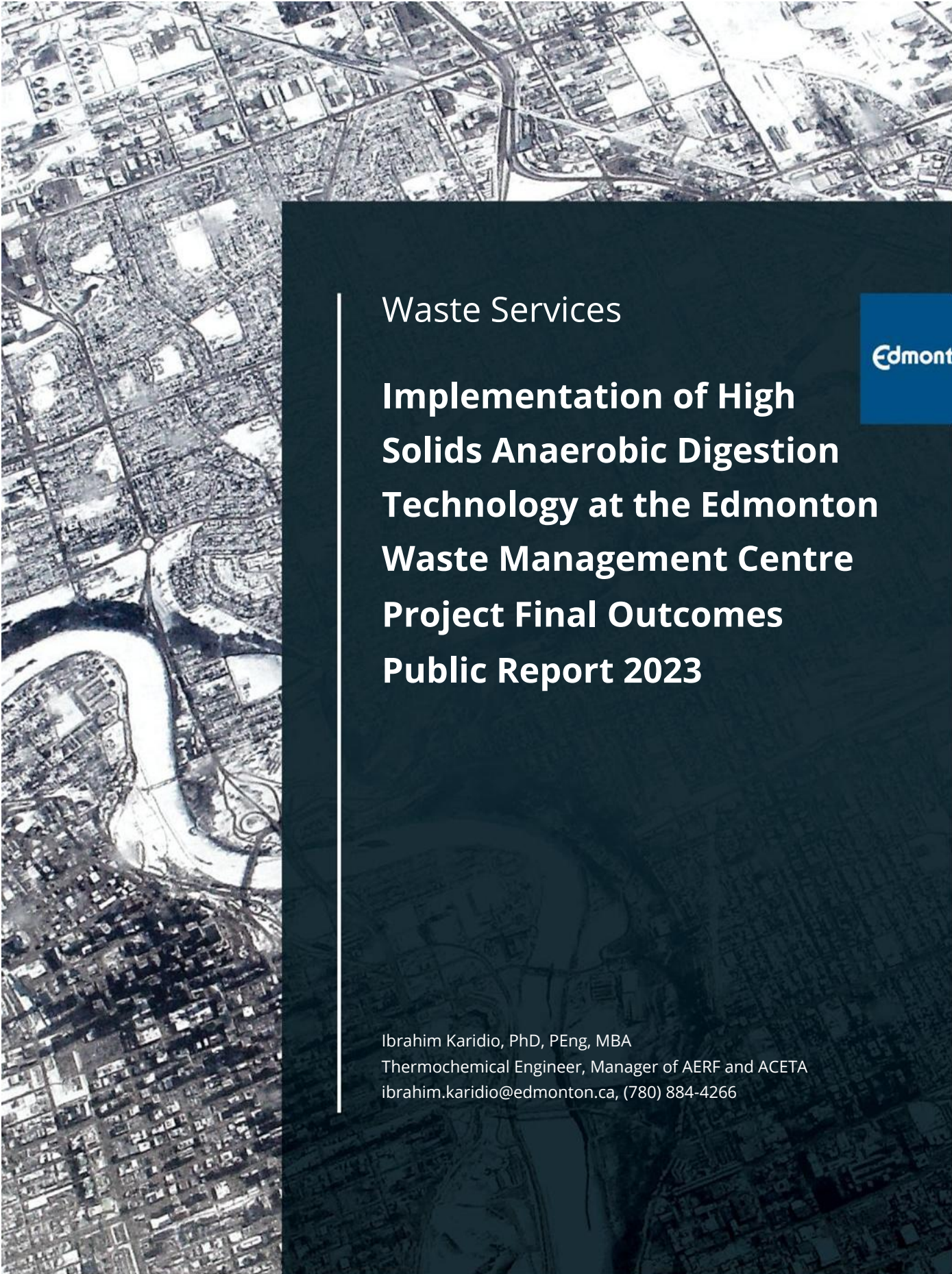




Waste Services

Edmonton

**Implementation of High
Solids Anaerobic Digestion
Technology at the Edmonton
Waste Management Centre
Project Final Outcomes
Public Report 2023**

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Title of Project Implementation of High Solids Anaerobic Digestion Technology at the Edmonton Waste Management Centre

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Terms

ACETA	Alberta Clean Energy Technology Accelerator
AERF	Advanced Energy Research Facility
CCEMC	Climate Change Emissions Management Corporation (now ERA)
CETS	Community Energy Transition Strategy
CHP	Combined Heat and Power
ECF	Edmonton Compost Facility
ERA	Emissions Reduction Alberta
EMMC	Edmonton Waste Management Centre
GHG	Greenhouse Gas
HSAD	High Solids Anaerobic Digestion
HSADF or the Facility	High Solids Anaerobic Digestion Facility
IPTF	Integrated Processing and Transfer Facility
MRF	Material Recovery Facility
Organic materials	Source-Separated organics and/or residual MSW materials
RDF	Refuse Derived Fuel
RFP	Request for Proposal
SSO	Source-Separated Organics
U of A	The University of Alberta

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1 EXECUTIVE SUMMARY

The City of Edmonton (the City), with financial contributions from the University of Alberta (U of A) and Emissions Reduction Alberta (ERA), developed a High Solid Anaerobic Digestion (HSAD) Facility (HSADF or the Facility) at the Edmonton Waste Management Centre (EWMC). The HSADF is a first-of-its-kind facility in Alberta. It was designed to process and divert up to 40,000 tonnes per year of organic materials, producing compost as a by-product for beneficial use (the “Project”). The Facility generates and utilizes biogas through the anaerobic breakdown of organic waste. This biogas is then employed to create electricity and heat energy using two combined heat and power (CHP) systems. The produced electricity and heat are consumed internally for HSADF operations and any surplus electricity is exported to the power grid. Using the electricity and heat energy from biogas reduces greenhouse gas (GHG) emissions by displacing fossil fuel energy sources, and by preventing methane release from landfilling organic materials. The HSADF is capable of processing organic solid waste originating from residential, industrial, commercial, and institutional sectors.

The Project’s goal was to sustainably process and harness the nutrients and energy content of organic waste generated from the growing city of Edmonton. This Project furthers the City’s Community Energy Transition Strategy which seeks a 35% reduction in community GHG emissions from the 2005 baseline by 2035.

When operating at the designed capacity, the HSADF is anticipated to produce, annually, 20,000 tonnes of compost, 12.5 million kilowatt-hours of renewable electricity, and up to 42,100 gigajoules of renewable heat (at 89% plant availability). In 2022, the Facility processed 32,767 tonnes of feedstock and 31,548 tonnes in 2021. Operational data from the 12-month period from June 2021 to May 2022 indicates the Facility eliminated the equivalent of about 33,759 tonnes per year of carbon dioxide (CO₂) emissions. Third-party verification of the carbon dioxide equivalent (CO₂e) reduction in the 12-month period is pending.

2 PROJECT DESCRIPTION

2.1 INTRODUCTION AND BACKGROUND

The City's Waste Services Branch (Waste Services) provides integrated residential waste management solutions that are sustainable, cost-effective, and mindful of the environment. Waste Services is responsible for collecting, processing, and disposing of residential solid waste from the entire city in an environmentally responsible manner. Increasing waste diversion from landfills and reducing associated GHG emissions have been important goals for the City from the late 1980s onwards.

The City initially began investing in infrastructure at the EWMC to increase diversion of residential solid waste from the Clover Bar Landfill to extend its operating life, as it was nearing full capacity in the late 1980s. Ultimately, these early efforts, along with securing landfill space at an alternative location, prolonged the usable life of the Clover Bar Landfill until 2009 when it reached capacity and was closed for operation.

Waste diversion from landfills was adopted as a strategic goal in 1993 (the "1993 Strategy"). At that time, the City committed to investing in infrastructure and promoting changes to waste management practices to achieve the 1993 Strategy goal of diverting 90% of residential waste from landfills within 30 years.

After the 1993 Strategy was approved, the EWMC expanded its operations by adding a unique collection of advanced waste processing and research facilities. These include a variety of processing and waste recovery facilities and infrastructure such as:

- Integrated Processing and Transfer Facility (IPTF)
- Materials Recovery Facility (MRF)
- Edmonton Compost Facility (ECF)
- Compost Cure Site and Aerated Gore Cover System
- Construction and demolition waste processing
- Electronics and electrical waste processing
- Waste to biofuels facility
- Refuse Derived Fuel (RDF) processing facility
- Clover Bar Landfill gas collection system
- Advanced Energy Research Facility (AERF)
- Alberta Clean Energy Technology Accelerator (ACETA)

The City and several industrial partners currently or previously operated these and other facilities for the purpose of recycling, research and development, conversion, and processing of various waste streams. These efforts contribute toward reducing GHG emissions and diverting waste from landfills. At this time, the EWMC is the largest fully-integrated municipal solid waste management facility in Canada (See EWMC Overview in **Figure 2.1**).



Figure 2.1: Overhead view of Edmonton Waste Management Centre (EWMC)

The 1993 Strategy emphasized diverting waste away from landfills and utilizing waste materials for the creation of products and energy. Constructing and operating the MRF and the ECF enabled initial blue box/bag recycling and composting activities. ECF operated from 2000 to May 2019, when it was closed permanently due to structural issues in its roof. Before its closure, ECF had a processing capacity of 125,000 tonnes of organic waste plus 40,000 wet tonnes of biosolids (75% moisture content) from the Gold Bar wastewater treatment plant.

In 2002, the City investigated additional ways to divert and process the fraction of the waste stream which was not being recycled or composted. There was strong motivation to identify and develop processes to utilize the remaining solid waste that was being sent to the landfill. The goal was to identify technology capable of converting some, or all, of the remaining waste into electricity, biogas, and biofuels. Thermal conversion technologies were reviewed and evaluated along with traditional waste-to-energy technologies and emerging conversion technologies such as gasification and

pyrolysis processes. This work ultimately led to the development of the current Facility, which utilizes biogas from organic waste to produce electricity and thermal energy.

The City's focus on organic material processing technology was due to the age of the ECF and the need for additional capacity to process increased volumes of organic waste from seasonal spikes in yard waste and from population growth. Without increased processing capacity, the City would continue to dispose of significant volumes of organic materials at the Riley Landfill (80 km South-East of Edmonton), compromising the City's landfill diversion target.

In 2012, City Council approved a proposal for Waste Services to identify technological solutions to increase organic materials processing capacity. In May 2013, Waste Services received a \$10 million grant from the Climate Change Emissions Management Corporation (CCEMC; now Emissions Reduction Alberta) for the construction of the HSADF. The U of A contributed \$843,000 towards the Project and the City agreed to process SSO collected at the U of A. The overall goals of the Project were to:

- Increase organic materials processing capacity to serve the growing city of Edmonton
- Increase the diversion of solid waste from landfill disposal
- Harness nutrients from organic waste through composting
- Harness the energy content from the organic waste fraction
- Reduce GHG emissions resulting from landfilling organic waste

The Project supports the 2015 Community Energy Transition Strategy (CETS), which set a 35% reduction target in community GHG emissions by the year 2035 from the 2005 baseline.¹ In 2019, Waste Services developed the 25-Year Comprehensive Waste Strategy to adjust programs and services to achieve the strategic goals.² Council directed an update of the CETS to align with the Paris Agreement's long-term temperature goal to hold the global average temperature increase to 1.5°C to reduce the risks and impacts of climate change. The update included a target for the City to be an emissions neutral corporation by 2040, and committed the City to developing a carbon budget that "helps the City to allocate and monitor emissions".³ The City's first carbon budget was released in 2022, and indicated that total emissions from the City of Edmonton will be targeted towards a limit

¹ <https://www.edmonton.ca/sites/default/files/public-files/assets/PDF/EnergyTransitionStrategy2021-04-20.pdf?cb=1675637457>

² COE's 25-Year Comprehensive Waste Management Strategy [COE's 25-Year Comprehensive Waste Management Strategy](#)

³ <https://www.edmonton.ca/sites/default/files/public-files/assets/PDF/EnergyTransitionStrategy2021-04-20.pdf?cb=1675637457>

of 176 million tonnes to align with the Paris Agreement target of limiting global temperature increase to 1.5 degrees.

2.2 OPPORTUNITY FOR HIGH SOLID ANAEROBIC DIGESTION TECHNOLOGY

Multiple factors guided the choice to implement HSAD technology, including:

- I. Increasing organic waste processing capacity at the EWMC
- II. Energy recovery from organic materials to use at EWMC
- III. Generating high quality compost, for beneficial use

HSAD technology was selected as it enables energy recovery from organic materials by capturing biogas released during decomposition. Biogas produced through anaerobic digestion can be utilized in CHP generators, generating eco-friendly electricity and heat that aids in promoting the anaerobic digestion process. HSAD technology designed for SSO material feedstock, along with CHP generators, can produce high-quality compost, lower GHG emissions through landfill diversion, and provide fuel for electrical power, offsetting consumption costs. At the time of the City's decision to pursue HSAD technology, the intention was to use biogas to produce electricity and heat for use in the ECF. Due to unforeseen structural issues with the ECF building envelope, the ECF ceased operations in 2019. The heat and electricity generated by the Facility is used instead by the Facility itself; energy in excess of this usage is sent to the power grid.

In 2015, a Design Basis Memorandum was prepared for the HSADF with the following criteria:

- Design capacity throughput of 40,000 tonnes of organic materials feedstock annually, based on peak loading.
- Biogas produced through anaerobic digestion to be used for heat and electricity generation in CHP generators.
- Operate the CHP generators in an "island mode" that is with no connection to the power grid. However, this is not possible in their current configuration.
- CHP generators that can blend in natural gas to accommodate the use of HSAD-derived biogas of variable composition and quality.
- Ability to accept current organic waste fraction materials isolated from IPTF processes.
- Ability to produce compost products suitable for cure site and ultimately beneficial use.
- An easy-to-operate system with minimum maintenance requirements.

As with any adaptation of technology to a new environment, the City anticipated there would be obstacles to overcome. Being the first of its kind in Alberta, regulatory approval processes had not yet been established. Using the experience of HSAD technology vendors in Europe, the City worked with Canadian vendors to plan for and mitigate regulatory roadblocks, like permitting and engineering considerations particular to Alberta. The Project required numerous contracts for

supply, design, construction, and commissioning. Procuring HSAD technology was a challenge for the typical municipal procurement processes, requiring a team experienced in procurement and project delivery to lead and manage it. The team structure shown in **Figure 2.2** was established to lead the Project. A project execution plan was also defined, as further explained in Section 2.3.

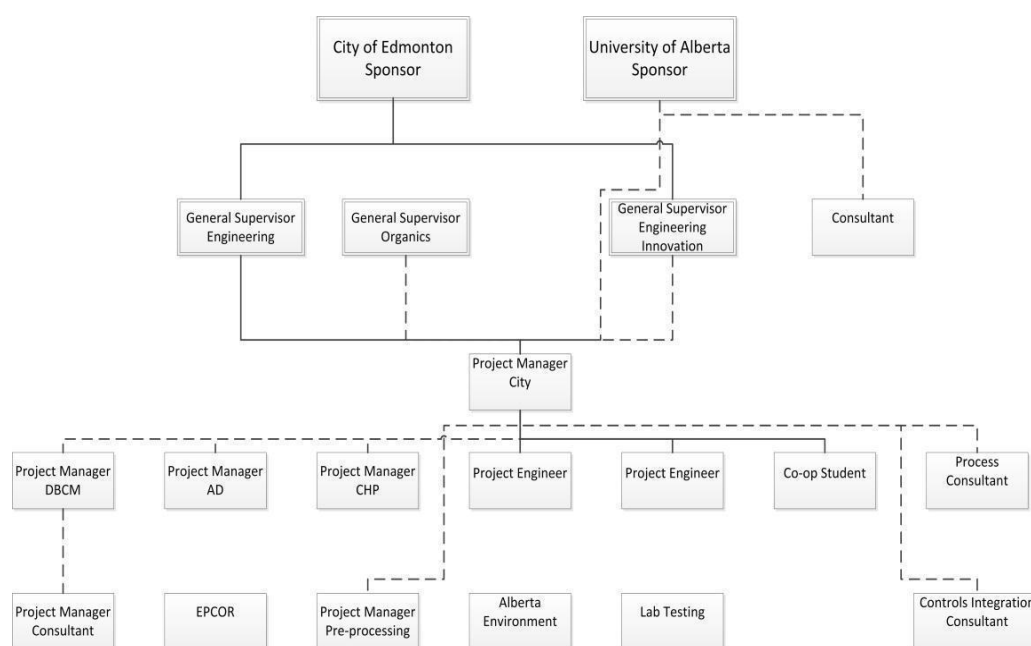


Figure 2.2: HSADF project management team

2.3 HSADF PROJECT EXECUTION PLANNING

The novelty and complexity of this HSAD Project necessitated a detailed project execution plan. The execution plan focused on five critical areas during the planning process prior to selecting the HSAD technology supplier. The key areas were:

- I. Conceptual design of the technology (includes preliminary design/ finalization of the concept engineering, site structural design, buildings and equipment design, and the design approval)
- II. Permitting process
- III. Integration of the Facility within the EWMC
- IV. Procurement process
- V. Construction schedule

2.3.1 CONCEPTUAL DESIGN OF THE TECHNOLOGY

The Facility's conceptual design needed to consider the expected biogas production rate and quality, as these aspects influence the design and sizing of the CHP generators and the flare system. Biogas quality determines the type and nature of pretreatment required before use in the CHP generators. The quality also determines the type of expected emissions from the plant and therefore, the effluent treatment processes required. These factors were considered during the technology procurement phase when selecting between HSAD technology vendors and suppliers. The City hired an independent third party to conduct the performance testing.

2.3.2 PERMITTING PROCESS

Environmental guidelines for HSAD facilities did not exist in Alberta or in many jurisdictions in Canada. The City anticipated challenges in permitting and engaged in early project discussions with permitting organizations to facilitate this process. Primary concerns regulators identified during engagement were: the type of emissions (primary pollutants during construction and from the Facility during operation), noise, and odour. Engineering controls were put in place to facilitate the permitting requirements.

2.3.3 FACILITY DESIGN INTEGRATION

Multiple technology suppliers (vendors) were available for the integration of their respective technologies. As each vendor has their own design standards, a third-party design consultant was hired to coordinate design meetings between the vendors' technical staff and the Project team to integrate the various technologies and design standards. Design reviews were held at 30%, 60%, and 90% completion points. The City incorporated hazard identification, safety reviews, and hazard and operability reviews to mitigate potential risks during the design phase.

2.3.4 PROCUREMENT PROCESS

The project was put out to tender following the standard procurement terms of the City of Edmonton. A Request for Proposal (RFP) was released for a "turnkey" solution, necessitating vendors to collaborate with local design and construction companies for project execution. The RFP underwent two tenders. In November 2013, when the first tender took place, all bids received were significantly above the expected budget. Almost a year later, in October 2014, a second RFP was issued, with some equipment components re-tendered separately. After securing the equipment contracts, the Design-Build Construction Management portion was tendered in June 2015. Suppliers were accountable for the cold commissioning of their equipment, while the City employed a

commissioning agent for hot commissioning. Upon successful completion, performance holdbacks were issued.

2.3.5 CONSTRUCTION SCHEDULING

Construction commenced in April 2016 and was scheduled for completion by November 2017. Due to delays, mechanical completion was not achieved until October 2019.⁴ Commissioning also took longer than anticipated and was completed on May 31, 2021.

2.4 DETAILED TECHNOLOGY DESCRIPTION

2.4.1 ANAEROBIC DIGESTION PROCESS AND EWMC INTEGRATION

Anaerobic digestion is a process in which bacteria break down organic matter — such as animal manure, wastewater biosolids, and food waste — in the absence of oxygen, which produces biogas. Anaerobic digestion takes place in a sealed vessel called a digester. The shape and size of the vessel is designed and constructed taking into account the site and feedstock conditions.⁵

Digesters contain complex microbial communities that break down organic waste through enzymatic digestion processes which produce biogas and digestate. Digestate consists of solid and liquid end-product materials from the anaerobic digestion process. Depending on the concentration of total solid material in the feedstock, the process may be called high-solid or low-solid (also called wet) anaerobic digestion.

Biogas is used to generate electricity and heat using Jenbacher Gas engines in a CHP configuration. The heat energy is used for HSAD process heating and drying, and the electricity is used on-site for internal power needs. The digestate is removed from the digesters and is then further composted at a cure site to reach final maturity and product quality. The final compost product can be put to beneficial use by various end users such as the agricultural sector and land developers. The benefits of renewable energy production and utilization, improved “compostability” of the digestate product, and the reduced environmental footprint were motivating factors in the decision to proceed with the HSADF rather than increasing the capacity of the existing ECF. The design of the HSADF aimed to seamlessly incorporate the building and its processes into the existing operations of the IPTF and

⁴ Mechanical completion means the checking and testing of equipment and construction to confirm that the installation is in accordance with drawings and specifications and ready for commissioning in a safe manner and in compliance with Project requirements.

⁵ <https://www.epa.gov/agstar/how-does-anaerobic-digestion-work>

ECF at the EWMC. **Figure 2.3** illustrates integration of the HSADF into the existing EWMC waste management processes.

Anaerobic digestion technology has been implemented in more than 244 projects in Europe with an organic treatment capacity of approximately eight million tonnes.⁶ Over the past decade, improvements in technical and operational experience have led to HSAD plants being a reliable technology in mainland Europe, with HSAD facilities processing 25% of the organic waste stream. This technology is still not widely adopted in North America. The Facility at EWMC is one of the first commercial applications of HSAD technology in Canada for municipal solid waste management.

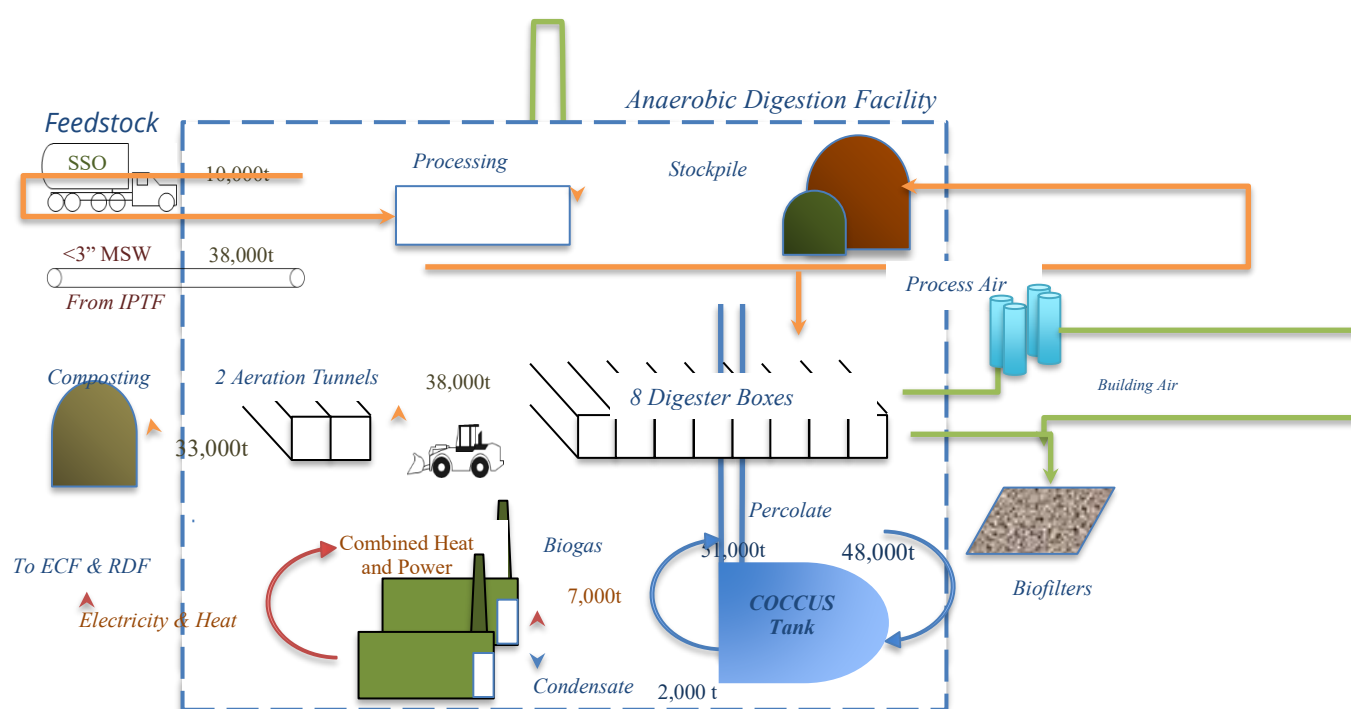


Figure 2.3: Schematic view of the AD technology integration into co-composting

2.4.2 DESCRIPTION OF THE ANAEROBIC DIGESTION TECHNOLOGY AT EWMC

[Viessmann Group/BIOFerm Energy Systems](#) was selected as the HSAD technology provider. Tetra Tech performed the detailed engineering design. Construction was managed by Chandos Construction Ltd. as the on-site construction manager and by Maple Reinders Inc. as the design-build construction manager. Fifteen to twenty other equipment suppliers (CHP, process controls,

⁶ G. Chinellato, F. Battista, D. Bolzonella, C. Cavinato, Waste Management, Vol. 125, 15 April 2021, Pages 103-111.

computers, feedstock pre-processing equipment, etc.), service providers, and sub-trade contractors were also involved in this Project, either contracted by the City or through BioFerm.

As the design-build construction manager of the Facility, Maple Reinders Constructors Ltd. prepared the structural design, constructed foundations, built the steel superstructure, and were responsible to install all equipment and fabrication of cast-in-place concrete, including digester and aeration boxes. Maple Reinders Constructors Ltd. was recognized with the Canadian Construction Association's 2018 Environmental Achievement Award for this Project.⁷

The Facility was designed to process up to 40,000 tonnes of organic waste feedstock (either SSO or the organic fraction from municipal solid waste or a combination of the two) annually. The Facility design capacity for total volume is 48,000 tonnes annually because the HSAD process requires bulking agents to facilitate the digestion process. In this Project, the process would use 8,000 tonnes of wood chips as a bulking agent for a total material handling capacity of 48,000 tonnes each year. In the report, the data provided for throughput tonnage of organic waste is for only SSO or the organic fraction from MSW and does not include the tonnage of bulking agents. Organic throughput data obtained is properly compared to only the 40,000 tonne per year design intent for this material because GHG emission reductions are calculated solely by the organic materials processed to the exclusion of bulking agents.

Primarily, this waste includes municipal solid waste, SSO from institutional waste sectors, and yard waste. At full capacity, the Facility would produce approximately 20,000 tonnes of high-quality compost for beneficial end use and eliminate approximately 33,759 tonnes of carbon dioxide per year. A general overview of the Facility and digester is shown in **Figure 2.3** and **Figure 2.4**, respectively.

⁷ <https://www.wasterecyclingmag.ca/awards/edmontons-anaerobic-digestion-facility-wins-environmental-award/1003282422/>



Figure 2.4: Overview of the HSADF digesters

Photo from <https://www.wastetodaymagazine.com/article/anaerobic-digester-processes-forty-thousand-tons/>

The Facility design allows pre-processed organics to be loaded into the digester's eight fermentation boxes where anaerobic digestion takes place. Biogas from the digestion process is fed to two combustion gas engines in a CHP configuration supplied by EPS AB Energy Canada Ltd. This CHP system has a capacity of 1.6 megawatts (MW) for electricity and 1.5 MW for thermal heat, which corresponds to an average annual energy production of 12.5 million kilowatt-hours of renewable electricity and up to 42,100 gigajoules of renewable heat (at 89% plant availability).

The digestate and nutrient-rich percolate fractions are used to produce high-quality compost. After digestion is complete, digestate solids are removed from the digester boxes and transferred to a cure site to allow further decomposition and production of the final compost product. Wet scrubbers and a biofilter remove odours emitted during digestion and from the flue gases to prevent them from entering the atmosphere.

2.4.3 WORK SCOPE OVERVIEW

Implementing HSAD technology at the EWMC was a major undertaking. It was a pioneering and innovative project with a scope to design and build a turnkey organic waste conversion facility with an annual material processing capacity of 48,000 tonnes of organic waste and bulking material. The HSADF uses the high solid anaerobic digestion technology from Bioferm Energy Systems, coupled with a CHP system. The whole process was integrated into EWMC's waste sorting and composting processes to produce electrical and thermal energy along with high-quality compost. When in full

operation, the heat and power produced are consumed at the HSADF and, in the near future, will also be connected to the nearby MRF at EWMC. The compost produced is used as a beneficial end product.

The complexity and innovative nature of the Project broadened its scope and extended its completion date. This increased the initial 2013 cost estimate by 35% while diluting ERA's contribution to 24%. Project scope changes are elaborated on in section 3.1.

3 PROJECT OUTCOMES AND LEARNINGS

3.1 OVERALL PROJECT SCOPE

The Project scope was to design, build, and operate an HSAD facility at the EWMC capable of processing up to 40,000 tonnes of organic waste annually plus 8,000 tonnes of wood chip bulking materials while capturing biogas to convert into electricity and heat energy using CHP generators. Residual solid digestate from the process is cured into a final compost product for beneficial end use.

3.2 OVERALL PROJECT ACHIEVEMENTS

The Project was the first HSADF constructed in Alberta. The Facility contributes to the City's waste diversion goals and to Alberta's GHG emission reduction targets. GHG emissions are reduced by generating and using biogas as clean energy in place of fossil fuel energy sources and by reducing methane emissions that would result from landfill disposal of organic materials.

Facility construction was completed in 2018; then began commissioning which was completed on May 31, 2021. The Facility has been operated since while maintaining periodically planned shutdowns for maintenance. During the commissioning process, organic waste feedstock was processed generating biogas. The purpose of the commissioning process was to measure performance of the Facility in order to identify system bottlenecks and improvement opportunities. The Facility was shut down in 2018 and reopened in May of the following year for a second hot commissioning. In September 2019, the Facility was again shut down to make modifications to improve plant safety, environmental performance, and operational efficiency. This is discussed in Part 3.4 below.

3.3 TECHNOLOGY DEVELOPMENT, INSTALLATION, AND COMMISSIONING

This Project did not develop new technology, but, it was novel in that it was the first HSAD facility to be constructed in Alberta using technology that has been implemented in many European countries over the previous decade. In order to design and construct the Facility in Alberta, local feedstock characteristics and the wider range of climate variability in Alberta compared to European countries had to be considered amongst many other factors.

On-site construction work of the Facility took place between 2016 and 2018.

Commissioning was performed in collaboration between various parties. Cold commissioning began in 2018 which involved the start-up and operation verification of key process equipment and instruments without organic waste being loaded into the digesters. It also included the operation verification of the control system for the feedstock pretreatment process, the digesters, the biogas cleaning process, and the operation of the CHP units. The cold commissioning phase enabled the Facility operator and its staff to begin learning about the processes and equipment. It also was used to verify the operability of the key process equipment in a lower-risk environment due to the absence of methane production from the digesters.

Hot commissioning proceeded afterward, during which organic material was gradually added to an increasing number of digesters. Staggering the loading of digesters was considered important to minimize safety risks from methane production until safety control equipment could be tested and verified more thoroughly. Hot commissioning was done to test operating conditions of the Facility in the presence of methane, to train the plant personnel on the operation of the Facility, and to evaluate Facility performance.

Several issues were identified during hot commissioning (discussed further in section 3.4 below). Out of an abundance of caution – to protect the safety of workers and to avoid any potential of damaging the Facility components – operations were suspended until modifications could be made.

These issues were resolved and the Facility restarted cold commissioning in the first quarter of 2020 and hot commissioning during the last quarter of 2020. In the meantime, 11 technical enhancements to address deficiencies and safety issues were implemented; including upgrades to the flare system to meet environmental compliance. The Facility resumed hot commissioning in December 2020 and completed it on May 31, 2021.

3.4 CHALLENGES, DELAYS, OR OBSTACLES

The Project experienced technical challenges resulting in cost increases and schedule delays. For example, geotechnical conditions at the Project location caused a cost increase and schedule delay during construction.

The procurement process experienced challenges which led to design and construction delays, including initial bids that were over budget. There was also a dearth of equipment providers for the flare and hydrogen sulfide (H₂S) scrubber system. In future, as HSAD technology becomes more common in Canada, a greater number of HSAD specific equipment providers will hopefully come into existence.

During commissioning, issues were identified with key equipment in the Facility which required modification. The Facility had to be shut-down in order to make the modifications. These issues related to various Facility components such as:

- Pipes external to the main building froze. Heat trace lines were installed.
- A three-way control valve forming part of the methane safety control system was not operating properly. It was replaced.
- The flare had difficulty operating over a significantly broad enough climatic temperature range. Modifications were required to ensure sufficient confidence in its reliability given that this is a key methane control safety component.
- Upgrades were made to the acid and base wet scrubber system to increase reliability.
- Leaking seals in process equipment, ranging from aeration box doors to ventilation ducting, required replacement or modifications.

Beyond these issues, the commissioning process also revealed that improvements could be made to better facilitate future maintenance and servicing. This involved the addition of isolation valve controls, pressure relief valves, and similar mechanical controls to more easily allow equipment to be serviced. The lack of adequate isolation control points was an obstacle to making equipment modifications while the plant was in operation.

3.5 PERFORMANCE METRICS FROM THE CONTRIBUTION AGREEMENT

The performance metrics of the Project are summarized in **Appendix A**.

3.6 END OF PROJECT TECHNOLOGY RISKS

The technology risks of the Project, identified during the development, implementation, and commissioning phases, were mitigated by various engineering, administrative, and process control measures.

The main technological risks anticipated at the outset of the Project were the impact of severe climate in Alberta (extremely low temperatures during wintertime and large temperature gradients between the warm and cold seasons), knowledge transfer, establishing sufficient operational procedures, and the nature and variability of local feedstock material. Alberta's low temperature led to frozen pipes during commissioning that required correction through heat trace line installation. Temperature fluctuations can affect the mechanisms and kinetics of biological reactions, and should therefore be accounted for in the digester design and the dimensioning of the whole plant. These risks were mitigated by emphasizing communication with the technology provider, training personnel, and developing a competent in-house team to test, monitor, and document all major issues. Operational, financial, environmental, and social risks were evaluated at the outset of the Project. Mitigation strategies were developed and implemented where appropriate.

The operational risks identified at the Project's outset were related to management and procurement aspects of the Project. The project management risk was considered low, given the significant in-house experience at the City's Waste Services. All facets of the Project – from procurement, design, construction, and start-up – were managed by a dedicated senior project manager with more than 22 years of engineering experience managing multi-million-dollar projects inside and outside Alberta. A team with multiple years of experience managing large capital projects supported the project manager. Aspects of the Project's management structure were elaborated on in Section 2 of this report.

Environmental risks included the potential delays or refusal of regulatory approvals before construction and the risk of meeting compliance requirements. An environmental permit request was submitted during Q3 of 2015, and Approval No. 20440-02-00 Edmonton Organics Processing Facility was issued as of April 29, 2016 under the provisions of the Environmental Protection and Enhancement Act. To mitigate the environmental compliance risk, the RFP required that the technology vendor and designers prepare a detailed odour management plan (through encapsulation, engineered airflow management, and odour control systems) and adhere to performance specifications provided by Waste Services.

Several other risk factors were anticipated at the outset. Mitigation strategies were developed and implemented. Some of these risks were operational, financial, environmental, and social.

3.7 COMMERCIALIZATION, COMMERCIAL DEPLOYMENT, OR MARKET ADOPTION

Technology development was not within the scope of this Project.

The City is unable to comment on the market for HSAD technology in Alberta as it has no reason to make a market assessment.

3.8 TECHNOLOGY ADVANCEMENT DURING PROJECT

The commercial implementation of the first HSAD facility in Alberta demonstrates the potential for HSAD technology to be used in northern climates despite high climate variability. The novel technology implemented here may serve as a starting point for future HSAD facilities, with opportunities for further enhancement, specifically relating to the flare, H₂S scrubbers, among other items. With Edmonton being home to the Alberta Clean Energy Technology Accelerator (ACETA), the EWMC is an ideal location to test HSAD technology in a northern climate with a high degree of temperature fluctuation. An advance resulting from this Project is the adaptation of HSAD technology and related peripherals to a cold climate which may promote more widespread adoption of HSAD technology for waste management. While this technology was already mature in Europe, with this Project, the technology has now been demonstrated in Alberta. The technology may now be considered at the TRL nine level in Alberta (see Section 3.10). Another advance is to have familiarized regulatory authorities with HSAD technology which should facilitate other entrants to obtain necessary permits for construction and operations.

3.9 TECHNOLOGY READINESS LEVELS AT PROJECT COMMENCEMENT AND COMPLETION

Although HSAD facilities exist in Europe and in some jurisdictions in North America, this Project is the first of its kind in Alberta. In this respect, the Technology Readiness Level (TRL) at the beginning of the Project in 2013 was at eight and is at the final level, nine, after the completion of the Project.

3.10 Analysis of Results

The HSADF processed 32,767 tonnes of feedstock in 2022 and 31,548 tonnes in 2021 (See **Figure 3.1 & 3.2**) producing more than 2.6 million m³ of biogas in 2021 containing about 47% methane and 37% CO₂ (See **Figure 3.3**). Other impurities in the biogas include H₂S which has to be scrubbed out

before the biogas is sent to the CHP engines. For the first four months of 2021, most of the biogas produced was flared. However, the amount of biogas flared dropped to 30% toward the end of the year 2021, and it is expected that it will continue to drop as the Facility is optimized (**Figure 3.4**).

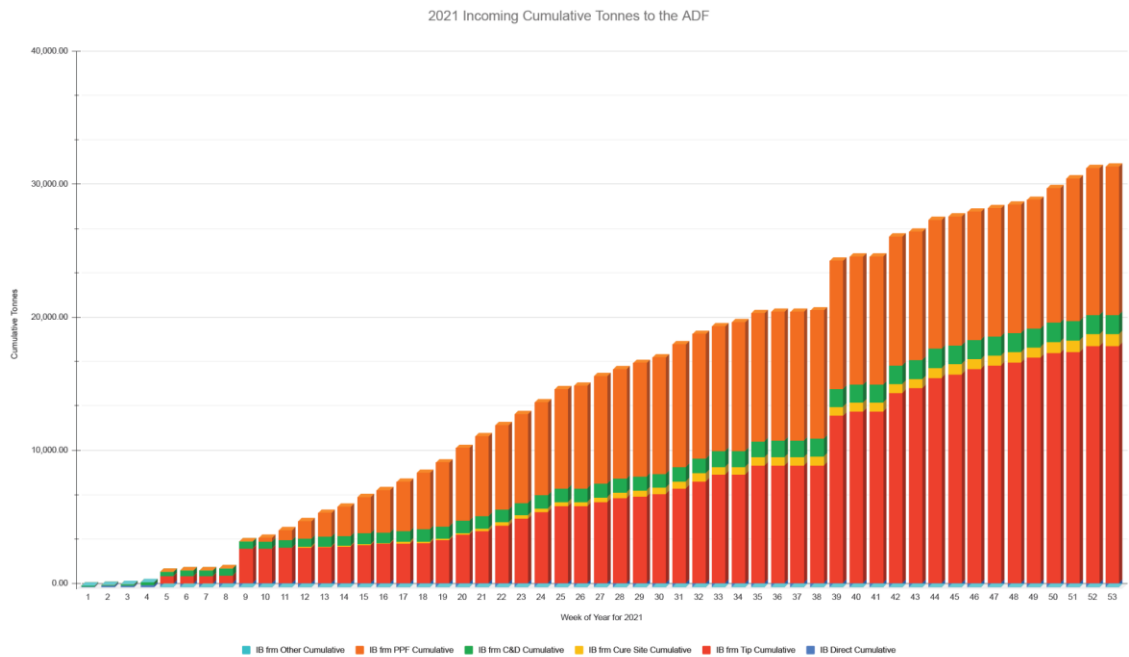


Figure 3.1: Weekly feedstock processed in 2021

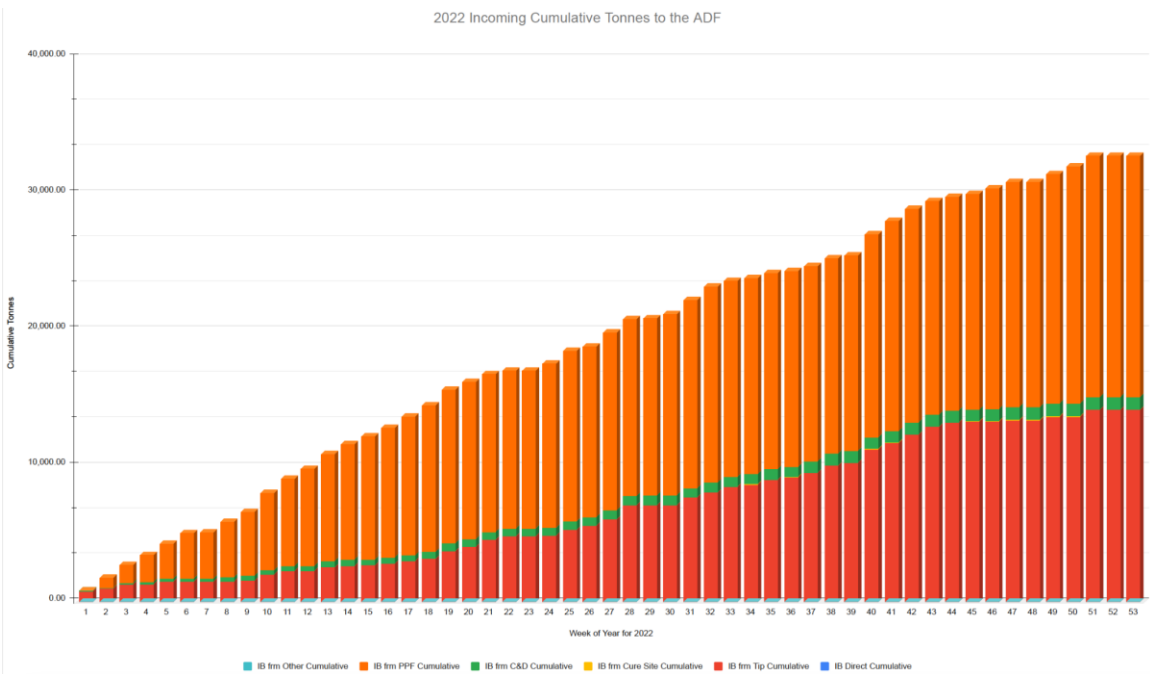


Figure 3.2: Weekly feedstock processed in 2022

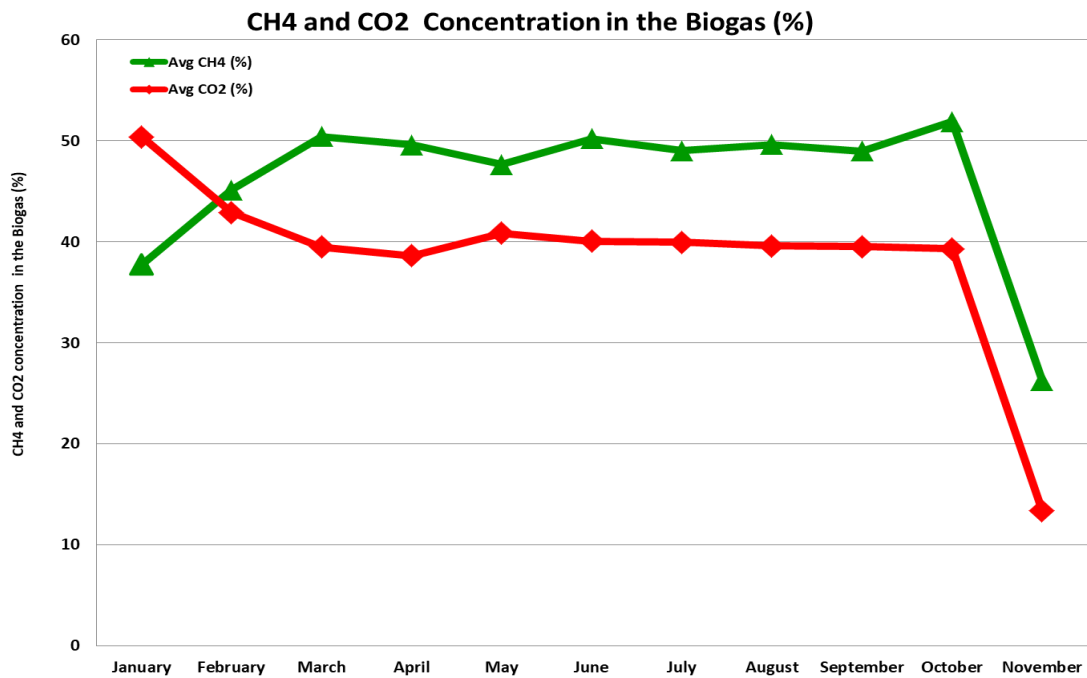


Figure 3.3: Methane and carbon dioxide composition in the biogas

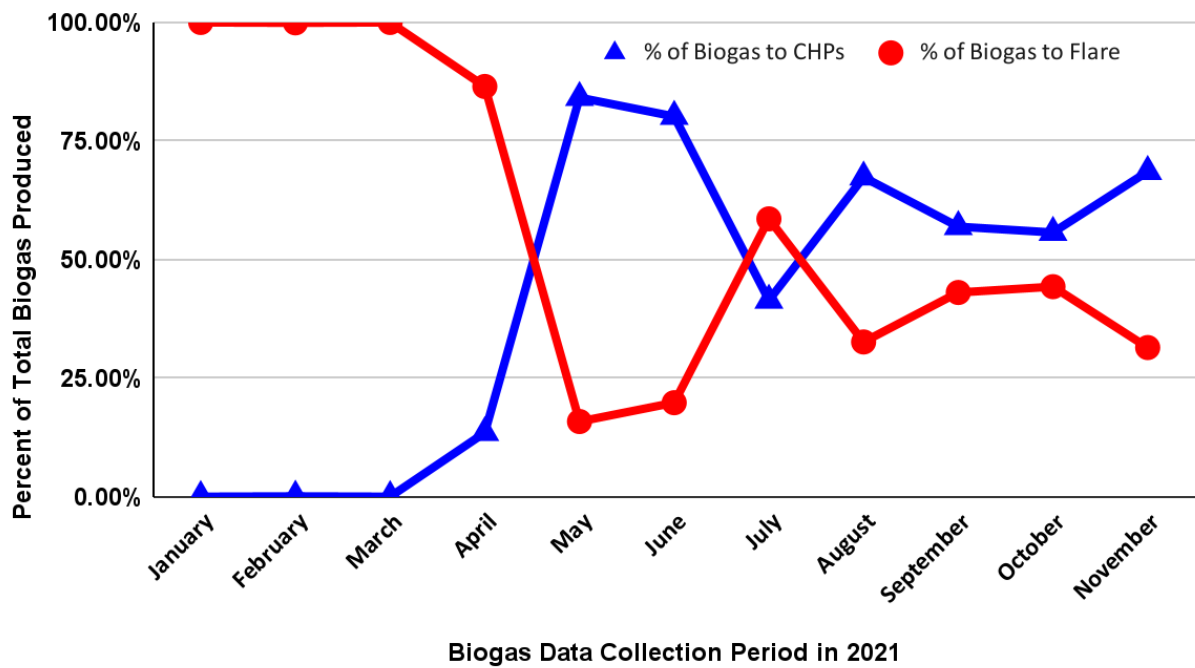


Figure 3.4: Use of the biogas produced during the first year of operation

3.11 LESSONS LEARNED

Lessons learned from this Project which may benefit other HSAD facility proponents include the following:

The absence of a well-developed regulatory framework specific to HSAD technology in Alberta impeded the ability to make certain design and engineering decisions. However, engaging with regulatory authorities early on was beneficial so that concerns could be identified and addressed.

System redundancy is desirable for the various processes required in an HSAD facility. If greater redundancy had been integrated into the process at the outset, that may have enabled more accurate troubleshooting of issues to improve throughput.

The City worked closely with Alberta Environment and Parks on the appropriate operating approval of the Facility and environmental parameters. There was no historical information or data for such a facility in Alberta; therefore, we relied on experimental evidence and analytical models to work together on the approval parameters. The City will continue to collect operational data and analyze and monitor performance, which may help develop a baseline for future projects.

The variability and the heterogeneity of the feedstock mixtures need to be considered in the design of these types of facilities to ensure sufficient biogas quality for utilization downstream. In the specific case of CHP use downstream, a steady quantity of high-quality biogas, free of moisture and impurities, is required for the smooth operation of the engines.

The design of the biogas lines and other critical components of the plant should consider accessibility for repair or maintenance. To gain a better insight into the HSAD process and to be able to optimize it, more instrumentation (pressure, temperature, gas flow rate, and composition) in key areas of the process would be helpful.

4 GREENHOUSE GAS BENEFITS

4.1 DIRECT AND INDIRECT GREENHOUSE GAS EMISSION REDUCTIONS IN ALBERTA

The HSADF processes SSO and the organic fraction of municipal solid waste diverted from landfills. These organic materials are digested anaerobically, and biogas (a mixture primarily of methane and carbon dioxide) generated during digestion is captured and combusted in CHP engines to produce electricity and heat. The Project results in both direct and indirect GHG emission reductions in Alberta. The completed Project directly avoids methane emissions from landfilled waste in Alberta.

Using biogas for heat and power generation indirectly reduces GHG emissions through natural gas substitution.

4.2 PROJECT EFFECT ON A LOW-CARBON ECONOMY AND ALBERTA'S FUTURE

This Project is the first HSAD facility in Alberta. The implementation of the HSADF at EWMC demonstrates the feasibility of this technology to other municipalities and provides experience to others in the design, construction, and operation of HSAD facilities. This Project contributes to a low-carbon economy through gaining engineering and operational knowledge and experience.

As expressed by Bioferm Energy Systems, “Deploying state-of-the-art anaerobic digestion technology in Edmonton will create a model for municipalities throughout North America, enabling them to implement community-based organics solutions that fit well within their existing tipping fee infrastructure.”⁸

4.3 QUANTIFIED DIRECT GHG REDUCTIONS FROM PROJECT IMPLEMENTATION

The HSADF process flow diagram is presented below (**Figure 4.1**).

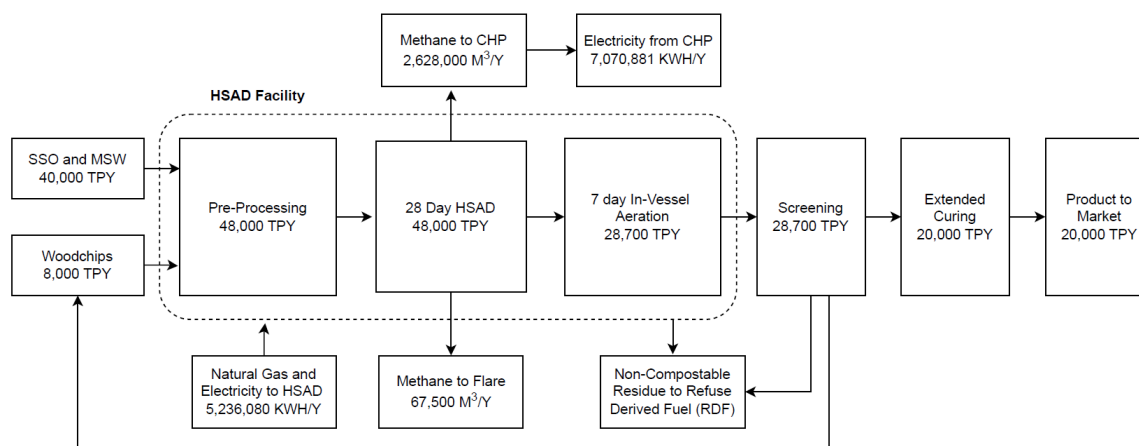


Figure 4.1: HSADF process flow diagram

The organics first undergo a 28-day digestion. The digestate produced is then processed in aeration boxes that further reduce pathogens to meet the pathogen criterion of the Canadian Council of Ministers of the Environment Guidelines for Compost Quality. The material resulting from the aeration process is subsequently screened and cured at the EWMC's Cure Site to produce compost.

⁸ <https://www.wastetodaymagazine.com/article/city-of-edmonton-alberta-university-bioferm-anaerobic-digestion/>

The quantification of GHG reduction was developed in reference to Quantification Protocol for Biogas Production and Combustion (Version 1.0, December 2020), as applicable. As shown in **Figure 4.1**, the production process boundary for GHG quantification includes the digestion through curing stages. The net GHG reduction from the Project is calculated based on the following equation:

$$\text{Net GHG Emissions Reduction} = \text{Baseline Emissions} - \text{Project Emissions}$$

The baseline condition is the disposal of the eligible waste in a landfill, where anaerobic decomposition of these wastes will occur. The justification of the baseline condition is presented in Section 4.5 of this report.

The HSADF post-commissioning operational data from June 2021 to May 2022 (12 months) were used for quantification reduction. It was assumed that the Facility will operate in the same conditions as the 12-month period in subsequent years, starting from 2022 and through its lifespan. Emission factors and constants from Alberta Carbon Offset Emission Factors Handbook (Version 2.0, November 2019) and the Quantification Protocol for Biogas Production and Combustion (Version 1.0, December 2020) were also adopted for GHG calculation. The pre-processing of municipal solid waste was beyond the boundary of the Facility, and, as such, GHG emissions associated with pre-processing were not included.

The annual GHG emission reduction from the HSADF Project is estimated to be 33,759 tonnes of CO₂e annually. Based on the feedstock processed in the 12-month period of June 2021 to May 2022 and the calculated GHG reduction during the same period, the estimated GHG reduction intensity was 0.99 tonnes CO₂e / tonne of feedstock. The quantification of the GHG reduction from the Project will be verified by a third-party in accordance with ERA's Greenhouse Gas Verification Requirements and Guidance (Version 1, December 2022). The verifier will review the Project following ERA's requirements and deliver a third party GHG verification report that meets ERA's standards and guidelines. The verification report is anticipated to be submitted to ERA in August 2023.

4.4 FORECASTED ANNUAL GHG REDUCTIONS FROM TECHNOLOGY COMMERCIALIZATION

The estimated annual GHG reductions in Alberta would depend on the number of comparable HSAD facilities similar to Edmonton's HSADF that are constructed in the future by other municipalities and businesses. The City of Edmonton does not have plans to construct another HSAD facility, and it is unknown if other municipalities or private parties will build HSAD facilities in the future.

However, assuming future HSAD facilities meet the estimated GHG reduction intensity of the Edmonton HSADF (ie. 0.99 t CO₂e/tonne feedstock), a chart depicting the potential GHG reduction of other HSAD facilities is presented below. As shown in **Figure 4.2**, the GHG reduction would be 49,500 t CO₂e per year, provided that the HSAD facilities in Alberta reached 50,000 tonnes of feedstock capacity in 2025.

GHG Reduction vs. Feedstock Processed

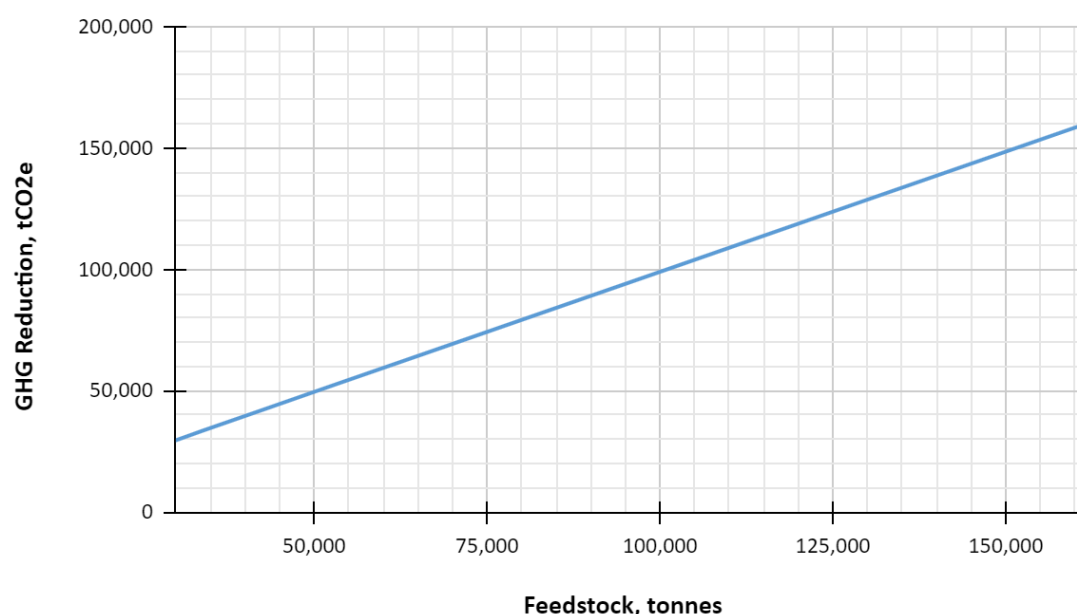


Figure 4.2: GHG reduction vs. feedstock processed

4.5 GHG REDUCTION BASELINE SCENARIO

The ECF at the EWMC was constructed over 20 years ago. Its capacity was 125,000 tonnes of waste plus 10,000 dry tonnes (equals 40,000 wet tonnes) of biosolids. Due to the high volumes of residential waste generated during peak spring and fall seasons, the City diverted the peak waste volumes to landfill as it exceeded ECF processing capacity.

In 2018, 2019, and 2020 – prior to the operation of the HSADF in 2021 – over 350,000 tonnes of municipal solid waste was sent to Ryley Landfill yearly. The Ryley Landfill is not equipped with a landfill gas collection system.

The operation of the HSADF diverts a portion of this waste stream from landfills. Therefore, the most appropriate baseline condition for HSAD technology is the disposal of the eligible wastes in a landfill where their anaerobic decomposition will occur. The opportunity for generating emission reductions

arises from avoiding GHG emissions from landfilling the organic waste and from the offset of grid-supplied electricity to the facility.

5 ECONOMIC AND ENVIRONMENTAL IMPACTS

5.1 PROJECTED ECONOMIC IMPACT IN ALBERTA

This Project has economic and environmental benefits for Alberta. During construction, over 20 Alberta companies were involved. More than 100 full-time equivalent jobs were created during construction and millions of dollars were invested in Alberta's economy. Dozens of undergraduate co-op and graduate students have spent internship time on this Project. Two of the students used the valuable work experience and expertise from this Project to complete their Master's thesis work. Now that the Project is complete, at least a dozen full-time employees work at the Facility to operate the plant.

As suggested by the Conference Board of Canada, investment in waste diversion technology will create jobs; every 1,000 tonnes of waste diverted will support (directly and indirectly) at least two jobs⁹; All the jobs created are not only those employed at the facility. It also includes contractors, service providers and suppliers of parts to the facility. Since the Facility was designed to process 40,000 tonnes per year of organic waste, the City will save the cost of transporting and landfilling that waste. Additionally, the plant will generate revenue from the sale of the high-quality compost produced. Sales were \$35K in 2020, \$49K in 2021 and \$231K in 2022. Sales are budgeted to be \$206K in 2023 & \$218K in 2024. Some CHP will be generated by burning a mix of biofuel gas with natural gas and used on-site, which will result in lower facility heating bills and lower generation charges on the monthly electrical utility invoice.

5.2 IMMEDIATE AND FUTURE ENVIRONMENTAL BENEFITS

This Project will reduce GHG emissions and will also prevent potential groundwater contamination through the leachate that could be generated by these waste streams if they were landfilled. Compared to combustion, this technology will also prevent emissions of criteria air contaminants. Similarly, the valorization of these waste streams on-site at EWMC will also reduce or eliminate criteria pollutant emissions from the transportation of this waste to remote landfills.

⁹ <https://www.newswire.ca/news-releases/the-value-of-garbage-greater-waste-diversion-would-boost-ontarios-economy-514376471.html>

5.3 INCREASE IN PROVINCIAL INNOVATION CAPACITY

The commercial scale HSADF, alongside the Clean Energy Innovation programme at EWMC – which includes ACETA, AERF, and research and development work on anaerobic digestion in collaboration with the Environmental Engineering Department of U of A – will create a state-of-the-art clean technology research hub in Alberta. This clean tech hub also has the potential to attract other national and international researchers and investors and thereby uphold the reputation of Alberta as a leader in clean energy innovation.

Personnel hiring at EWMC is fair, competitive, and based on competencies. However, students at all levels are encouraged to apply for internships, full-time employment, or apprenticeships. The HSADF will greatly contribute to the training and development of Highly Qualified Personnel (HQP) in this field, and these HQPs will continue to benefit society in the long term.

6 OVERALL CONCLUSIONS

The HSADF is the first of its kind in Alberta and is expected to divert up to 48,000 tonnes per year of organic solid waste from landfills. This Facility generates renewable energy from biogas produced when processing the organic portion of municipal solid waste. Using biogas in CHP generators reduces GHG emissions by displacing fossil fuel sources, and by avoiding landfill methane emissions through diversion. The compost end-product will be used commercially which is also beneficial.

The goal of the Project is to address the crucial need for a sustainable solution for the increasing amount of organic waste generated in the growing city of Edmonton, by harnessing its nutrients and energy content to increase diversion and reduce GHG emissions from landfill. This Project is aligned with the City's Community Energy Transition Strategy, which seeks to reduce community GHG emissions 35% from the 2005 baseline by 2035.

This Project provides heat and electricity for internal use at EWMC and high-quality compost for the soil amendment market.

The HSADF provides a model that may be useful to municipalities throughout North America with respect to sustainable organic waste processing.

7 SCIENTIFIC ACHIEVEMENTS

7.1 LIST OF PATENTS, PUBLICATIONS, ARTICLES, PRESENTATIONS, ETC.

Several presentations were offered at conferences and to interested audiences by those involved in the Project. In addition, several articles were published by equipment suppliers. Graduate students at the U of A were able to use their experience gained with or without samples of feedstocks or inoculum from the HSADF as part of their graduate work. Academic papers co-authored with the U of A were accepted for publication^{10,11}.

8 NEXT STEPS

8.1 NEXT STEPS AND FOLLOW-UP

The Implementation of the High Solid Anaerobic Digestion Technology Project at the Edmonton Waste Management Centre, as funded by Emission Reduction Alberta (ERA), is currently complete. The Facility has been commissioned and is now in its operational phase. Work to optimize the productivity of the plant is ongoing. Through ACETA, the HSADF may be able to support clean energy technology development projects.

8.2 TECHNOLOGY COMMERCIALIZATION AND PARTNERSHIPS

The commercial rights to the Project technology do not belong to the City.

¹⁰ Hok Nam Joey Ting, Long Lin, Raul Bello Cruz, Bappi Chowdhury, Ibrahim Karidio, Hamid Zaman and Bippro Ranjan Dhar, "Transitions of microbial communities in the solid and liquid phases during high-solids anaerobic digestion of organic fraction of municipal solid waste", *Bioresour technol.* 2020 Dec;317:123951. doi: 10.1016/j.biortech.2020.123951. Epub 2020 Aug 3.

¹¹ Felipe Pereira de Albuquerque, Mayank Dhadwal, Wafa Dastyar, Seyed Mohammad, Mirsoleimani Azizi, Ibrahim Karidio, Hamid Zaman, Bippro Ranjan Dhar, Fate of disposable face masks in high-solids anaerobic digestion: Experimental observations and review of potential environmental implications, *Case Studies in Chemical and Environmental Engineering*, Vol.3, June 2021,100082

9 COMMUNICATIONS PLAN

9.1 KEY KNOWLEDGE-SHARING OR COMMUNICATIONS ACTIVITIES

The City of Edmonton and the technology providers issued several communications and news releases throughout this Project^{12,13,14,15}. Some of these were to mark milestones, such as the ground-breaking event and at the beginning of commissioning.

The City also regularly organized open houses and guided tours for the community (except during this period of health-related restrictions). The Alternative Energy Program at Northern Alberta Institute of Technology (NAIT), The U of A's Chemical Engineering Design Class, and many other members and guests of professional organizations – Solid Waste Association of North America (SWANA), Association of Professional Engineers and Geoscientists of Alberta, etc. – were regular visitors to the EWMC.

9.2 THIRD-PARTY COMMUNICATION PLANS

Guided tours of the site, conference presentations, and publication of articles in industry and academic journals will continue.

Waste Services have great partnerships with NAIT (Alternative Energy Programme) and the U of A. Academic publications have already started, as mentioned in section 9.1. In addition, there has been great collaborative work with Suez Environment (now Veolia) and InnoTech Alberta through the operation of the HSADF.

¹² https://webdocs.edmonton.ca/news_archives/news-archive-496249-dc6a.pdf

¹³ <https://www.mswmanagement.com/landfills/article/13018370/viessmann-groupbioferm-energy-systems-selected-for-municipal-anaerobic-digestion-project-with-the-city-of-edmonton-and-the-university-of-alberta>

¹⁴ <https://finance.yahoo.com/news/climate-change-emissions-management-ccemc-161233447.html>

¹⁵ <https://www.maple.ca/blog-and-news/anaerobic-digestion-facility-at-edm/>

APPENDIX A: SUMMARY OF PROJECT SUCCESS METRICS

The key performance indicators (KPI) for an anaerobic digestion facility cover the following three major areas: process-related technical, economic and financial, and environmental benefit and compliance.

Process-Related Technical Performance Indicators

1. **The operating capacity of the HSADF** – For this project the design maximum capacity rating (MCR) is 48,000 tonnes of organic materials (including 8000 tonnes of wood chips as bulking agent) annually at 28 days retention time utilizing 8 digesters. This equates to 385 tonnes per cycle (40,000 tonnes / (365 days /28 day x 8 units)). During the 2022 performance test, the digester’s loading was estimated at 34,000 tonnes which is about 85% of MCR.
2. **Biochemical methane potential (BMP)** – Generated biogas quality and methane content is related to the feedstock properties, the health of the digestion process, and is partially influenced by physical characteristics of the system. In general, the fraction of methane generated is highest from lipid-containing materials, then proteinaceous waste, and, finally, lowest from carbohydrate based materials. Thus, the feedstock, if inconsistent, can alter methane concentration of the produced biogas.

The health of the digestion process is also a major factor because a healthy system produces more methane and less other gases per unit of digester volume, thereby increasing the concentration. Finally, the physical properties of the system influence the partitioning of water soluble gases (primarily CO₂) in the biogas, affecting the methane concentration. The lower the biogas production per unit of liquid in a digester, the higher the fraction of carbon dioxide that can be absorbed into the liquid, which is primarily water. Additionally, as the digester temperature rises, less CO₂ can dissolve into the digestate. Physically trapped air within a feedstock can also play a role in final biogas composition. For complete mix systems, high-moisture, waterlogged materials are generally void of air, but dry stackable materials often have residual air trapped in the porous matrix. Although this air is readily purged in the digester, it can influence the biogas composition at the start of the dry digester cycle.

For the HSADF Project, the threshold is 55% methane concentration or more in the produced biogas, as measured at the common point of the percolation digester (or the COCUS unit as it is called at the HSADF). At this point the biogas will be a blend of

biogas from all dry digesters and the percolation digester, which will likely exhibit some partitioning effects on the biogas, improving the methane content.

3. **Methane yield (ie, concentration of methane in the biogas produced)** – The final parameter for the process performance measure is methane yield. Methane yield is commonly expressed as cubic meters of methane produced per kg of volatile solid supplied to the digestion process. This is the universal measure of performance and is regularly compared to small batch culture tests or biochemical methane potential (BMP) tests. BMP tests are performed under ideal conditions with small amounts of substrate in large amounts of verified quality inoculum and are designed to ascertain the maximum amount of methane that can be extracted by digestion from a material. The BMP yield is often compared to a full system yield to determine how healthy the process is operating. If the process is healthy, it should be readily breaking down the carbon of the feedstock and achieving yields near that of the feedstock BMP. For the HSADF project, the target is to achieve a methane yield in the system that meets or exceeds 70% of the feedstock BMP.

PERFORMANCE MEASUREMENT CONDUCTED AT THE HSADF

A third-party consultant, InnoTech Alberta, was brought in to develop a testing plan for the Facility. Testing was done for the performance guarantee and tests outside of the operational scope for additional information to develop a performance baseline. The testing took measurements from the feedstock, cocculus tank, and percolate digester of:

- Biochemical methane potential
- Bulk density
- Solids
- Nitrogen
- Trace elements
- Salinity

These tests were to determine if the process achieves the methane production criteria of capturing 70% of the BMP from the feedstock and to monitor the condition of the percolate. Plans to sample the resultant digestate as an indicator of aeration bunker performance and the alignment of the compost produced with industry standards were impeded by technical issues during the commissioning. The product quality was impacted by the non-ideal digestion due to intermittent stops. Samples were tested, anyway, but without ideal operation, the results from ideal operation are unknown.

The results from the testing, though impacted by intermittent stoppage, were consistent with results gained from pilot testing in 2014. A comparison of the results of Cycle 3 and the testing average is presented below in **Table A.1**.

TABLE A.1: Cycle 3 Results compared to testing averages

	2022 Cycle 3 Results	2021-2022 Testing Averages
Total Solids	49.5%	50.3%
Volatile Solids	60.4%	59.8%
Bulk Density	327 kg/m ³	332 kg/m ³

Basic conclusions from the performance measurement process include:

- Numerous cycles of steady state operation are required to ensure the contributions of recycle material to the overall biogas production and calculated methane yield from a dry batch digester system are consistent and not atypical (higher than true yield because of the use of unspent digestate recycle or lower yield because of long delays in cycle exchange resulting in very spent recycle material).
- The percolation process is critical to the operation of a dry batch digester because this provides the means to wet the process. Digestion is at its core a wet process and thus consistent reliable percolation throughout the entire feedstock matrix within the digester is needed to establish high rates of digestion and achieve high yields.
- From the Cycle 3 loading data, the plant biogas production data, measured TS, VS and BMP data we have projected that the HSADF is only reaching 44% of the potential BMP of the material, which is well short of the 70% requirement. However, some of this data was within a known time frame of poor percolation (last 2 Cycle 3 loadings) that would typically reduce yield.
- It should also be noted that apportion of the gas is being made from Cycle 2 loadings and there is no BMP data for these loadings. However, the loading and BMPs appear consistent enough that major differences from this calculation are unlikely even if the data was available to incorporate into the equations.
- The current loading rates of the HSADF during cycles 2, 3, and 4 do not support attainability of the target 40,000 tonne per year loading of fresh material.

- The low yield measured during the performance guarantee appears to be a combination of operational difficulties (such as reduced percolation) and also poor digester health, since the biogas production numbers presented to InnoTech were not near the benchmark production required at any point during the examined time frame.

ECONOMIC AND FINANCIAL PERFORMANCE

Evaluation of the financial performance of this facility will require gathering several types and sets of information which is yet to be done:

Set 1 Data:

- Material balance to quantify all SSO inputs and all products outputs from the facility
- Energy balance to quantify all energy inputs to the facility and all energy output from the facility

Set 2 Data:

- Quantification of the cost of operation (cost of materials and energy input to the facility, plus labor and maintenance cost)
- Quantification of revenues from product sales (Power and compost) and GHG offset credit
- Amortization of capital cost

ENVIRONMENTAL BENEFIT AND COMPLIANCE

The environmental benefits are largely due to GHG offset credits which are detailed in Section 4 of this report.

TABLE A.2: PROJECT METRICS

Name	Value	Unit
TRL at Start	8	#
TRL at End	9	#
\$ Future Capital Investment	Unknown	\$
# New Jobs Created from Project	>100	#
# Projected New Jobs Created from Future Deployment	Not available	#
# Actual GHG Emissions Reductions from Project	To be Quantified	t/y
# Projected GHG Emissions Reductions from Future Deployment (to 2030)	To be Quantified	t/y
Field Pilots and Demonstrations	Yes	Yes/No
Are Clients Selling Goods or Services Internationally	No	Yes/No
Are Clients Selling Goods or Services Domestically	Yes	Yes/No
# of Publications		#
Knowledge Mobilization	>12	#
# HQP Trained	12	#
# Patents and Records of Invention filed	0	#
Innovation Ecosystem Development	Yes	Yes/No
# New Policies Informed/Influenced	Not Yet	#
# Practices Informed/Influenced	Not Yet	
# New Products/Services Created	2	#
# New Spin-Off Companies Created	0	#
Completion Date Delta	12	#
Did Total Project Costs Meet Budget Expectations?	No	Yes/No
Renewable Electricity on Grid	1.0	MW
# Clean Tech Companies with HQ in AB	Yes	Yes/No