5	9.8
O_2 Content [Vol. %]	0.7	0.8	1.0	1.3

Table 5: Measurements of Gas Quality in CW47

	Measuring Point 1	Measuring Point 2	Measuring Point 3	Measuring Point 4
CH_4 Content [Vol. %]	50.7	48.1	51.3	40.5
CO_2 Content [Vol. %]	8.3	9.7	8.8	9.3
O_2 Content [Vol. %]	0.5	0.9	1.2	1.5

Additionally, the gas flow was measured with a mobile measurement device by the customer on multiple occasions during a phase of stable production. These numbers were averaged and are used for the Impact Calculations in 4.5. The measurements were taken on each occasion 3 times to reach more reliable results.

Table 6: Measurements of Gas Flow in Nm^3/h

	Measuring 1	Measuring 2	Measuring 3	Average
CW 26	48.3	43.6	51.0	47.6
CW 30	45.1	48.9	49.2	47.7
CW 36	51.2	51.5	52.0	51.6
CW 42	51.7	51.4	52.3	51.8
CW 46	50.3	50.4	51.7	50.8
			Total Average	49.9

To test the Leachate and Permeate Quality, we measure the Conductivity of the Liquids, the lower the conductivity is the cleaner the leachate/Permeate is. The following Figures show the results from the measurements taken in Calendar Week 35.

Figure 8: Measurement of Leachate

Figure 9: Measurement of Permeate

Always two samples were taken to make sure the noted values below are the right ones,

Table 7: Measurements of leachate quality

	Calendar Week 35		Calendar Week 47	
	Leachate	Permeate	Leachate	Permeate
Conductivity [mS]	65.1	0.653	70.3	0.531
Temperature	28.4	27.8	26.4	26.8

4.4 Multiplication / Replication Preparation

During the project duration each party involved was advised and asked by Hofstetter Gastechnik AG to take extensive notes on the project. Be it production issues, material issues, possible improvements and things that went well.

All these notes, internal and external reports were gathered and combined. The P&ID has been reworked from the ground up to take into consideration all the learning acquired during this project. Further tasks are being worked on such as a new parts list for the improved plant which shall be of a standardised nature. Standardised in such a way that all the parts that are always needed the same, independent of sizing requirements shall be identified exactly. All parts that cannot be standardised shall have options where possible to simplify the process further.
New 3D-Drawings for a similar sized plant will be created after the new parts list has been approved by the internal committee.

On the side of Sales landfills that fit to the requirements of our plant are contacted and discussions for future projects are proceeding.

4.5 Impact / Sustainability

Table 8: Summarising Ecological, Economic and Social Impact of the project

Ecological	**Unit**	**At the REPIC Project's Completion**
Installed renewable energy capacity	[kW]	20
Renewable energy produced	[kWh]/year	87'300
Amount of fossil fuel energy saved	[kWh]/year	87'300
Greenhouse gas reduction	[t CO_2-eq]/year	5'436
Newly collected and separated waste	[t]	9'800
Newly recycled waste	[t]	-
Economic		
Energy costs (LCOE)	[ct/kWh]	71 / 60
Triggered third-party funding/investments	[CHF]	90'000
Local private income generated	[CHF]	56'000
Social		
Number of beneficiaries	[Number]	1
Number of new jobs	[Number]	1
Number of trained personnel	[Number]	2

Assumptions upon which the numbers above have been calculated:

- Yearly numbers were calculated based upon the numbers received for the first 6 months, it needs to be noted that the availability of the plant should increase in the second half of the first operating year.

4.5.1 Ecological

Renewable energy produced:
As the systems only needs to provide the energy required to run itself and the leachate treatment system the need for electricity does not equal the installed capacity. During normal operation the system needs between 12 to 16kW for this calculation 15kW was assumed. The operating hours for the year are based on the first 6 months of operation.

Amount of fossil fuel energy saved:
As the installation of another system for electricity generation based upon fossil fuels would require in minimum the same amount of energy to run the system it can be assumed that the same amount of energy was saved. Neglecting further savings from the transport of fuels and additional energy costs.

Greenhouse gas reductions:
To calculate the greenhouse gas potential, one needs to define an equivalent to be able to calculate with all greenhouse gases. The EPA defined a standard where CO_2 has the magnitude of 1, Methane (CH4) is estimated to have a GWP of 28–36. These numbers were calculated by the EPA by considering a 100-year time period to adjust for the various lifetimes of different greenhouse gases in the atmosphere.

16g of CH4 oxidized create 44g of CO2 emissions. For this project the t of CO2 equivalent emissions relation to t of CH4 is assumed to be 32:1.

Therefore, following calculation can be done:

CO2 equivalent emissions without project	
$\text{to of CO}_2\text{ equiv.} = \mathrm{V}_{Average} * t_{operation} * \rho_{LFG} * \%_{CH4} * GWP_{CH4}$ $\text{to of CO}_2\text{ equiv.} = 49.9\frac{Nm^3}{h} * 5820\frac{h}{a} * 0.00128\ \frac{to}{Nm^3} * 50\%\ CH_4 * 32$ $\text{to of CO}_2\text{ equiv.} = 185.86\frac{to\ of\ CH_4}{a} * 32\ \frac{\text{to of CO}_2\text{ equiv}}{\text{to of CH}_4}$ CO2 equivalent emissions without project $= 5'947.76$ t of CO_2 equiv	$\mathrm{V}_{Average} = \text{Average Volume flow of landfill gas} \left[\frac{\mathrm{Nm}^3}{\mathrm{h}}\right]$ $t_{operation} = \text{Operating hours of the plant for year 1} \left[\frac{\mathrm{h}}{\mathrm{a}}\right]$ $\rho_{LFG} = \text{Density of Landfill gas} \left[\frac{to}{Nm^3}\right]$ $\%_{CH4} = \text{Concentration of CH}_4\text{in Landfill gas}\ [\%]$ $GWP_{CH4} = \text{Global Warming Potential of CH4} \left[\frac{\text{to of CO}_2\text{ equiv}}{\text{to of CH}_4}\right]$
CO2 equivalent emissions with project	
$\text{to of CO}_2\text{ equiv.} = \frac{\mathrm{m}_{CH4}}{M_{CH4}} * M_{CO_2} * GWP_{CO2}$ $\text{to of CO}_2\text{ equiv.} = \frac{185.86\frac{to\ of\ CH_4}{a}}{16\frac{g}{mol}} * 44\frac{g}{mol} * 1\frac{\text{to of CO}_2\text{ equiv}}{\text{to of CO}_2}$ CO2 equivalent emissions with project $= 511.14$ to of CO_2 equiv	$M_{CH_4} = Molar\ Mass\ of\ CH_4 \left[\frac{g}{mol}\right]$ $M_{CO_2} = Molar\ Mass\ of\ CO_2 \left[\frac{g}{mol}\right]$ $GWP_{CO2} = \text{Global Warming Potential of CH4} \left[\frac{\text{to of CO}_2\text{ equiv}}{\text{to of CO}_2}\right]$

Greenhouse Gas Reductions	
$\text{Greenhouse Gas Reduction} = 5'947.76 \text{ to } CO_2 \text{ equiv} - 511.14 \text{ to } CO_2 \text{ equiv} = 5'436.62 \text{ to } CO_2 \text{ equiv}$	

The amount of waste newly collected is according to the local partner on the road to reach the projected amount of 9'800t for the first year of operation of the plant.

4.5.2 Economic

The LCOE was calculated based upon the data gathered for the first 6months and represents a worst case, as especially at the start of a new product more time needs to be invested to get the system running well. This leads to higher maintenance costs and to less operation hours. Those numbers will improve every year. The lifetime planned for the plant is 10 years. Furthermore, for future project costs can be reduced due to less work necessary due to improvements in the construction, planning and training phase of the project.
The LCOE calculations can be found in the appendix of the report.

Hofstetter expects that the costs for Hofstetter support will halve for coming years, furthermore local service and technical assistance should also be reduced by up to 60%. Also operating hours of the plant will increase over time, it can be assumed the plant will reach an average of 125h/week. Taking these numbers into consideration in the calculation of LCOE it can be seen that the costs are reduced to 0.60 EUR/kWh.
It can be assumed that the costs of operating the plant are further lowered if Multiple Benefits, such as reduction CO2 equivalent emissions, odor pollution and more are quantified and monetized.

According to our local party the triggered third party funding was within the budget and is therefore the same amount as prognosed in the proposal.

Similarly, the local private income generate was reported to us as being almost reached compared to the proposal.

4.5.3 Social

this project created 1 new job for operating the plant. In Total 2 personnel on site of the local partner have been trained, One as the main operator and one as the backup.

Other Indicators		
Lanfill gas used and pollution reduced	Nm^3/h	49.9
Lanfill leachate treated and pollution reduced	l/d	3800-4200
Odor pollution	Not quantifyable	The odor pollution has been reduced according to workers on site and nearby inhabitants.

5. Outlook / Further Actions

5.1 Multiplication / Replication

For the multiplication and replication phase of the executed project it can be expected that the various lessons learned will lead to major improvements during the planning and manufacturing stage. Furthermore, learnings on operating the delivered system will allow for further improvements, especially for the ease of use of the local operators.

As discussed in the chapters before the whole system will be planned again from the start rather than trying to modify the existing plant. This allows us to start from a clean plate helping to avoid issues that were inherent to the executed design.

Future Projects are already in detailed discussions and the likelihood of these projects commencing is high. In year 2022 IFAT Munich (World's Leading Trade Fair for Water, Sewage, Waste and Raw Materials Management) will take place again after the pandemic interruptions in year 2020 and 2021. Hofstetter Gastechnik AG will be on site and present a presentation prototype to the public and interested parties. This is expected to bring much more visibility to the project and subsequently should lead to new projects.

The ecological performance of future plants will be increased due to less reworking required. Furthermore, Uptime of new plants shall start at a higher point after commissioning and shall increase at a faster rate.

The LCOE shall also be considerably decreased by reducing the overall costs of the system. This can be achieved by reducing working hours of production and montage as well as reducing materials needed for the project due to improved layouts and other efficiency measures.

5.2 Impact / Sustainability

It is important to keep the plant running as much as possible to retain the positive effects the plant provides to the local environment and stakeholder. Therefore, a good maintenance scheme is being implemented in cooperation with the local operator. Also, the higher the operational time of the plant can be increased the better the environmental performance becomes.

The sustainability of the project is given as was laid out in the application to REPIC at the start of the project. Key to its sustainable success however is the local operator who has to keep the plant maintained and operational.

6. Lessons Learned / Conclusions

The Project as initially imagined is working as it was planned to. However, there are various lessons learned from this research project which shall be applied to the next ones:

1. Time Planning
   a. The detail planning phase needs to be increased to reach the detail necessary and also to reinspect everything proposed to reduce the need for ad hoc adjustments during the implementation phase of the project.
   b. The Montage and Production phase should have a bigger time window, also all parts need to be ordered and mostly arrived before this phase can start.
   c. Delays shall be communicated in an timely manner.
2. Layout of Plant
   a. Include already in the detail planning phase or even earlier the production and montage team so initial feedback can be taken into account for production, reducing the need for iterations.
   b. During the montage and installation phase it was discovered that a more 3 dimensional planning, to be specific taking the vertical space more into consideration, can lead to a better product with more space available to the operator.
3. Communication of Modifications
   a. During the project implementation phase many things needed to be changed, new devices needed to be installed. This however was not always communicated well to all parties, especially the electrical engineer responsible for programming the control system and building the electric cabinet.
   b. For future projects a biweekly update report shall be sent to all parties involved.
   c. Communications to parties such as Repic shall also happen on a more regular basis to increase stakeholder engagement.

Overall, the project is considered as a success with high potential for the future. It is a step forward in the right direction to reduce the impact of landfills around the world independent of location and availability of electricity or clean water. Up to this project no other solution existed which has the character of an off-grid solution which is able to treat landfill gas and leachate, reducing air, water and odor pollution.

The local authority, including the mayor as well as other officials from ministry of environment in Serbia expressed their gratitude for the project and the possibility to be the first municipality installing such an innovative system to treat their landfill problems.

7. Final questions after submission

To the report presented on 26th of January 2022, four additional questions where asked and integrated in this section of the report on 02 of May 2022.

7.1 What was the real challenge of the project?

The real challenge for Hofstetter as a company was to keep the cost of the project within the budget. The project was extended longer than expected, the prices of components and materials increased.
From the technical point of view being a first project the challenge was the design and the unexpected changes.

7.2 Is there an energy surplus and if so what happens with it?

Because the energy is not stored (the battery is small and its only purpose is the start-up) the electrical production is limited to own consumption and regulated by landfill gas suction.
In case of surplus it is then consumed by the cooling system as heat dissipation.

7.3 Who actually bears the costs in the future? Is it the operator of the landfill? Is there a legal basis for this?

The aim of the plant is self-sustainability, the main cost of the operation should be absorbed be the electricity generation. The other cost of maintenance are really low.
The operator of the dumpsite is the municipality and they bear the cost of operation and maintenance within its budget for operation of the dumpsite.

7.4 The benefits for the environment and the surrounding population could be better demonstrated?

The benefit for the environment can be demonstrated by measuring it. By the Greenhouse gas reductions and the quantity of leachate treated before the system was installed and after.
Before the complete emissions of methane of the dumpsite were untreated and released to the atmosphere.
Before not a single litter of leachate has been treated nor collected.
The social impact of it is evident since but contaminants are not only dangerous for the environment but also for the health.

8. References

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