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PREFEASIBILITY STUDY
KUUJJUAQ WASTE TO ENERGY

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0. INTRODUCTION

Ramboll have been engaged by Société du Plan Nord (SPN) to assist with a prefeasibility study for a Waste to Energy plant in Kuujjuaq, Canada.

Kuujjuaq is the largest northern village (Inuit community) in Nunavik, Quebec (58°06’24”N 68°23’55”W). The village of Kuujjuaq has around 2800 inhabitants and is only accessible by plane or by boat (during the summer months). The Nunavik territory is characterized by fragile ecosystems, harsh climate, isolation and a specific land regime rooted in a treaty signed between the Inuit of Nunavik and the government of Québec (the James Bay and Northern Québec Agreement). Kuujjuaq lies 48 km (30 mi) upstream from Ungava Bay.
With ocean access and two runways at the Kuujjuaq Airport, Kuujjuaq is the transportation hub of the Nunavik region. Ships delivers cargo from app. beginning of July to mid October. There are no roads to outside the region.[1]

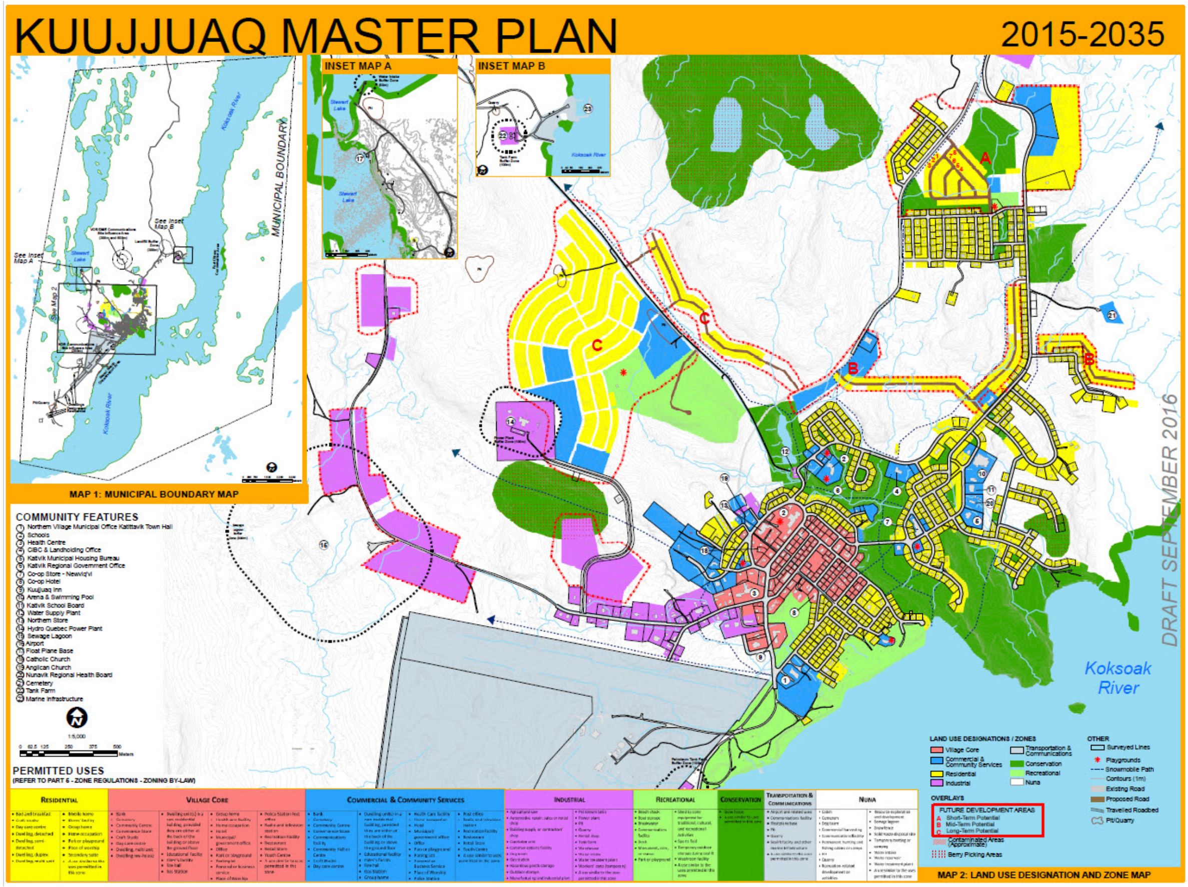


Figure 1 - View of Kuujjuaq from the Master Plan 2015-2035

Kuujjuaq has a very cold subarctic climate, with temperatures easily getting below -30 °C in the winter, and permafrost is present in many places throughout the village and area. The summers are relatively warm with temperatures reaching above +15 °C. However, the ice in the Ungava Bay is often present until July making transportation by boat impossible until the bay is clear of ice. The river starts to freeze again in October.

[1] https://en.wikipedia.org/wiki/Kuujjuaq

Kuujjuaq has two schools serving students from kindergarten up to secondary 5. The village boasts a number of hotels, restaurants, stores, arts and crafts shops and a bank.

Kuujjuaq is growing in size and population, and the current population of 2800 is expected to rise to 4025 by 2035, with waste amounts expected to rise linearly.

In 2009, a total of 29 million liters of diesel oil[2] was used to heat buildings and water. The need for power and heat is also expected to rise almost linearly with the increased population.

Kuujjuaq is not connected to the national power grid of the state-owned corporation, Hydro-Québec. This means that Kuujjuaq relies upon a sealift cargo for its fossil fuel supply to fulfil all its energy needs. Electricity is produced in a centralized diesel power plant operated by Hydro-Québec. Building heating is decentralized such that every building has an oil-tank, boiler and furnace.

Because of permafrost, landfills cannot be implemented like it is the case in the South of the province. Therefore, to decrease the volumes to be managed, the law requires the northern villages to open burn domestic, institutional and construction waste. Currently, recycling is only applied to hazardous and electronic waste, pop cans and car tires that have a rim diameter lower than 62.23 cm. Domestic, commercial and institutional waste is collected directly at each building, trucked to the landfill and burnt without prior sorting. The remaining ashes and non-burnable material are then landfilled and accumulated in Northern Landfills, which have their own specific regulation. The inefficient burning of the residual matters and their landfilling contribute to the dissemination of air, soil and water contaminants in the ecosystem.

Similar to other remote regions of the world, workforce training, recruitment and retention is a challenge in Nunavik.

The aim of this prefeasibility study is to assess whether or not a Waste to Energy Plant with a positive energy output is feasible for the village of Kuujjuaq.

The report has been structured in the same way as the assignment including the Fact Finding Mission, Review of commercially available technologies, Conceptual Design of the recommended technology, Cost Evaluation for the future Waste-to-Energy Plant and Overall Time Schedule.

[2] Scenarios Analysis Waste-to-Energy for Building Heating, Société du Plan Nord, 2016

1. FACT FINDING MISSION

In order to ensure the success of the project, a fact-finding mission to Kuujjuaq was arranged. The fact-finding mission was planned to provide Ramboll with knowledge of the actual conditions in Kuujjuaq, including infrastructure, climate, accessibility, layout of the village, possible sites, possible heat-off-takers etc, that could influence the project.

As is always the case in remote locations like Kuujjuaq, local awareness and acceptance of a project is key to success. For this reason a range of meetings with local stakeholders was planned throughout the visit including Makivik, Kativik Regional Government, Landholding Corporation, Northern Villages council and various possible consumers of heat.
The stakeholder meetings also allowed the stakeholders to take advantage of Ramboll's extended knowledge on Waste to Energy projects in arctic regions and receive a greater insight into the possibilities and challenges of taking on a Waste to Energy Project in a village like Kuujjuaq.

The fact-finding mission was carried out by Siv Sigvardsen and Christian W. Knudsen lasting from 27th to 30th November 2018.

1.1 Data collection

During the fact-finding mission various information was collected including:

- Supply temperatures used in various buildings in Kuujjuaq. This is of importance when installing a district heating supply, in order to determine which buildings can be supplied with district heating. District heating will be supplied with a maximum temperature of 110 degrees, and more likely around 90-95 degrees. The buildings inspected all had an internal supply temperature of around 80 degrees.
- Location of largest consumers. The largest consumers in Kuujjuaq are also the largest buildings. These include the hospital, the schools, the KRG building, the Forum etc. The oil consumptions for some of the largest consumers can be found in Appendix 6 on page 20. It should be noted, that the consumption for the hospital includes diesel for production of steam, and thus the heat demand will only be a certain percentage of the total consumption for the building. The precise demand is unknown but can be estimated using the size of the building and comparing it to other similar sized buildings.
- Topography of Kuujjuaq. Kuujjuaq is located by the river Koksoak and runs mainly in a north-south direction. The area is fairly hilly and considerations for where to place an eventual Waste to Energy plant should take the topography of the area into account. A high location will produce better dilution of the emissions coming from the stack. A map showing the topography of the area can be found in Appendix 12.
- Areas with permafrost. As always when constructing buildings in arctic regions areas with permafrost should be investigated. The village of Kuujjuaq contains several areas with permafrost, as can be seen in Appendix 12. It is advised to be thorough when performing the geological surveys ahead of construction as some areas of permafrost can be very narrow.
- Wind direction. The wind in Kuujjuaq blows mainly from a west south-westerly direction as can be seen from Appendix 9.
- Temperature inversion is experienced in the area with unknown frequency. This also has to be considered.
- Usage of glycol in building heating systems. It is common practice throughout Kuujjuaq to have glycol added to the heating systems inside every building. The water used is not treated and thus leads to production of sediments in the pipes. As such, if a district heating system is to be established it would be advised to install heat exchangers for

every consumer to avoid mixing a treated water/glycol mixture with a non-treated mixture.

- Experience with sorting in Kuujjuaq. Efforts have been made in Kuujjuaq over the past couple of years to implement sorting of waste, however the results have not been very promising. Focus should be made on sorting out the main hazardous materials such as propane tanks, aerosol cans, electronics and PVC. Due to the high cost of shipping waste material south, sorting out other non-hazardous fractions will likely not prove economically advantageous. This has also been the case for cities in Greenland.
- Information on infrastructure including supply of oil, water and removal of sewage. The amount of piping infrastructure in Kuujjuaq is very limited. Water, oil and sewage are all being trucked around in the village. Water is being delivered daily to individually heated water tanks in every single household in the village from the water treatment facility. Sewage is collected daily from every single household in the village and taken to the lagoon. Oil is being delivered from the oil tank farm to each house upon request.
- Knowledge of skilled personnel in Kuujjuaq. As for other arctic regions the access to skilled workforce in Kuujjuaq is limited. As such having a high-tech Waste to Energy solution is not advised, as there are no or few skilled people in the village to fix high-tech solutions. It is advised to select a solution built for heavy duty usage and of a simple construction. Adding too many layers of automation will lead to excessive downtime in the event of a breakdown. If it is decided to go ahead with the project, it is advised to carry out a study in order to identify which skills are available in the village as this might have an impact on the specification of the plant.
- Operation of the dump site and burning of waste. During the fact-finding mission the current dump site was visited, and the open burning of waste was observed. As is the case elsewhere the open burning produced a lot of black smoke and when stirred grey and light-green smoke was observed. The dump site is managed by a single person who is also responsible for keeping the fire going. It is the intension only to burn waste when the wind blows the smoke away from the village, but as the fire will take 4-5 days to burn out this can be hard to predict, and it is not uncommon to have the smoke blow in over the village. The fire is maintained during the day and left to burn during the night unobserved.
- Water treatment plant. A new water treatment plant is currently under construction on the west side of the village. The current (and new) water treatment plant receives the water from Stewart lake located roughly 4 km away. The water is heated at the lake (to avoid freezing) and pumped to the village water treatment plant where it is treated. The water is maintained at a temperature around 3-5 degrees. On an average day 35-45 trucks each carrying 13.000 liters of water leave the water treatment plant in order to deliver water to the inhabitants of Kuujjuaq.
- Suggestions to sign contracts for buildings in the beginning of the year in order to make the most of the shipping season. As the shipping season is limited by the amount of ice in the river this will have a great impact on the delivery of goods. In 2018 the shipping season did not start until mid-July. Usually it will start a few weeks earlier. Large ships cannot sail the river due to limited depth, so all goods have to be transferred to prams. Kuujjuaq experience very high tidal changes and a such only one delivery per 12 hours is possible.
- General costs for construction of simple and technical buildings per m2. Ramboll was provided with costs per m2 for constructing simple building and building containing technical equipment such as the water plant. The costs seem to match very well with Ramboll’s experience from other arctic regions, Greenland in particular.
  As a rule of thumb base prices on 10,800 CA$/m^2 for technical buildings (like water treatment) and 7,500 CA$/m^2 for simple buildings can be assumed.

- Snowmobile tracks: During the winter months as the landscape changes, a number of traditional snowmobile tracks are used throughout the village. The tracks are marked on various maps and will need to be avoided when installing equipment.

1.2 Interviews with key persons

A range of the most important stakeholders were visited and interviewed during the visit including:

- Makivik
- NV Council
- The hospital
- KRG Environment
- KRG warehouse
- KRG Water Plant
- The landfill/dump
- Landholding Corporation Board
- KEAC and KRBHSS

Notes and information shared during the meetings can be found in Appendix 1 and 2.

1.3 Documentation with information about the waste quality

Ahead of the fact-finding mission, SPN had provided Ramboll with information on the waste composition and quality for Kuujjuaq, based on a report from Stantec Consulting Ltd.

Characterization took place during three five-day campaigns in August, October and November 2017. It produced data on composition and on annual and monthly generation of waste materials from the residential sector (including institutions and businesses), grocery stores (three establishments) and voluntary drop-offs (mainly from residential construction but also bulky waste). [Stantec Consulting Ltd, Analysis and characterization of waste streams in Kuujjuaq, July 4, 2018]

The report concludes that the inhabitants of Kuujjuaq produce close to 1.000 kg waste per year, including all types of waste. The combustible part of the waste is estimated to constitute 65% of the total waste amount[3]. As such the waste amounts for combustion are estimated to be 1860 t/y based on 3.000 inhabitants.
This is in line with what have been concluded in similar villages in Greenland, where 650 kg/y of combustible waste is the average per person.

The report indicates that the calorific value of the waste is expected to range from 9-13 GJ/ton, most likely leaning towards the higher calorific value. These figures are similar to what Ramboll have observed for similar sized villages in Greenland.

The annual amount of waste available in Kuujjuaq and the calorific value is well suited for a Waste to Energy plant.

The report on Kuujjuaq waste composition can be found as Appendix 8.

1.4 Identification of scenarios for energy recovery

A Waste to Energy plant is able to thermally treat the combustible fraction of the waste and produce heat at the same time. The heat can be distributed through a District Heating system (substituting oil in this case) provided that the quality of the heat is good and transmission

[3] Waste-to-Energy scenarios for Kuujjuaq, Société du Plan Nord, Myriam Blais

distances are not too great. This approach has been employed in many parts of the world including Greenland.

Most Waste to Energy plants will have the option to supply hot water to a district heating system with the temperatures required for the current building heating installations. The study will include recommendations for which technologies are suitable for a possible district heating system in Kuujjuaq.

The heat produced at the plant can be transferred to a district heating network through a heat exchanger. District heating pumps, often located close to or at the Waste to Energy plant, will provide the district heating system with the necessary flow and pressure.
It is advised to connect consumers through a heat exchanger as well which will ensure a more robust system with a lower risk for the operator of the district heating network.

It is advised to attach the largest consumers to the system as this will provide the greatest financial benefits. Start-up cost to attach a consumer to a district heating network are high leading to relatively high cost/kWh for small consumers and relatively low cost/kWh for large consumers. A number of building were inspected during the visit to Kuujjuaq in order to assess the possibilities for connecting them to a possible district heating network. The installations inspected proved suitable for connection to a district heating network.
Experience from similar sized cities in Greenland (Aasiaat, Sisimiut, Maniitsoq, Qaqortoq) suggest that around 10-20 % of the heat demand in Kuujjuaq can be covered by a Waste to Energy plant.

A sketch of a very basic District Heating system is shown below. Heat exchangers should be installed at the plant and for every consumer.

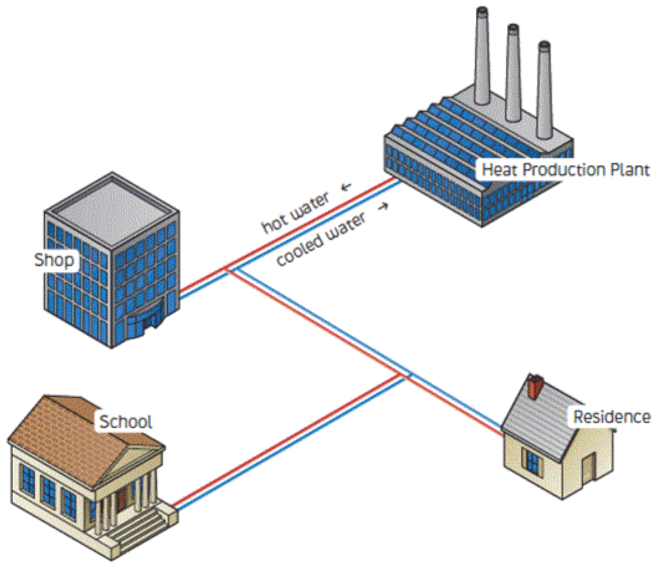


Figure 2 - District Heating sketch (Source: www.statkraft.com)

As the design of a district heating network is not part of this study, it is advised to set up a separate project to assess the options for design of a district heating network.

Consideration and planning shall be given to the size, location and layout of the district heating network, ensuring that expansions are possible at a later stage. Pipes can be run both under the ground in culverts, on the ground and over the ground on pipe bridges providing many options for low cost installation (on ground) and the ability to cross roads etc.

When investigating the possibilities of establishing a district heating network there is a big opportunity in including Hydro Quebec (diesel power plant) as a large supplier to the district heating network. If the village of Kuujjuaq is anything like the similar cities in Greenland, then with the addition of the heat produced at Hydro Quebec, 60% of the heat production in Kuujjuaq could potentially be provided by centralised heat producers (Hydro Quebec and a Waste to Energy plant), leading to a drastic reduction in diesel oil usage in Kuujjuaq. It is strongly advised to set up a separate project to engage Hydro Quebec and convince them to supply the waste heat to a district heating network.

2. REVIEW OF COMMERCIALLY AVAILABLE TECHNOLOGIES

2.1 Preconditions

In order to evaluate the possible commercially available technologies, a number of criteria's have been set up with which each technology will be evaluated against.

- Positive energy output; The technology shall have a positive energy output meaning that the energy that can be extracted in the form of heat is greater than the amount of support fuel and electricity that is needed to run the plant. The energy contained in the waste is not included in this calculation.
- Emissions; The Waste to Energy facility shall be equipped with a flue gas treatment system in order to capture as many of the harmful emissions that arise when waste is thermally treated. With the addition of a well-designed flue gas treatment plant the plant should emit substantially fewer emissions than the current open burn solution provides today.
- Waste amounts; The technology shall be able to treat the current (and future) waste amounts of Kuujjuaq.
- No prior sorting; As no substantial sorting is expected to take place over the coming year, the technology shall be able to cope with mixed waste.
- Facility Complexity; Due to the remote arctic location of Kuujjuaq, and the problem of training, recruiting and retaining the workforce the technology shall be robust, easy to operate and not feature a myriad of advanced features that are unlikely to be fixed in case of failure.
- Two-chamber combustion; Due to the current Canadian legislation the chosen technology shall feature a two-chamber combustion, where the second chamber shall include a support burner using clean oil in order to maintain 1000°C for 1 second minimum.
- ASME; The technology shall conform to relevant ASME norms.

2.2 Waste amounts and energy content

According to studies performed by SPN[4], Kuujjuaq currently produces roughly 1860 tons of combustible waste per year with an energy content of 9-13GJ/ton rising to 2600 tons in 2035

The following numbers are estimates of an average plant, variation should be expected from technology provider to technology provider.

Given that time for maintenance is needed every year and throughout the year, it is not possible to operate a plant 8760 hours per year. For plant sizes applicable to Kuujjuaq 7000 hours of operation is to be expected. 7000 hours corresponds to the plant running 24/7 with 2 days out every other week (for cleaning) and a stop of 3 weeks for maintenance every year (usually during summer).

Current situation (2,700 inhabitants):
Provided that the plant will operate with waste for 7,000 hours per year in order to treat 1,860 tons of waste with an energy content of 9-13 GJ/ton, the average hourly throughput will be 265 kg/h containing 2.92 GJ/h (=0.81MW). As no plant has an efficiency of 100% and efficiency diminishes with smaller sizes, a boiler efficiency of 85% is estimated, leading to 0.69 MW (2,350,965 BTU/h) energy that can be utilised every hour when the plant is operating at full load.

[4] Serre-Plan-affaires.2016-08-31ANG.pdf

2035 situation (4,025 inhabitants):
Provided that the plant will operate with waste for 7,000 hours per year in order to treat 2,600 tons of waste with an energy content of 9-13 GJ/ton, the average hourly throughput will be 375 kg/h containing 4.125 GJ/h (=1.15 MW). As no plant has an efficiency of 100% and efficiency diminishes with smaller sizes, a boiler efficiency of 85% is estimated, leading to 0.97 MW (3,309,800 BTU/h) energy that can be utilised every hour when the plant is operating at full load.

The high calorific value of 9-13 GJ/ton means that the waste is able to drive the treatment process on its own without adding support fuel, except for start-up and potentially shut down of the plant where support fuel may be needed for warming up.

2.3 Batch-fired vs. continuous

To treat the waste in Kuujjuaq, two main principles can be applied; batch-fired or continuous.

A batch-fired process is a process where fuel (in this case waste) is loaded into a device/plant all at once in a batch and subsequently processed over the course of several hours, after which the device is stopped, cleaned and reloaded. Heat output and emissions will vary throughout the treatment-cycle.
A batch-fired process will produce relatively large amounts of heat for short periods of time (usually a few hours per day) and then produce less and less until nothing is left.
Batch-fired processes are usually preferred for destruction of waste.
Most batch systems are not equipped with heat recovery and their operation in intervals makes stable operation close to impossible.
Batch system that live up to some of the environmental regulations only do so due to very high temperatures in the stack.

A continuous process will have fuel (waste) fed continuously to the device/plant at all times which provides more stable conditions for the treatment itself, possible energy output and emissions.
A continuous process will produce slightly less heat than the peak output of the batch-fired process, but the energy will be produced continuously throughout the day. Continuous processes are usually preferred where energy recovery is important, as the operating conditions for continuous operating plants are more predictable and stable. This will also return lower emissions and make it easier to meet regulations, as the plant and operation is easier to tune.

Theoretically, the total energy output will be the same regardless of which process is selected (if the efficiency is the same) but the delivery of the heat will not. When looking at positive energy outputs batch-fired systems are not deemed interesting as the energy production varies too much and cannot be counted on as a reliable source of heat, as can be seen from the figure below, illustrating the challenges in using a batch fired process for heat distribution. For the sake of transparency, it should be noted that the figure does not include the same total heat release for both processes, as the batch-fired process is constrained by the fluctuating heat output making it impossible to design a boiler of just the right size. However, the principle of fluctuating and stable energy release remains the same.

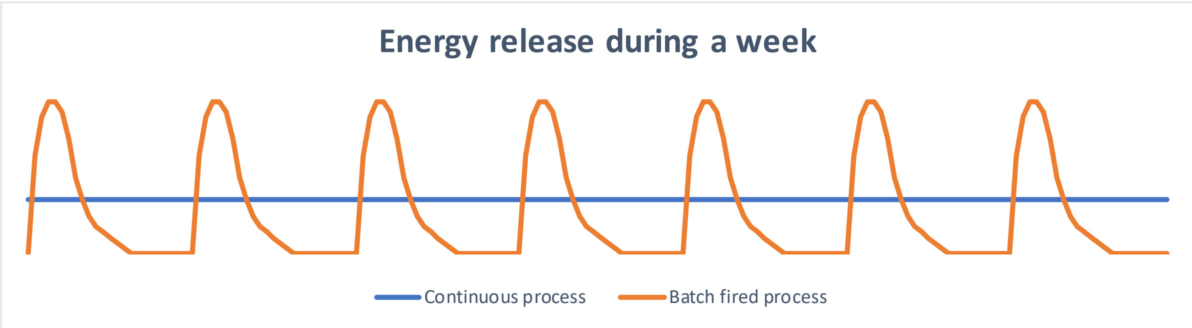


Figure 3 - Energy release from a batch-fires process vs. a continuous process – for illustration purposes only

Emissions are likely to follow the same pattern, although not they will not differ as much as the energy release. More emissions are created using a batch-fired process than a continuous, for the same reasons as stated above, that with continuity comes predictability which means that the process (be it combustion or gasification) is easier to tune. As for the sizing of the flue gas treatment system for the batch-fired system, it will always be a compromise due to the changing conditions in the thermal treatment stage.

As such, emissions for a batch-fired process will always be higher than a continuous process. The figure below illustrates the rough emissions of various thermal treatment options. No numbers are included as the actual numbers can vary based on the selected technology within each option. However, the magnitude of emissions is in the right ball park. Some specific emissions will drop even more than what is illustrated, and some will drop a bit less, but the overall message remains the same; any thermal treatment in a controlled environment is significantly better than open burn, and a continuous process will yield far lower emissions than a batch-fired process, when treating the same amount of waste.

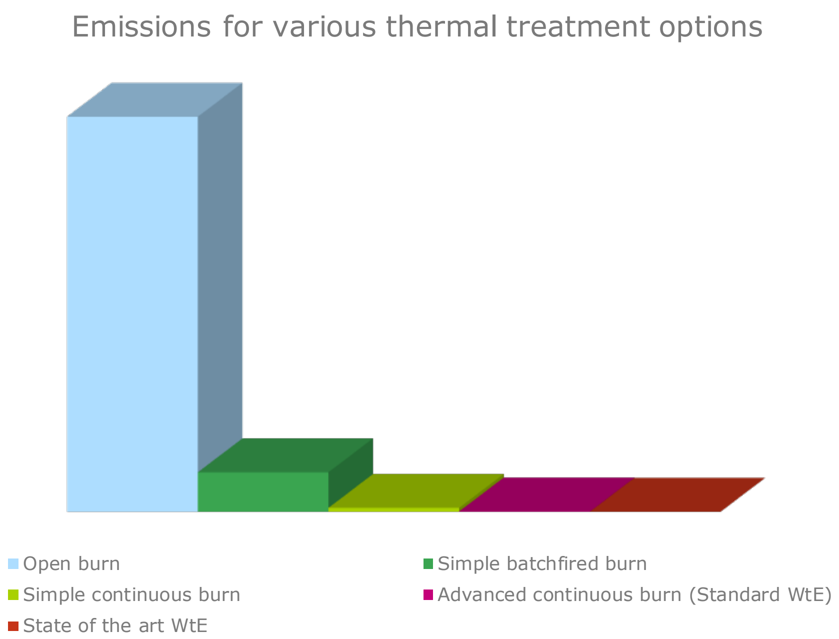


Figure 4 - Scale of emissions from various thermal treatment options - for illustration purposes only

What should be noted as well, is that the first two steps on the ladder will provide significant reductions in emissions compared to an open burn. The subsequent steps are only justifiable when treating large amounts of waste where economies of scale can be applied.

2.4 Micro-scale vs. small-scale

The study calls for an evaluation of micro-scale vs. small-scale technologies. The two sizes are defined in the contract as follows:

- Micro-scale: Technologies for 300.000 BTU/hr (greenhouse need, 88 kW)
- Small-scale: Technologies that can produce more than the greenhouse needs (88 kW)

2.4.1 Micro-scale

Looking at micro-scale technologies that will be able to cover the 88 kW needed to heat the greenhouse, thermal treatment of the waste in Kuujjuaq could be an option. However, it would make little sense to treat only part of the waste amounts equal to the amount needed to heat the greenhouse (<13% of the total waste heat amount).

Technologies capable of producing continuous heat from waste in such small amounts are very limited and not well proven. Options are available, but they will all be batch-fired processes, which will be able to treat the waste, but not able to supply stable conditions for heat production, even from batch to batch, as the limited waste amounts will give rise to large fluctuations in the calorific value of the waste, leading to a higher or lower energy production as demonstrated in the previous section.
Ramboll would not be recommended to utilise waste for producing heat to the greenhouse if the greenhouse is the only heat off-taker.

Therefore, if the choice is to go for a micro-scale solution which will only heat the greenhouse, a standard used oil burner capable of producing 88 kW would be a better solution. Obviously, a clean oil burner can also be used, but this would defeat the waste-to-energy purpose.

2.4.2 Small-scale

When going to small scale solutions for using the energy in waste, the options are greater. More types of proven technologies are available, and the energy needed to heat the greenhouse will only be part of the equation, as the energy output from treating all the waste in Kuujjuaq is far greater.

With the available waste amounts in Kuujjuaq, the technologies currently available for turning waste into energy are only able to produce heat and not power. Producing power requires the facility to have a turbine and produce steam instead of hot water. Adding a turbine and producing steam increases the complexity and drives the price of the plant up significantly, essentially killing the business case.

A small-scale plant will be able to treat all the waste in Kuujjuaq and ideally turn all the energy into usable heat which can then be distributed using a district heating piping system.

Small-scale plants are available as batch-fired or continuous processes. For the reasons mentioned in section 2.3, a continuous process would be preferred if energy recovery shall be included, as they are better at maintaining stable conditions for calorific value, energy output, emissions etc.

In the following sections a number of technologies relevant to Kuujjuaq will be reviewed.

2.5 Technology study: EcoWaste Waste-to-Energy (combustion)

2.5.1 Introduction

The SPN have been contacted by Eco Waste Solutions (EWS) for the possible Waste to Energy Project in Kuujjuaq. The SPN have forwarded material previously received from EWS to Ramboll. Ramboll have further had a teleconference with EWS in order to understand the technology more from a technical point of view.

EWS are based in Burlington, Ontario, Canada and claim to be one of the world's leading suppliers of modular thermal treatment and WTE technology for solid waste.

EWS pride themselves as being experts at implementing waste management projects for small communities, workforce camps and military bases, as they have more than 70 such references.

EWS claim that their technology can provide a 96% reduction in waste volume, which seems plausible if the density of the waste is fairly low.

2.5.2 Working principle

EWS have suggested two different methods for treating the waste; a continuous feed system and an intermittent continuous feed system both capable of treating 500 kg/h. According to earlier information from EWS, the batch systems on which the intermittent continuous system is partly based can be provided from 40 to 400 kg/h depending on final quantities of waste.

Option 1 – Continuous Feed Waste to Energy System:

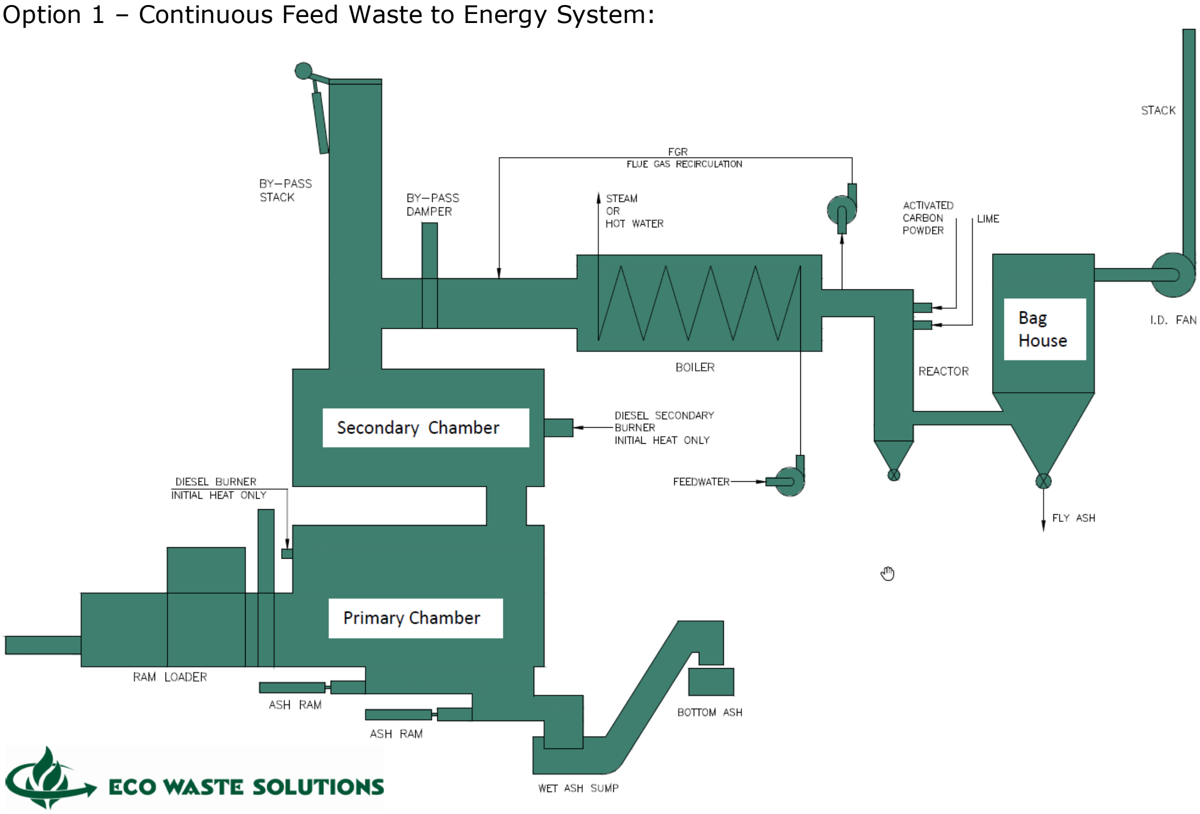


Figure 5 - EWS suggested layout for Continuous Feed WtE Plant

In their general brochure[5], EWS describes the continuous waste feed process as:
The process of continuous-feed differs from the batch process. The waste is charged into the continuous-feed Primary Chamber after it has achieved operating temperature of 600°C-850°C (1200-1560°F).

Feeding /Loading

The loading method and configuration may vary (comment by Ramboll: compared to batch) *but as the name implies waste must be supplied to the system on a continuous basis. Typically, the waste is delivered to the system using a mechanical materials handling device such as a skid steer loader, conveyor or* (comment by Ramboll: Waste Crane).

A waste charge or load is deposited in the first stage of the system via a hopper. The hopper directs waste towards the Primary Chamber where it is moved by a mechanical ram or platen that will push the waste into the system. The Operator is isolated from the heat of the process by a guillotine style door. Although this process may be highly automated, generally the Operator is required to be available to load the ram hopper every 20 minutes or so during the burn cycle.

Incinerations

Within the Primary Chamber the waste bed moves slowly along the stepped floor grate as it is pushed by a series of transfer rams. In this phase, which takes place over up to 6 hours, the solid waste is transformed into a gas that is drawn into the Secondary Chamber. What remains in the continuous feed Primary Chamber is sterile non-combustible material such as metals and glass and a non-toxic, non-leaching ash that is safe for disposal or re-use.

In the Secondary Chamber the combustion gases are exposed to a highly-oxygenated and extremely turbulent environment for a minimum of 2 seconds retention time at a temperature of 1000°C to complete the combustion reaction. The entire process is monitored and controlled by the EWS proprietary 4G control system.

APC

Given the increased turbulence of the continuous-feed Primary Chamber compared to that of a batch incinerator the off-gases may require an Air Pollution Control (APC) system. The emission levels mandated by local environmental regulations and the waste composition will dictate the design selection of the APC. Typically, the APC design includes stages to cool, neutralize and capture entrained particulate matter within the exhaust gas stream, before they can exit the stack.

Bottom Ash handling

The ash produced by a continuous-feeding system requires continuous-ash-discharge. Most commonly this function is performed by a wet ash conveyor system that will operate automatically.

Option 2 – Intermittent Batch/Continuous Waste to Energy System:

[5] EWS-General-Brochure-REV-A-Email.pdf

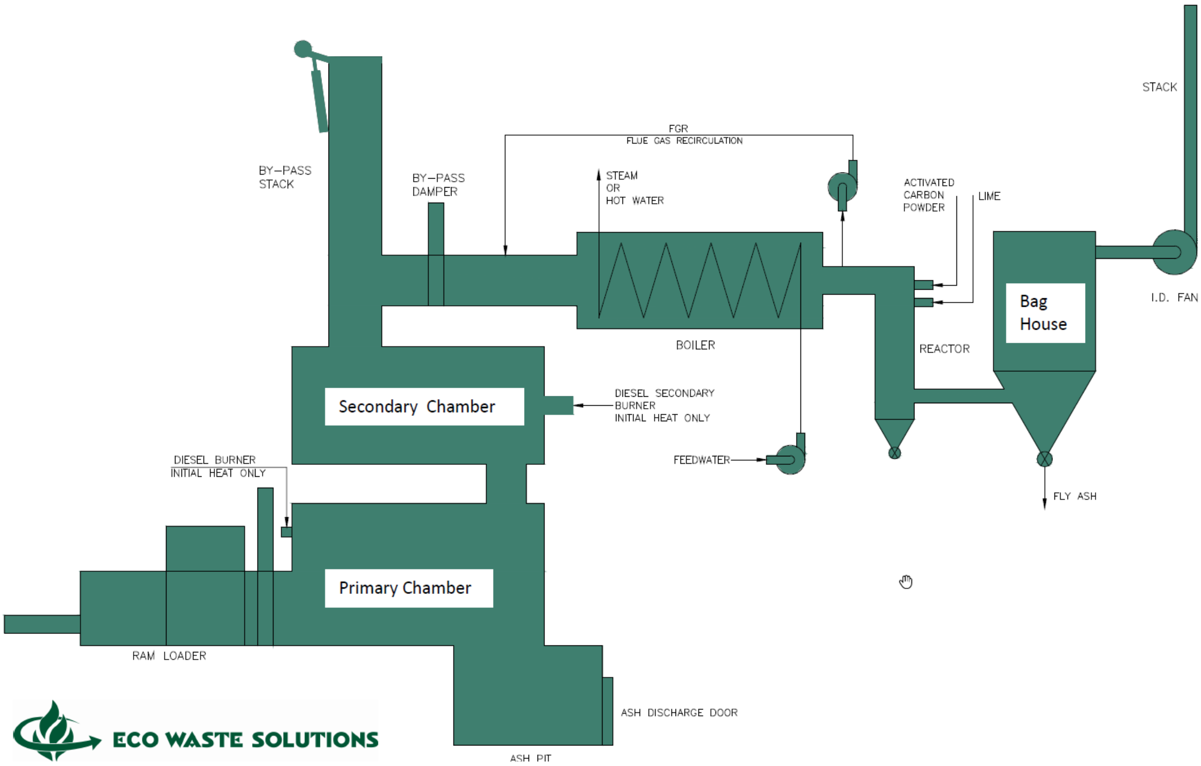


Figure 6 - EWS suggested layout for Intermittent Batch/Continuous Feed WtE Plant

EWS suggest an intermittent batch/continuous system is the most suited for Kuujjuaq. EWS call the solution Intermittent Batch, but according to Ramboll it is closer to an Intermittent Continuous system, as the waste is fed continuously to the Primary Chamber, even though the plant may be based on the EWS Batch system. As such, Ramboll will discuss the system as an intermittent continuous system in this report.

Intermittent continuous is to be understood as a continuous running process that needs a bi-weekly stop in order to perform some manual cleaning of the system. This is a similar operational strategy as the one being applied to the WtE plants in Greenland.

EWS have not sold a system that has the intermittent feeding option yet. However, as it is fairly similar to the ordinary batch process with the exception of the feeding process which is similar to the continuous process, the description below rewritten from EWS general brochure[6] on the batch and continuous process covers the topic.

Feeding /Loading

The loading method and configuration may vary but as the name implies waste must be supplied to the system on a continuous basis. Typically, the waste is delivered to the system using a mechanical materials handling device such as a skid steer loader, conveyor or (comment by Ramboll: Waste Crane).

A waste charge or load is deposited in the first stage of the system via a hopper. The hopper directs waste towards the Primary Chamber where it is moved by a mechanical ram or plate that will push the waste into the system. The Operator is isolated from the heat of the process by a guillotine style door. Although this process may be highly automated, generally the Operator is required to be available to load the ram hopper every 20 minutes or so during the burn cycle.

Incineration

[6] EWS-General-Brochure-REV-A-Email.pdf

vuWithin the Primary Chamber the waste moves down over a sloped hearth while doing this the solid waste is transformed into a gas that is drawn into the Secondary Chamber. What remains in the continuous feed Primary Chamber is sterile non-combustible material such as metals and glass and a non-toxic, non-leaching ash that is safe for disposal or re-use.
In the Secondary Chamber the combustion gases are exposed to a highly-oxygenated and extremely turbulent environment for a minimum of 2 seconds retention time at a temperature of 1000°C to complete the combustion reaction. The entire process is monitored and controlled by the EWS proprietary 4G control system.

APC

These packages may require an Air Pollution Control (APC) system, or Scrubber, to meet local environmental regulations. All EWS systems can be outfitted with an APC to further cleanse and neutralize exhaust gases to ensure compliance with local air emission standards.

Bottom Ash handling

The ash produced by an intermittent continuous-feeding system requires a large ash pit. The ash pit is slowly filled as the waste is pushed forward on the sloped hearth.

2.5.3 Discussion of working principle

EWS have stated that the feeding mechanism for the intermittent-continuous process is just like any other feeding mechanism options such as top loading, but from the front of the machine instead of from the top. The feed box requires some inhouse engineering, but EWS are confident they have the technology to provide this option to its clients.

The intermittent continuous feeding method was originally offered by EWS to Kuujjuaq to meet the community's main objectives of obtaining a simple WTE system that had a positive energy balance, utilized very little diesel fuel and with a low capex.

The main differences between the two systems are:

- The continuous Feed WTE system (more moving parts) includes ash rams and stepped hearth as well as an automated continuous ash process into a wet sump.
- The Intermittent Batch system (fewer moving parts) includes a slopped hearth without ash rams, the ash fall into the ash pit with gravity and the ash pit has to be emptied manually.

Both systems consist overall of a basic furnace, boiler and flue gas treatment system. The waste is fed to the primary combustion chamber using a ram loader that pushes the waste in on a predetermined time interval. The waste is treated in the primary chamber, and the flue gasses are then led to the secondary chamber where they are kept for 2 seconds at 1000 °C. From there they are directed to the boiler (with the option of a bypass) where the heat is extracted. After the boiler, parts of the flue gas can be recirculated in order to reduce the temperature of the flue gas before the boiler. After the boiler, activated carbon and lime are injected in a reactor in order to capture the pollutants, and they are then collected in the Bag House Filter. The subsequent Induced Draft (ID) fan ensures that the flue gasses are led through the entire process and out of the stack.

The primary and secondary combustion chambers are equipped with oil burners. The burners can use clean/virgin oil or used oil. In some cases EWS have mounted a clean oil burner and a used oil burner in the secondary chamber. EWS informs that both systems, once brought up to temperature with diesel fuel will become self-fuelling. Used oil can be added for extra heat input, but is not required for the process to run. The system loading mechanism (ram loader) will also be similar for both systems. Although pre-sorting of the waste is not required for either solution, proper mixing of waste materials should be adopted for efficient waste combustion.

EWS claim that if maintenance recommendations are adhered to the plant is capable of 20+ year of production.

2.5.4 Emissions

The EWS system is fitted with an emission control system that adds reagents to treat the flue gasses. According to EWS: *"Emissions meet or exceed all EU and North American standards".*

EWS is familiar with the provincial regulation for maximum permissible air emission limits and claim that the proposed system will include an appropriately designed and sized APC to meet these limits.

EWS comply with the 1000 °C / 1 sec requirement in the regulation.

Ramboll evaluates that the statements from EWS seems to be reliable. The fulfilment of the regulation will be subject to the decision of which APC that will be installed.

The quality of bottom ash has not been confirmed and should be investigated further before decision on supplier for a possible facility.

2.5.5 References

EWS have over 70 successful installations in 14 countries according to their sales material.

EWS have highlighted the following references in a presentation:

- Canadian Forces Station Alert, Canadian Arctic, processing MSW for 20 years.
- Agnico Eagle Mine, Canadian Arctic
- Cree Nation of Wemindji (1500 inhabitants), Canadian Arctic, 14 years operation,
- Village of Skagway, Alaska, 21 years operation, 500-5000 people/tourists
- Pittsfield, MA, USA, 35 years operation, multiple lines, 218 tpd total throughput
- Springfield, MA, USA, 28 years operation, multiple lines, 400 tpd total throughput

The only site that Ramboll has any knowledge of is the plant in Wemindji, where according to SPN and other sources in Kuujjuaq that have visited the plant, this has been operating well since it was commissioned.

2.5.6 Conclusion (Eco Waste Solutions)

The EWS system is evaluated to be a variation of similar mass burning technologies, e.g. the technologies used on Greenland.

The sloped hearth solution in the combustion chamber could be a viable option but only very limited information is currently available.

EWS are open to work with optimizing the auxiliary systems to the core combustion system. This means that the EWS system could be equipped with any type of feed which is evaluated to be the right balance between easy operation, stable operation, maintainability and CAPEX. The same is the case for the boiler (heat exchanger) and APC that also can be adjusted to customer or authority requirements.

The energy production of the EWS is based on 80 °C temperature heat or 5 bar steam. Utilization of this energy requires a standard district heating network and heat systems in the heat consuming buildings.
This is relevant for Kuujjuaq as all heat systems inspected by Ramboll was 80 °C systems.

2.6 Technology study: MAGS gasifier (gasification)

The SPN have been contacted by Terragon that have been keen to supply one of their gasifiers in order to help treat the waste in Kuujjuaq. The SPN have forwarded material previously received from Terragon to Ramboll. Ramboll have further included information from Terragon from previous experience.

The MAGS gasifier is produced by Terragon that are based in Montreal, Canada and employs 40 people. The company markets the MAGS-technology as well as a solution for wastewater treatment[7]. Terragon has marketed version V8 of the MAGS technology since December 2015, mainly targeting marine applications and waste management in small remote communities.

2.6.1 Energy- and mass balances

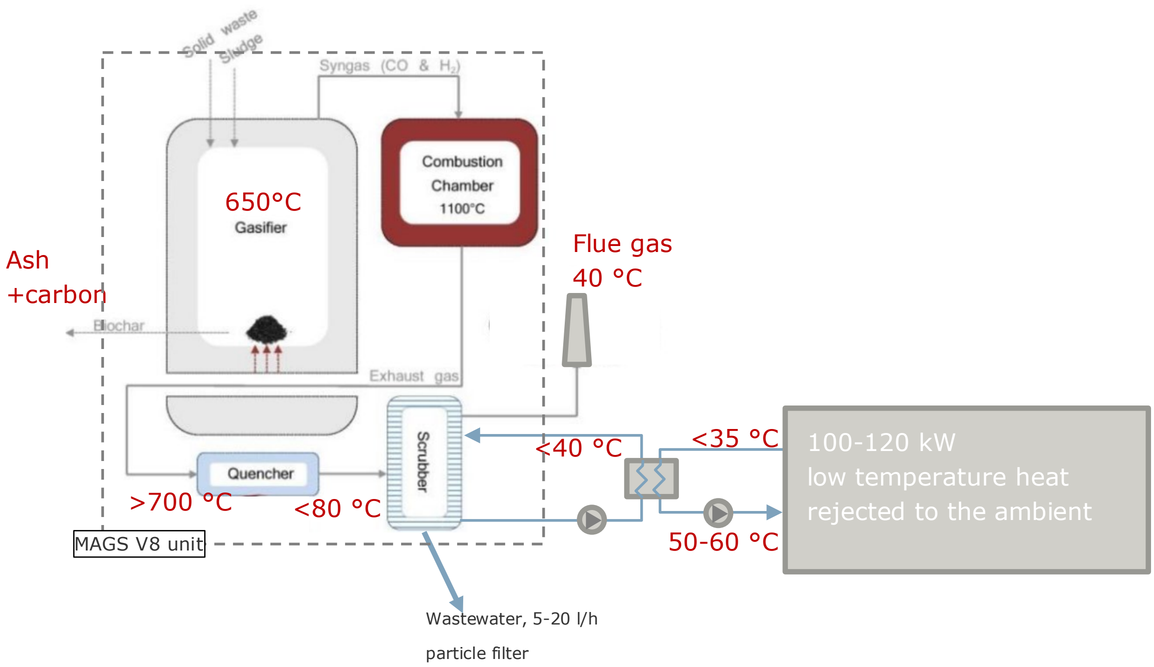


Figure 7. Process diagram for MAGS by Terragon. Temperature levels and external cooling added by Ramboll.

Figure 7 shows the Terragon process diagram for the MAGS process.

1. Gasification: The waste is fed to the preheated gasification chamber operating at "up to 650 °C". This is a very low temperature for a gasification process, so the rate at which waste can be fed to the system must be very low. The "bio-char"-ash extracted from this process has probably not been fully converted, and therefore contains some residual carbon (up to 50% of the inert carbon according to Terragon).
2. Combustion: The syngas, containing a non-specified composition of primarily CO, N_2, H_2O, CO_2, H_2, CH_4 as well as tars and their particles are led directly to the post-combustion chamber for combustion.
3. Process heat: The hot (1,100 °C) flue gas from the combustion delivers heat to the gasification chamber. In this process, the flue gas is cooled to approximately 700 °C.

[7] According to the company-website: www.terragon.net

4. The flue gas having a temperature of 700 °C is quenched by injection of water and cooled to <80 °C. This minimizes the formation of dioxins. The waste heat from this process is difficult to utilize due to its low temperature.
5. The flue gas treatment relies on a simple water-based scrubber. The circulated flow of water must be cooled to <40 °C in an external device. If heat is to be utilized, it must be delivered at 50-60°C and cooled to approximately 35 °C. If the heat cannot be utilized at these temperature levels, it must be rejected to the ambient, e.g. by air coolers.

2.6.2 Energy balance

Terragon has stated that a MAGS can deliver 100-120 kJ/s of low-temperature heat. At an incineration capacity of 50 kg/h, this corresponds to an energy yield of 7-9 MJ/kg of waste. This corresponds to roughly 60 % of the upper calorific value of the waste simulated by Terragon (estimated to be 13-14 MJ/kg by Ramboll). This would be a realistic value if the waste would undergo complete combustion. However, if half of the carbon content is to remain in the "bio-char", almost half of the energy content of the waste will not be released. Thus, the stated carbon content is in contradiction with the stated energy production of the process.

Terragon states that approximately 50 % of the carbon remains in the ashes. This is in contradiction with the stated 95 % reduction in waste amount. Terragon have stated that the amount of remaining carbon in the ash may vary significantly with varying waste compositions. It was shown that in the example mentioned above, the carbon content of the ash must be close to 0. It is thus unknown which type of waste would lead to a carbon content in the ashes of 50 %.

A high carbon content in the ashes is an indication of incomplete conversion of the waste. Thus, the high amount of "bio-char" stated by Terragon is caused by suboptimal process conditions. It is therefore possible that the presented figures for energy yield correspond a different operating condition (e.g. low load) whereas the figures stated for carbon content correspond to an operating in which there is poor conversion of carbon content (e.g. full load).

2.6.3 Emissions

In sales material, Terragon states emission measurements simulated with medical waste, which was designed for the purpose of resembling 60 % plastics (polyethylene and a "small amount" of PVC), 35 % paper, cardboard and textiles as well as 5 % water.

The content of heavy metals in such a well-defined mix is negligible and it is therefore not surprising that Terragon achieves low levels of heavy metals in both wastewater, flue gas and ashes. Even though Terragon claims the results to be "typical emissions", they are only demonstrated to be low in a case where the content of heavy metals in the waste is low.

The content of PVC can result in formation of dioxins in the flue gasses when cooled down. The MAGS technology quenches the flue gasses, which minimizes the time where the flue gases are in the temperature ranges that allow for formation of dioxins and furans. This is a well-known and efficient method to reduce the formation of dioxins without flue gas treatment. However, the method reduces the temperature of the energy content within the flue gasses, making it more difficult to utilize this energy.

MAGS have in previous evaluation inform that they do not comply with the demand of 1000 °C / 1 sec retention and none of the available information received contradicts this. The combustion chamber is stated to have a temperature of 1,100 degrees C. The retention time at temperature is a requirement to ensure sufficient degradation of dioxins and furans.

2.6.4 Assessment of environmental parameters

The published emission measurements conducted by Terragon indicate relatively low emission levels. However, they are a result of using homogeneous and clean waste with an engineered composition of plastics, cardboard and textiles. Since this composition contains almost no heavy metals, it is not surprising that the emission levels on heavy metals are good.

Terragon have only presented measurements using the engineered waste. It is possible that the MAGS units installed in marine applications are run with municipal solid waste to some extent. Terragon have not previously shown interest in supplying information regarding emissions from marine applications.

Terragon has not proven the stated performance regarding heavy metals under operations with "real waste". Since the MAGS process does not appear to have residues, in which heavy metals are concentrated, these must be distributed in (1) the ash ("bio-char"), (2) waste water, (3) particles filtered from the wastewater, (4) flue gasses. When considering the process, it is expected that a large fraction of the heavy metals will be in the "bio-char". Volatile substances, especially mercury, but also cadmium and copper, will follow the syngas and end up in the scrubber water and emissions to the air from the stack.

Terragon does not quantify the requirements to be met for waste treated in a MAGS but have provided the following information at an earlier occasion:
"Of course, the quality of the bio-char depends to a great degree on the quality of the waste being treated. If hazardous waste, such as batteries and paints, are found in the waste being treated, they may contaminate the bio-char with heavy metals, making it unsuitable for soil enrichment."

The stated levels of dioxins and furans are low. Dioxin is primarily formed in the conversion of PVC. According to Terragon, the engineered waste for the experiments did contain "a small amount of PVC", without stating the actual content. Due to the quenching of the flue gasses, low levels of dioxins are found to be realistic.

The conclusion of the assessment of the MAGS process is that the process is only able to handle very clean fractions of waste and is unable to retain heavy metals and other persistent sources of contamination.
If the ash is to be utilized as "bio-char", the treated waste must be of purely organic origin.

2.6.5 References

Location	Fuel	Status according to Terragon
Montebello		Not in operation. Probably prototype.
Ras al-Khaimah		Not in operation. Probably prototype.
Iqaluit, Nunavut	Municipal solid waste	Not in operation. The unit was delivered in 2014 and has not been in operation.
Costa Rica	Industrial waste (textils with oil, solvents etc.)	”Current installation”, operational status not stated.
Missouri	Industrial waste (contaminated plastic wrapping)	”Current installation”, operational status not stated.
Calgary	Industrial sludge containing polymers from a specific industrial facility.	”Current installation”, operational status not stated. Excess heat utilized in the operation.
Canadian Air Force Base, Alberta	Textiles containing oil, ”international waste”	”Current installation”, operational status not stated. Excess heat utilized for space heating.
Cambridge Bay	Biomedical waste	”Current installation”, installed at an industrial facility. Has been operational since 2014. Excess heat utilized for space heating.

Table 2 Land-based reference projects using the MAGS technology.

In Iqaluit, Nunavut, Canada a MAGS has been installed since 2014 with the purpose of being used for treatment of municipal solid waste due to the landfill of the village being full. Apparently, the unit has never been in use and in 2016 the unit had been installed without being operated for two years. Discussions regarding responsibilities for commissioning of the unit are ongoing between the municipality and Terragon[8]. Since the beginning Iqaluit had troubles finding a building suitable for installation of the MAGS[9].

The unit in Cambridge Bay is primarily operated with biomedical waste but is also operated with small amounts of municipal solid waste.

Terragon has no land-based references for the use of the MAGS where the primary objective is to incinerate municipal solid waste. Besides the references from Table 2, Terragon has five units installed on ships, operated with waste generated on-board. Experiences from operation and emissions from these are unknown.

2.6.6 Conclusion (MAGS)

Ramboll have found no documentation proving the ability of the MAGS technology to handle waste fractions that are not very clean and free of heavy metals. Given the process as described by Terragon, it must be assumed that these substances will be rejected to the surrounding environment. On previous requests by Ramboll, Terragon have been unable to present operational experiences or emission measurements of the technology when using municipal solid waste.

The amount of the “bio-char” from the process is unclear from the material provided by Terragon. When operated with very incomplete conversion of the carbon content, up to 50 % of the original

[8] Source: https://www.newsdeeply.com/arctic/articles/2016/11/23/talking-trash-in-the-remote-canadian-arctic

[9] Source: http://www.nunatsiaqonline.ca/stories/article/65674iqaluits_cannor-funded_gasification_scheme_gets_bogged_down/

carbon may be retained in the ashes according to Terragon. If this considerable amount of "bio-char" is to be utilized for agricultural purposes, it is very likely that the use of waste must be limited to the organic fraction only.

The energy production of the MAGS is solely based on low-temperature heat, supplied to the cooling water at temperatures from below 40 °C to around 60 °C. Utilization of this energy requires a low-temperature district heating network and heat systems in the heat consuming buildings or special purposes such as greenhouses or swimming pools.
This is not evaluated as relevant for Kuujjuaq as all heat systems inspected by Ramboll was 80 °C systems and CAPEX for low temperature system is higher.

Given the above findings, MAGS is currently not considered an attractive technology for treatment of municipal solid waste in a far north context.

2.7 WtE in Greenland

2.7.1 Introduction

In Greenland 6 of the villages have a Waste to Energy facility. The first waste to energy facility was built in Nuuk in 1987 and has, with proper maintenance and upgrades, been running ever since.
Also in the villages Qaqortoq, Maniitsoq, Sisimiut, Aasiaat and Ilulissat waste to energy facilities have been implemented as the solution for managing of the combustible part of the municipal solid waste.

The Greenlandic facilities vary in size from very small plants the size of what would be relevant for Kuujjuaq to a Plant in Nuuk which would be much too big for Kuujjuaq.

The table below shows the sizes of the plants compared to the waste amount and the population.

The case study will be based on Aasiaat but include references and part descriptions of facilities of similar size 400-600 kg/h. These include Qaqortoq, Maniitsoq, Aasiaat and Ilulissat.

Village	Capacity of WtE	Waste amount	Population 2018	Build year	Manufacture
Qaqortoq	400 kg/h	2000 T/year	3093	1998	REKA A/S
Maniitsoq	400 kg/h	1500 T/year	2534	2003	Weiss
Nuuk	1600 kg/h Upgraded to 2000 kg/h	17.000 t/year	17796	1987	B&S Bruun and Sørensen
Sisimiut	800 kg/h	3500 T/year	5491	2001	REKA A/S
Aasiaat	400 kg/h	2000 T/year	3120	2003	Weiss
Ilulissat	600 kg/h	3500 T/year	4563	2003	Weiss

Table 3: Overview of WtE in Greenland

Picture 1: Example of 400 kg/h WtE facility – Maniitsoq

2.7.2 Case Study Aasiaat

The plant is located on the outskirts of the village by the old heliport.

Picture 2: Aasiaat village with location of waste facility

The amount of municipal solid waste in the village is around 1,600 tonnes/year. In addition, the plant burns about 300 tonnes/year from the oil industry.

In order to fill the available capacity of the plant, the municipality have plans to transport waste from Qeqertarsuaq and burn it to the Aasiaat plant. Qeqertarsuaq is estimated to have about 700 tonnes/year of waste.

2.7.3 Description of the installation

In the following, the main components are covered, with waste reception, combustion and slag systems being described and subsequently followed by air and flue gas systems.

Waste reception and waste bunker

The waste is delivered to the plant by waste trucks, that load the waste directly into the bunker or, in the case the waste needs shredding, on the floor from where it is lifted into the shredder. The waste crane cannot be used for this purpose, as it does not cover the shredder area. The shredder directs the shredded waste to the bunker using a conveyor belt.

Used oil is poured or sprayed onto the waste in the bunker, provided it is not explosive. Originally, nozzles were installed in the waste pusher just before the oven, but they gave rise to back fire and coke of the pusher duct and were therefore dismantled.
In other WtE facilities in Greenland (eg. Ilulissat) a used oil burner is installed in the top of the boiler.

Waste feeding

From the bunker, the waste is lifted by the crane to the hopper, where a conveyor helps to ensure that it reaches the waste pusher. The waste crane is equipped with a system for weighing the amount of waste fed to the incinerator.

The crane is controlled from the Crane Operator chair located in the control room, overlooking the waste bunker.

Furnace and bottom ash system

The furnace is a sloped grate type with three separate grate sections (drying, combustion, burn out) where the waste is pushed towards the end of the grate. In the furnace, the waste is burned on the grate with the addition of air. The temperature in the furnace is typically designed for approx. 1000 °c. At the end of the grate a tilting grate is mounted in order to control when to tip bottom ash.

The bottom ash falls from the tilting grate into the bottom ash bath, where a bottom ash scraper transports the bottom ash to a vibrating conveyor that leads the bottom ash to an open skip.

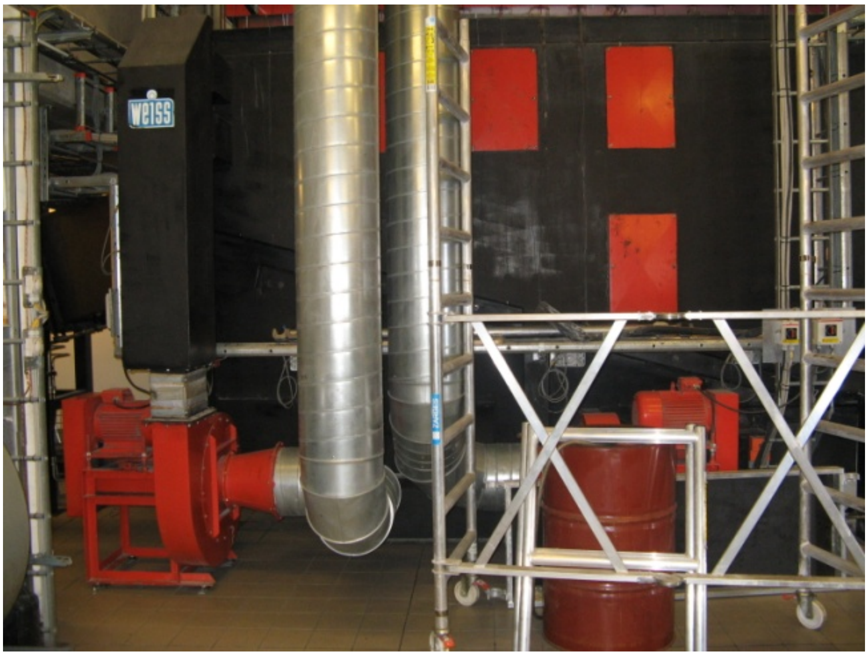
Smaller pieces of waste and bottom ash that fall through the grate (grate riddlings) are transported by means of a screw conveyor to a separate bottom ash bucket.

The content of bottom ash skip and bucket are emptied on the local dump.

The furnace, primary and secondary combustion chamber are lined with refractory.

Picture 3 - Wet bottom ash scraper, vibrating conveyor as well as a bucket for grate riddlings

Air system
The combustion air is provided as primary air underneath the grate, as well as secondary air in a number of separate nozzles in each side of the furnace. The fans are controlled by the SCADA system.



Picture 4 - Furnace with primary and secondary air fan and filter

Boiler
In the boiler, the energy content of the flue gas is transferred to the boiler water by a combination of radiant and convective heat exchange.

After the secondary combustion chamber the flue gas is directed to a vertical fire-tube-boiler, where the flue gas is led in pipes surrounded by boiler water. The pipes are gradually fouled by the boiler ash. In Aasiaat, the pipes are cleaned during the bi-weekly stops. After the boiler, the flue gas temperature should preferably be above 160 °c to avoid corrosion in the downstream flue gas cleaning installations and ensure optimal operation of the electrostatic precipitator.

Multicyclone
A multi-cyclone is installed as the first step in the flue gas purification. It has a tangential inlet and works using centrifugal forces. In the multicyclone, the larger and heavy particles are separated and fall to the bottom and pass through a rotary flap valve to a screw conveyor directing the particles to the bottom ash conveyor.

Electrostatic Precipitator (ESP)
The flue gas is finally cleaned in an electrostatic precipitator effectively removing also the fine ash particles. The ash is collected at the bottom and is removed used a screw conveyor covering the entire length of the precipitator.

The ash is collected in Big bags, which are then sent by Reno Nord (former Mokana) (Danish company that handles hazardous waste) to Denmark for landfill.

Picture 5 - View of the ESP

ID-fan

From the electrostatic precipitator, the flue gas is directed to the Induced Draft fan (ID fan), which directs the cleaned flue gas to the stack and ensures under pressure in the furnace/boiler/FGT so that flue gasses are not released into the building.

Air Cooler

The system is equipped with air coolers which, in the case of inadequate demand from the district heating network, can cool the excess heat produced.

Flue gas measurements

In the duct downstream the electrostatic precipitator flue gas temperature, O_2, CO and particulate matter are measured.

Control and monitoring system

The SCADA system is a computer-based system from where the process is monitored and essential functions are controlled and regulated automatically or through the intervention of the operator.

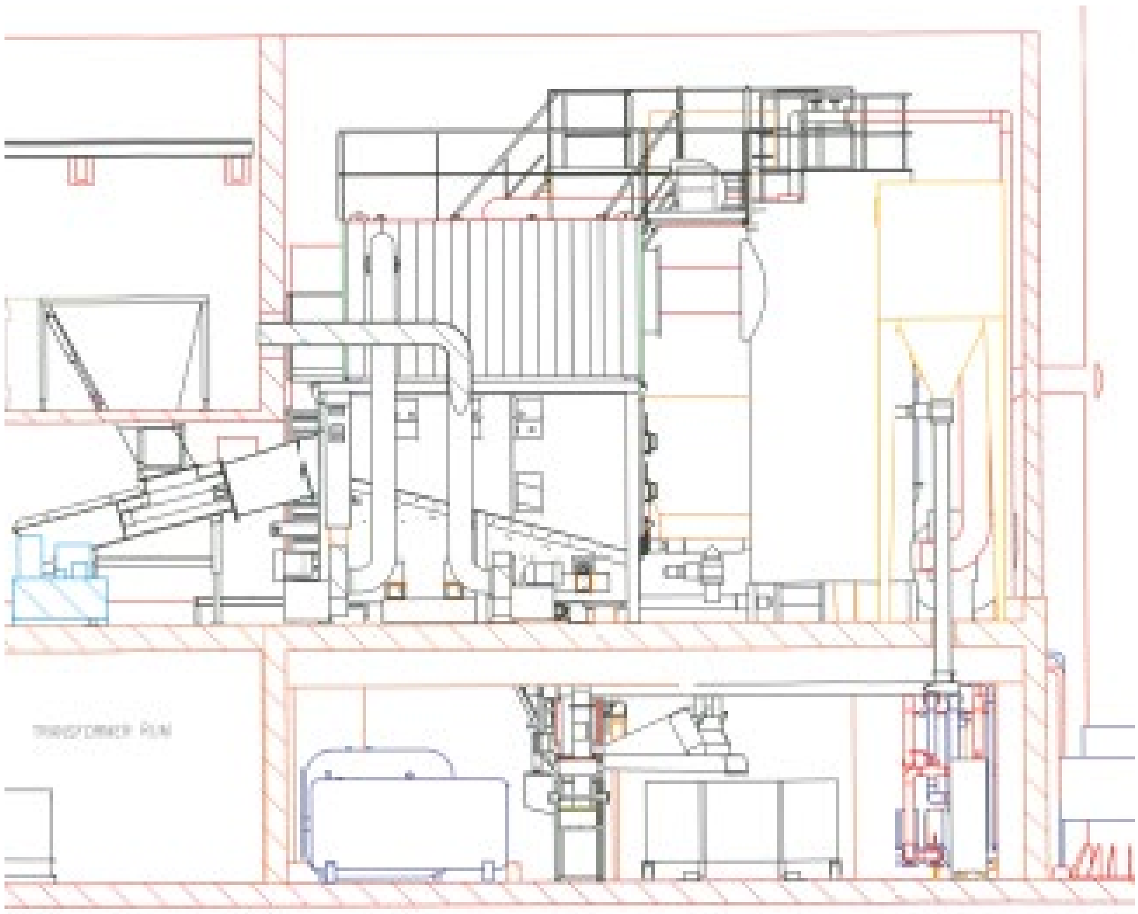


Figure 8 - Section of the plant in Aasiaat

2.7.4 Operation of the system

The plant receives combustible waste from the municipal solid waste collection, private people which themselves deliverer suitable waste to the plant, and industrial waste from the construction industry as well as the Shrimp Factory (packaging, plastics, plastic boxes, etc.). Occasionally, the plant receives blubber from the seals, which must be mixed very thoroughly with the remaining waste in order not to lead to problems with very high calorific values.

A shredder is installed at the plant, where larger parts, cardboard and wood are shredded. The operator ensures that the waste is mixed thoroughly with the waste crane.

Picture 6 - Shredder on the Aasiaat plant

The plant is in operation from Monday to Friday and is stopped and cleaned during the weekends. There is usually not sufficient waste to operate the plant weekends as well.

The plant is controlled from the control room by an operator that operates the waste crane and monitors the rest of the plant.

Due to the relatively small dimensions at the changeover between the hopper and the pusher, there have been numerous stops due to large waste items. The municipality has switched from plastic bags to paper bags for the household waste and this has alleviated a large part of the problem, as the crane is able to tear up the paper bags.

2.7.5 Emission

The operator strives to keep the temperature in the secondary combustion chamber above 800 degrees, but this is not always possible meaning that the plant often does not meet the requirement in the environmental approval of 1 sec. residence time above 800 °C.
This is mainly due to the fact that the oil burner in the combustion chamber has been taken out of operation.

The following table shows the requirements of the environmental approval and the state of operation of the plant.

Parameter	Device	Requirements in environmental approval	Registered values, average of 2011	Number of exceedances in 2010	Requirement in environmental regulation of Quebec
Dust	Mg/Nm^3*	60	52	98[1]	50
temperature in secondary combustion chamber**	Min. °c for 1 s	800	790	8336[2]	1000
O_2 in the flue gas	Min.%	6	11.9	37[3]	-

Table 4 - Key requirements of environmental approval and registered values at Aasiaat incinerator.

** v. 11% O_2, dry flue gas, Nm^3 refer to 0 °c and 101.325 kPa.*

*** No support burner in operation*

[1] Daily average exceedances

[2] 10 min with less than 800 °C

[3] 1 min with less than 6% oxygen

The filter does not work satisfactorily, but for the majority of the time the ESP complies to the dust emission requirements. After 2011 this has improved (confirmed by phone by department of nature, environment and justice)
Regarding the combustion in the secondary combustion chamber, the requirement for oxygen content is kept but there are major problems in complying with the Greenlandic requirement of 800 °C / 1 sec requirement in the secondary combustion chamber, which leads to increased dioxin emission.
The reason for this is mainly that there has been very little focus on this issue by the operators and the fact that the support fuel burner has been taken out of operation.
Comparing to the requirements of Quebec the design of the facility, especially the flue gas cleaning, has to be adjusted to meet the slightly different requirements.

The fly ash from the combustion (collected at the ESP) is collected in big bags, stored indoors and sent to the Reno Nord (Aalborg, Denmark) with Royal Arctic Line (RAL). RAL loads the big bags in 20' containers before shipment to DK. The bottom ash from the incineration process is deposited at the dump.

Picture 7 - Big bags with fly ash waiting for transport to Denmark

2.7.6 Energy Balance

The energy balance for Aasiaat for the year 2010 is presented below.

Aasiaat 2010		
Electricity	-250	Mwh
Oil	-18	Mwh
Heat Sales	4300	Mwh
Heat cooled away	1130	Mwh
Total output	4032	Mwh
Total Potential Output	5162	Mwh
Potential output per ton	2.6	MWh/ton @11MJ/kg

Table 5 - Energy balance for Aasiaat 2010

It is clear from the information in the table above that the energy balance is clearly positive, with an average of 2.6 MWh/t waste (@ 11 MJ/kg) being produced.

2.8 Overview of available technologies

In the following a summary table is presented for the various reviewed technologies.

Technology Provider	MAGS gasifier	EWS intermittent continuous	EWS continuous	Weiss, REKA, Envikraft Case Aasiaat, Greenland
Type of thermal treatment	Gasification	Mass burn	Mass burn / gasification	Mass burn
Nominal capacity	50 kg/h	500 kg/h	500 kg/h	400 kg/h
Useable energy output (BTU/hr)	-	+1.8 MWh/ton* (6.1 M BTU/hr)	+1.8 MWh/ton* (6.1 M BTU/hr)	+2.6 MWh/ton (8.9 M BTU/hr)
Energy Balance	Positive	Positive	Positive	Positive
Compliance with Québec's environmental regulations	Unclear for heavy metals	Yes	Yes	With an updated APC compared to Greenland
CAPEX (estimate)	App. 1.5 mil CAD [10] Excl. waste handling, APC, ACC, building, stack etc.	App. 3-4 mil CAD Excl. waste handling, ACC, building etc. Incl. APC and stack.	Not known but more than 4 mil CAD. Excl. waste handling, ACC, building etc. Incl. APC and stack.	App. 4-5 mil CAD for Plant App. 2-3 mil CAD for building Total 6-8 mil CAD Incl. building, waste handling, APC, ACC, stack etc.
Reference plants	- Montebello, - Ras al-Khaimah, - Iqaluit, Nunavut, - Costa Rica, - Missouri, Calgary, - Canadian Air Force Base, Alberta, - Cambridge Bay,	- Canadian Forces Station Alert** Agnico Eagle Mine, - Cree Nation of Wemindji**	- Village of Skagway, Alaska*** - Pittsfield, MA, USA*** - Springfield, MA, USA***	- Aasiaat, - Maniitsoq, - Qaqortoq, - Ilulissat, - Sisimiut
Treatable waste composition	Engineered waste	Mixed solid waste Municipal and industrial	Mixed solid waste Municipal and industrial	Mixed solid waste Municipal and industrial
Far north suitability	No	Yes	Yes	Yes
Reliability	Not proven technology	Several similar installations in operation	Yes, several installations in operation	Proven robust design. Several installations in operation
OPEX	-	-	-	300 CAD/ton Not taken heat sales into account

Table 6 - overview of available technologies

** This figure needs to be checked, as some uncertainty remains to the energy output.*

*** No heat recovery*

**** Not WtE facilities*

2.9 Recommendation for technology

Based on the reviews carried out above, Ramboll recommends proceeding with a continuous small-scale mass burn technology as the gasification process demonstrated by MAGS is not a viable option. The EWS continuous process is more complex than the intermittent continuous process and the reference plants in Greenland.

The mass burn technology is scalable and can be tailored to meet the requirements of Kuujjuaq.

[10] SPN: Waste to Energy scenarios for Kuujjuaq 2016, videos and telephone conference with ECO waste.

Each component in the plant can be designed to meet certain requirements and sized according to the needs. Various options are available for each component. Each with its strengths and weaknesses.

The regulations of the Quebec Ministry of Environment shall be complied with for incinerators under 1 ton/h. With this, a certain number of demands for the emissions of CO_2, CO and O_2 shall be adhered to with continuous monitoring as well as the 1000 °C / 1 sec retention time in the secondary chamber. The general requirements in the regulation for particles, HCl, dioxins, furans and mercury shall also be complied with but not continuously monitored.
The regulations shall only be complied with during normal operation, and not during start-up and shut-down.

An important aspect of the flue gas treatment is to make sure that the correct technology for the flue gas cleaning is selected. The requirements for the emission lean towards a Bag House Filter, but an Electrostatic Precipitator may provide sufficient cleaning as well and will be easier to maintain, which may prove to be an advantage with the limited skilled workforce available in Kuujjuaq.

The energy balance of the plant will provide a positive energy output, enabling the village of Kuujjuaq to take advantage of the heat produced at the WtE facility and reduce the amount of fossil fuels currently used for heating of buildings and water.

There are a limited number of suppliers capable of delivering a mass burn technology WtE plant.

Eco Waste: https://ecosolutions.com/

REKA: https://www.reka.com/da/solutions/

3. CONCEPTUAL DESIGN OF THE RECOMMENDED TECHNOLOGY

In this section the conceptual design of the recommended technology is presented. The conceptual design will consider the technical and environmental issues identified in the previous sections of the report, as well as draft the layout of the plant.
As stated in the previous section a mass burn technology is the preferred method for treating the waste in Kuujjuaq. The process will yield a positive energy output enabling heat to be distributed in the village of Kuujjuaq through a district heating network.

3.1 Waste composition

The composition of waste is important as the individual waste fractions have different content of combustible matter, ash and moisture content and thereby subsequently impact the overall net calorific value of the waste. According to information from the SPN, 62% of the waste could be used to recover energy; paper-cardboard (5% + 8%), wood (14%), other combustibles (14%) and organic matter (21%). Some 2 644 tons of waste are currently produced each year in Kuujjuaq. Kativik's Public Works Department has estimated that Kuujjuaq will produce up to 3707 tons of waste in 2030[11].

According to the waste characteristics report from Stantec, the calorific value for the waste in Kuujjuaq is currently 10.76 MJ/kg for Municipal Solid Waste (MSW) and 11.01 MJ/kg for Contractor and Industrial waste (C&I).

Stantec also estimated the LHV of the used oil currently stored in various places in Kuujjuaq and that of used tires. The overall LHV of used oil is estimated at 37.65 MJ/kg and the LHV of used tires is estimated at 32.87 MJ/kg.

It is recommended to design the WtE facility for a nominal net calorific value at 10.5 – 11.0 MJ/kg (based on the current knowledge of the waste characteristics) and that the WtE facility will be flexible for changes and daily variations. It is recommended to design the WtE facility for a calorific value between 7.5 – 14.5 MJ/kg, going up to 15.5 MJ/kg if tires and oil are included. Again, these values will change along with any updated knowledge of the waste characteristics during the design phase.

3.2 Plant size

The WtE facility shall be designed with flexibility to handle MSW and C&I with a wide range with regard to the net calorific value, moisture content and ash content.

The following fractions are not expected delivered to the plant:

- Hazardous waste
- Auto shredder waste
- Tires
- Sewage sludge
- Radioactive waste
- Inert waste (except what comes with mixed MSW and C&I waste)
- Construction and demolition waste (except after pre-treatment/sorting)
- Electrical and electronic waste (except what comes with mixed MSW and C&I waste)

[11] Serre-Plan-affaires.2016-08-31ANG.pdf

The nominal load point (defined as LP_N) shall be set to 0.3 - 0.5 tonnes per hour (tph) at 10.5 MJ/kg. Finally to be decided at the design stage and based on the future expectations for waste levels and operational philosophy. At this load-point the plant will be operating at 100% thermal load and the mechanical throughput has to be reduced proportionally as the calorific value of the waste increases. The WtE should be able to operate between 70-100% thermal load and the mechanical load range from around 70-100%.
The boiler will be able to handle shorter periods (half hour) with up to 10 % 'thermal' overload (MW thermal input), but a set point above 100 % load is not recommended. The grate can usually handle a 10 % 'mechanical' overrun (t/h fuel) and still maintain full burnout.

The plant should be sized in order to accommodate the changes in incoming waste during the year. If possible, it could prove beneficial to store the dry, burnable waste fractions during the summer, in order for these fractions to be used during the winter months where more heat is needed.

3.3 General Design Requirements

The equipment shall be fit for purpose and shall be produced by manufacturers that have an established record of supply to the waste industry. The equipment shall have been used in similar installations with good track records.

The layout of plant shall ensure suitable and adequate points of safe access and means of escape to comply with all current legislative and practical operational requirements. All permanent platforms are to have at least one fixed staircase and where possible have two suitable points of access. Plant and equipment will be designed and arranged to facilitate safe access with the minimum changes in level and stairways required.

3.3.1 Redundancy of Key Equipment

The overall plant philosophy - to minimize an unscheduled shut-down - shall be based on the premise that:

- It shall be possible to maintain and work on areas of the plant which are known to require regular attention or regular inspections during operation
- No single instrument failure shall result in a plant shut down
- Redundancy of critical plant items shall be evaluated taking into account the effects of downtime
- Low complexity making it possible for local competences to solve the problems

As a general principle, the plant shall not have to shut down as a result of the failure of a component which cannot be replaced from the plant spares holding within short period of time.

A maintenance and spare part strategy shall be developed during the design phase. This strategy shall meet the requirements and enable the desired availability with safe margin and ensure that the most common problems can be solved locally.

3.3.2 Air Emissions

The air emissions at the stack have to be measured continuously for CO_2, CO, O_2.

Dust/particles, acidic gas (HCl), CO, Dioxins and Furans and Mercury will be tested once every three years.

In addition, a number of parameters will be controlled entirely by the combustion process such as 'CO' and 'TOC' (Total Organic Carbon). An efficient combustion process will secure that these parameters are below the emission requirement at all time. The temperature of the secondary combustion chamber shall be measured continuously as well.

The limits for the air emissions are listed in the table below (REIMR).

Emission standards according to Québec's environmental regulation

Emission type	REIMR	RAA	RAA + HW (3)
Opacity (1)	20%	20%	20%
Particulates	50 mg/m3	50mg/m3	50mg/m3
HCl	100mg/m3	100mg/m3	100mg/m3
CO	57mg/m3	57mg/m3	100mg/m3
Dioxins and furans (2)	0,08ng/m3	0,08ng/m3	0,08ng/m3
Mercury	20µg/m3	20µg/m3	50µg/m3

(1) according to Micro-Ringelmann scale
(2) polycholorodibenzofurans & polychlorodibenzo (b, 3) (1,4) dioxins and the like
(3) different standands apply for RAA when hazardous waste (HW) is incinerated
values are presented in mass unit per m3 dry gas, at 25 celcius and 101,3 kPa at 11% O2

Table 7 - Emission levels relevant for the WtE plant

3.3.3 Noise level

Ramboll suggests that a sound pressure level of maximum 85 dB(A) as the general requirement for noise emissions inside the building. Quebec regulations sets a limit of 90 dB(A).
Most equipment within the building must fulfil the 85 dB(A) requirement. In certain areas it might be necessary either to accept a higher noise level or place the equipment in dedicated noise areas (rooms) or be acoustically insulated/ covered by noise hoods.
The noise level at fence is expected to be set by the environmental permit. As the site is located in an area not too far from residential areas restrictions may be present during night time.

3.4 Conceptual Design, M&E

This section will describe the main process of the recommended technology and list the main equipment for an WtE that complies with REIMR regulation, meaning that the plant will only treat the waste collected in the Northern Village of Kuujjuaq and from the construction-renovation-demolition sector, excluding any hazardous waste such as used oil or tires. This will be known as the reference scenario. An alternative scenario is described in section 3.5, *"Alternative Waste Treatment Scenario"* which includes used tires and used oil.

The principle concept for almost all small size continuously operated WtE facilities is somewhat similar, as it consists of the following key components, described in more details in the following sections:

- Waste Handling
- Waste Hopper and Feeder
- Combustion Process
- Bottom Ash Handling
- Heat Recovery
- Flue Gas Treatment System
- Auxiliaries

- District Heating System (where applicable)

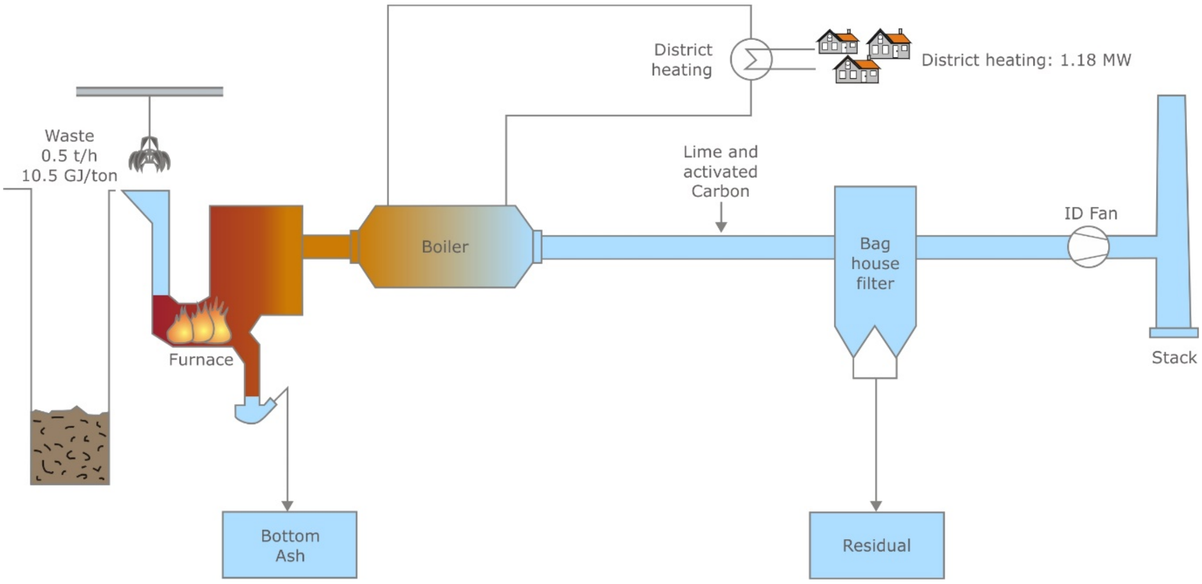
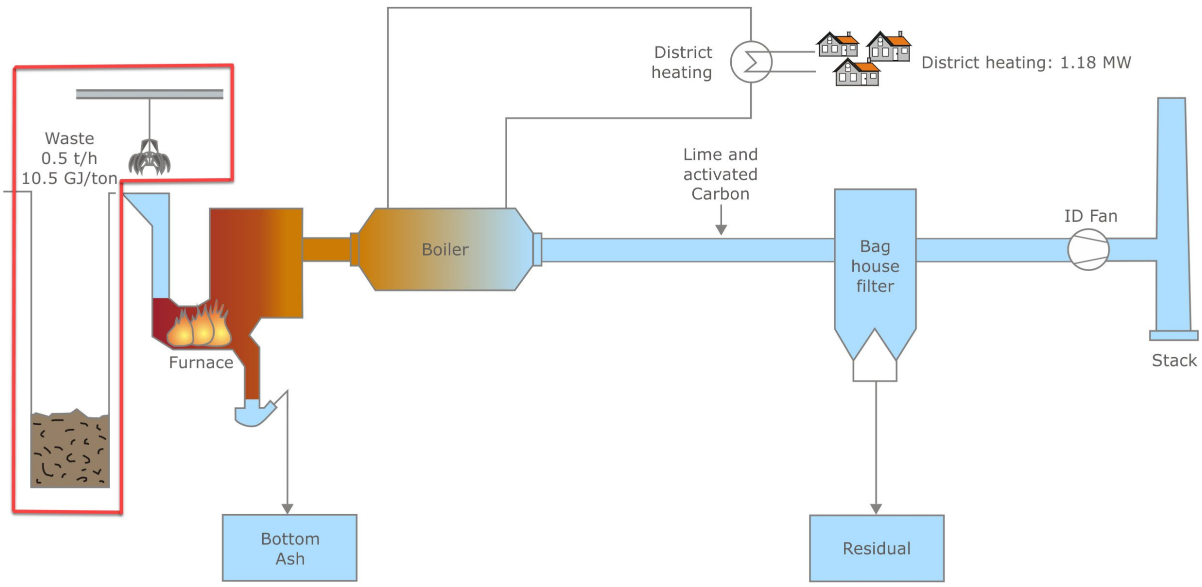


Figure 9 - Schematic of a WtE plant for Kuujjuaq

3.4.1 Waste Handling

The incoming waste shall be unloaded, preferably mixed and fed to the WtE plant. There are several ways to achieve this operation.

1. Unloading the waste on the floor and using a front loader to feed the WtE plant. This is a very low-tech solution but requires a person at the wheel of the front loader 24 hours a day in order to feed the WtE plant. A large flat area is needed to store waste during the night and weekends which the front loader can access. Covering it in a building will be costly. Storing in the open air may lead to odour problems.
   Mixing of waste is poor and could affect the operation of the plant negatively. Large objects are most likely detected.
2. Unloading directly from a skip or similar container to the WtE plant. The current waste trucks used in Kuujjuaq are compressor trucks. They can unload into open skips or containers if needed, but spillage is foreseen. Skips will then need to be managed by another vehicle to place them at the WtE ready to be fed to the WtE plant. A large area and a number or skips/containers are needed to store the waste to be used during night-time and weekends. A person needs to be allocated to handling the skips 24/7, unless a fully automated system is selected, taking up substantial space.
   Mixing of waste is poor and could affect the operation of the plant negatively. Large objects are most likely not detected.
3. Unloading into a bunker and use an overhead crane to feed the WtE plant. The trucks unload into a bunker (a big hole) where the waste is stored (for night-time and weekends) and mixed. An overhead crane picks up the waste and feeds it to the WtE plant. The crane can work in automatic outside delivery hours (nights and weekends). 1 person is needed to operate the crane during delivery hours.
   Mixing of waste is good and stable operation of the plant is possible. Large objects are detected though not as good as in option 1.
   This is the preferred waste handling solution.



A tipping hall is recommended in order to avoid odours spreading from the waste to the outside air. It shall be designed with sufficient height to allow trucks to unload waste whilst indoors. The bunker is designed to allow for sufficient storage and mixing of waste before being fed to the waste hopper. If trucks are carrying bulky waste, this shall be unloading into the shredder, where it will be shredded before it is diverted into the bunker. It is possible to shred all incoming waste in order to improve mixing but seeing as this comes with an electricity cost this is not recommended.

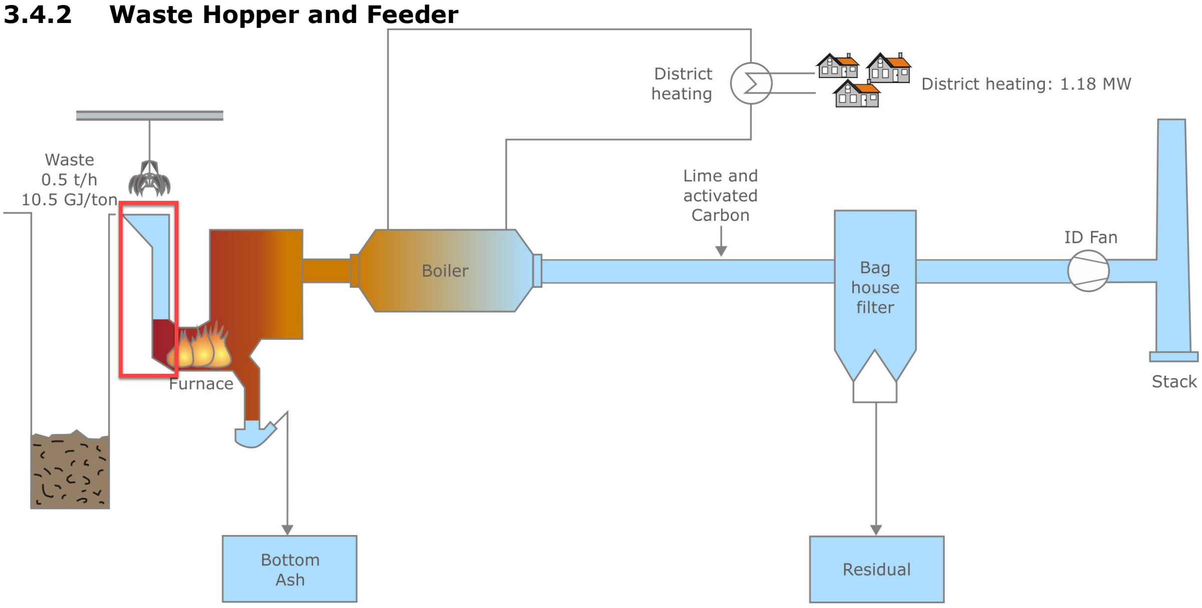
The waste bunker shall be equipped with a waste crane to handle the waste. The crane services include: clearing the offloading area close to the tipping hall, mixing of waste; and feeding the waste into the waste hopper.

The waste cranes may be designed to operate in manual or semi-automatic operation mode with the option of night-time automatic. The crane shall be operated from a crane operating chair located in the control room.

The crane shall be able to withstand the dusty and humid conditions which are inherent in a waste bunker. In order to optimize grab movements in the bunker, the crane control system shall include a pendulum damping system.

The weight of each crane load shall be logged in the DCS system before discharge to the waste hopper.

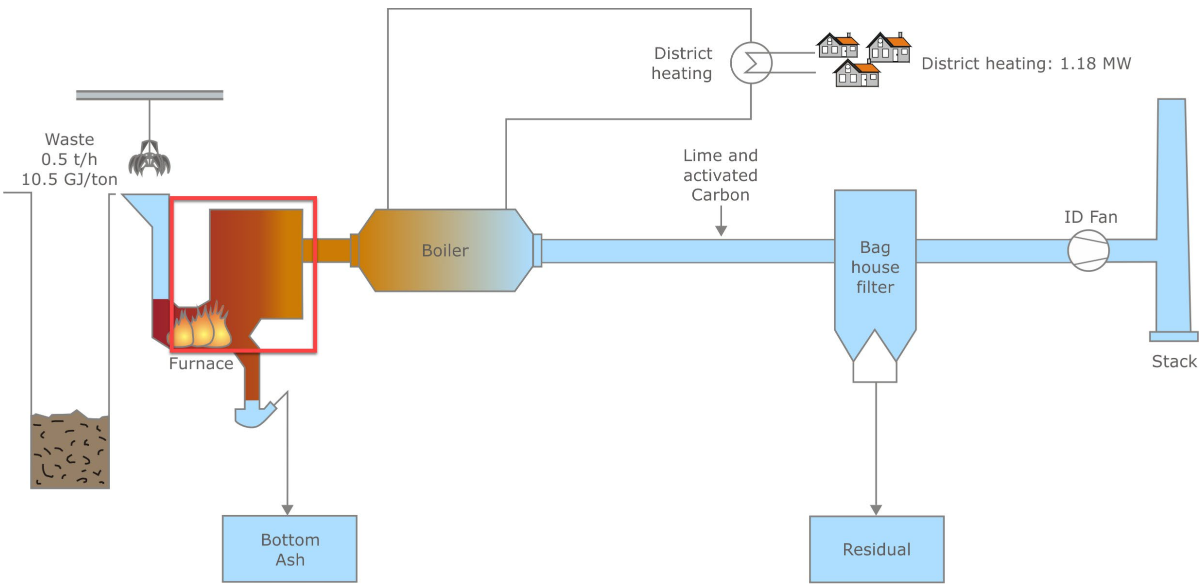
3.4.2 Waste Hopper and Feeder



The feed hopper shall be designed in such a way that, when the waste is fed into the hopper by the crane grab, no waste is dropped over the edges. The shape of the hopper shall ensure that clogging and bridging could be avoided. Level measurement shall be installed.

The waste feeder shall be designed as a hydraulically operated ram feeder (pusher type). The waste feeder pushes the waste onto the grate.

3.4.3 Combustion Process



<u>Grate and Primary (and possible second) Combustion Chamber:</u>
The incineration technology should be based on a 'moving grate' which is the best technology for incineration of MSW. The grate fired technology is found to be the only treatment technology for MSW with good track record with regard to process reliability and energy performance.

Considering a nominal calorific value at 10.5 MJ/kg and a net calorific value of up to 14.5 MJ/kg, and the requirement for a simple system, an air-cooled grate is recommended. The grate shall be designed and sized to ensure smooth operation in accordance with the quantity, characteristics, varying calorific value and composition of the waste to fulfil requirements for waste capacity, operational availability, burn-out rate and quality of the slag.

Several international technology providers are on the market. Fewer for small grates as required for Kuujjuaq. Grate bars and other components that are exposed to high temperatures shall be made from chrome-nickel steel alloy in accordance to the experience of the technology providers. The grate shall be divided into individually adjustable grate zones and shall ensure sufficient mixing of the waste and a levelling of waste across the grate.

The grate riddlings (materials that falls through the grate) shall be transferred to the bottom ash chute.

A lubrication system for the grate system is required.

According to Canadian law the furnace for incinerators with a nominal capacity below 1 ton/hour shall feature two separate combustion of waste and combustion of gasses.
It is commonly regarded as a need for two separate chambers. According to information from the Ministry of Environment there is a bit of flexibility in the definition but other designs than separate chambers will need to be approved by the Ministry. In the following a two-chamber solution is suggested and described.

The furnace (primary and secondary combustion chamber) should be designed as a gas tight construction and be protected by refractory or ceramic lining. The furnace shall feature an access door for maintenance and include inspection windows allowing for full inspection of the grate and slag chute during operation.

The primary combustion chamber shall feature a virgin oil burner used for start-ups and shut-downs. Under normal operation once the process is up and running the burner is not used as the waste burning process is self-sustaining.

<u>Secondary combustion chamber:</u>
According the Canadian legislation, the combustion gas coming from the primary chamber must remain in the secondary chamber for at least 1 second at a temperature of at least 1 000 °C.

The incinerator must therefore be designed with enough volume to allow for the retention time and equipped with secondary burners in order to ensure that the requirement is met at all times. The burner will be used during start-ups and shut-downs.

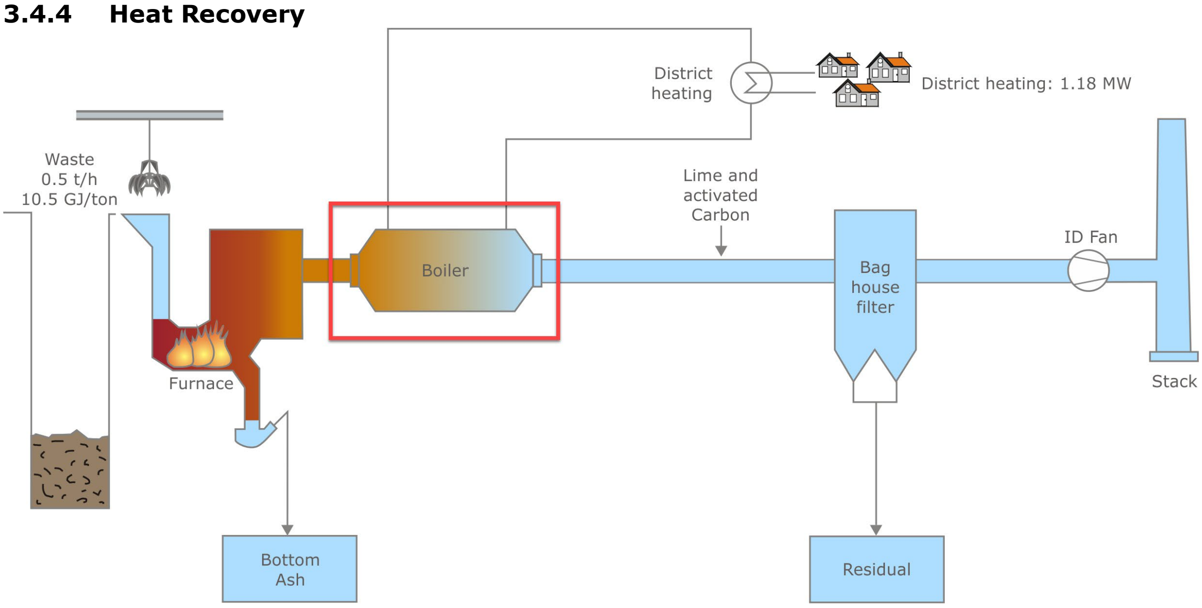
<u>Combustion Air System:</u>
The system shall be equipped with a combustion control system. The combustion air system including ducts, fans etc. must be designed to operate at all load points.

The combustion air shall be taken from above the waste bunker. Initially the plant shall be designed without flue gas recirculation.

<u>Bottom Ash Handling</u>

The furnace shall be equipped with a bottom ash extractor, designed to remove unburned items that has passed over the combustion grate. Sizing of the equipment shall be so that item that can pass the feed arrangement can also pass the slag extractors.

3.4.4 Heat Recovery



<u>Boiler Water</u>

The boiler water refers to the water that enters the boiler. It is of the utmost importance to ensure that the boiler will always stay water-filled, thus the water tank shall be designed for a net water content between normal water level and the water level that would cause it to trip (normally equivalent to minimum 30 minutes operation of the boiler at nominal load or with sufficient volume for safe shut down in accordance to the contractor's final design).

<u>Boiler</u>

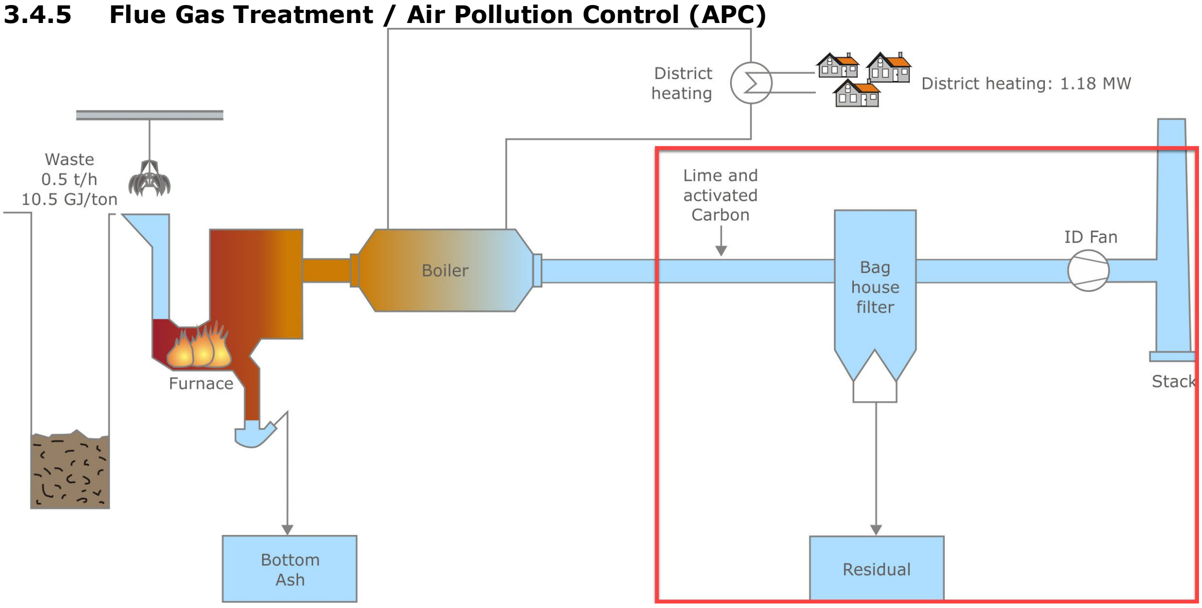
The boiler shall be constructed, manufactured and certified in accordance to the relevant ASME standards for fire tube boilers.

The boiler shall feature a radiation and a convection part. The tube pitching, flow velocity and possible turnings/transitions shall be designed in such a way that they will not give rise to undesirable flow conditions, erosion, corrosion, fouling and ash accumulation. Tube sizes shall allow for moderate gas flow. The boiler shall have good access for inspection, repair and maintenance.

The boiler shall be able to cool the flue gas from 1100°C to around 170-180°C and it should be possible to use the boiler exit temperature as a setpoint for the operation of the plant. The 170-180°C is expected with a clean boiler. As the boiler becomes fouled during operation the exit temperature will increase. It is recommended to limit this temperature to around 190°C in order to maintain a good heat production and to protect the flue gas treatment system whilst ensuring that the optimum temperatures are available for the chemical processes.
The water temperature into the boiler should be 80-90°C and the exit temperature should be 110-120°C. The flow shall be monitored in order to able to calculate the heat offtake. The water inlet temperature is usually maintained through a shunt which shall be placed in a distance so the temperature profile into the boiler is uniform.
The boiler can be designed as a vertical or horizontal boiler.

Cooling to 170-180°C (clean boiler) before the flue gas treatment section is recommended in order to stay clear of corrosion, improve the chemical processes in the flue gas treatment system and protect the flue gas system.

3.4.5 Flue Gas Treatment / Air Pollution Control (APC)



When selecting the flue gas treatment system for an arctic plant, focus should be on selecting a relatively simple system with a proven track record, even if this means importing consumables from the South.

An electrostatic precipitator (ESP) have previously been the preferred solution in these regions, but with the documented high impact of heavy metals in the arctic regions this solution can no longer be recommended. Furthermore, dioxins and mercury are not removed with an ESP and would therefore not be able to meet the REIMR emission requirements.

Bag House Filter

As such, the recommended flue gas treatment (FGT) system is a dry flue gas cleaning system consisting of a bag house filter with upstream injection of lime reagent and activated carbon for the removal of the acidic gases (HCl, SO2, HF), particles, heavy metals and dioxins/furans.

The simplest technical FGT concept is a dry or semi-dry flue gas system where activated carbon and lime is injected upstream the bag house filter. The dry system requires stoichiometric overdosing of lime to handle pollutant peaks of HCl and/or SO2 within the untreated flue gas. The majority of the heavy metals are removed together with the particles as they are bond to the surface of the fly ash particles. Activated carbon is added to remove volatile mercury and dioxins/furans.

The process can take place with temperatures up to 180-190 degrees without reducing the ability of the activated carbon to bind the mercury significantly.

In order to avoid ATEX classifying parts of the system when using activated carbon, the recommended approach would be to use a pre-mixed product of lime and activated carbon with a low activated carbon content and a high lime content. Due to the mixing, the dosing system does not need to be ATEX classified. If more lime is needed than what is included in the mixed product, this can be injected separately.

The mixed product is usually delivered in big-bags that can be unloaded into a silo on the plant.

The dry flue gas cleaning system will result in the generation of a dry residual product (in bag-bags) that needs to be deposited at suitable hazardous waste storage. This will usually be around 2% (mass basis) of the incoming waste amounts.

It is important to investigate further the price and availability of the mixed activated carbon and lime in Canada in order to avoid the supplier to prescribe a product which is not easily accessible in Canada.

The flue gas cleaning system shall be designed so that it can absorb variations in the composition of the waste and hence the corresponding produced flue gas from the combustion process. Experience shows that when C&I waste is treated the raw gas data may vary significantly from the average/nominal design figures.

The bag house filter will need to be heated during shorter shutdowns due to the risk of corrosion. If longer shutdowns are foreseen if may prove difficult to keep the filter warm. In these cases, the bags shall be cleaned with compressed air prior to shut-down in order to avoid corrosion. When the plant is started again, the bags should be precoated with lime and the filter bypass shall be used until the flue gas has reached an acceptable temperature where condensation on the bags is reduced to a minimum. When the acceptable temperature is reached the bypass will close and the filter is now in operation.

<u>Induced Draft Fan (ID Fan)</u>
The flue gas cleaning plant shall be equipped with an induced draft fan (ID-fan) to overcome the pressure loss of the incinerator/boiler, flue gas cleaning system and stack.

The fan shall be centrifugal and shall be connected to an emergency electrical system at reduced capacity. The motor shall be equipped with frequency converter. The ID Fan shall be equipped with vibration and temperature measurements on the bearings and the signals must be transferred to the DCS.

The velocity of the fan shall not exceed 1,100 RPM at nominal load in order to avoid noise and wear.

The fan shall be designed for an air flow rate at 1.3 times the nominal flow rate (LP1) and the corresponding pressure increase.

<u>Continuous Emission Monitoring Station (CEMS)</u>
At the end of the flue gas treatment system a Continuous Emission Monitoring Station (CEMS) shall be installed. As a minimum, CO_2, CO, Opacity, Particles and O_2 shall be monitored and the data shall be shown at the measuring station as well as being transmitted continuously to the CEMS. HCl, dioxins, furans, mercury will be tested once every three years.

<u>Stack</u>
The WtE plant shall be connected to a stack in order to disperse the remaining emissions.
The end of the stack shall be designed to reduce the risk of droplet carry-over and allow for droplets to be drained off.

The stack height shall be determined by dispersion modelling.

Silos for consumables

The number and size of silos for consumables shall be decided during the design phase. The silos shall be equipped with load-cells and radar/ultrasonic measurements for level indication.
The design of the silo bottom (end of cone) shall be made in such way that bridging can be prevented. The silos shall be equipped with a bridge breaking system, e.g. a hammering system on the cones as well as on the shells.

The safety valve of the silo and the bag filter shall be vented over the roof of the building and the bag filter shall allow for emission measurements.
An emergency emptying system shall be included, so that the silo can be emptied even if the normal emptying system is clogged.

3.4.6 Auxiliaries

Water Treatment Plant

The water treatment plant will supply conditioned water to the boiler (and district heating system) to compensate for losses and for fillings after maintenance stops. The rejects from the production of conditioned water can be reused for cooling the bottom ash.
The water treatment system shall have sufficient capacity to prepare 120% of the water supply for the boiler system when the WtE is operating at Design Capacity.
The water quality is to ensure a long lifetime of the system and shall be measured continuously by on-line equipment (for some parameters) as well as by spot sampling (for a more detailed analysis).

The water used in the boiler will be conditioned water, in order to increase the efficiency of the boiler and avoid problems with glycol sediments.

Air Coolers

In case the district heating (DH) system is not operating or the heat offtake from the DH system is insufficient the air coolers will ensure that the plant can continue to operate at nominal load if necessary.

The air coolers shall be able to handle 120% of the full heat load at boiler nominal load regardless of the outside temperature.

The air coolers will be connected to the boiler water system using a heat exchanger. The air cooler shall be filled with a water-glycol mixture.

Compressed air

A complete compressor system to supply the plant and instruments with compressed air suitable for arctic conditions shall be established.

The needed air volumes shall be finally designed at a later stage and be large enough to absorb all variations in the demand for compressed air.

A distribution system for compressed air shall be established and sufficient nozzles shall be supplied for tools in the vicinity of normal areas of maintenance so that long air hoses lying on gangways etc. is avoided.

3.4.7 Distributed Control System (DCS) and Electrical System

Control and Monitoring of the plant

In order to control and monitor all the processes and components and to support automatic operation of entire facility, a Distributed Control System (DCS) is required

The DCS shall perform the dedicated control and monitoring tasks for specific equipment in the plant and support operator control of the said equipment. The DCS shall support full-automatic and semi-automatic operation and control of the various process sections of the plant, and support plant operation staff in operation, control and monitoring of the entire plant.

The DCS shall support plant operation staff in reporting to internal as well as external parties (e.g. supervising authorities) and support plant maintenance staff in planning, organisation and performance of maintenance of the plant.

The operation of the plant shall be supervised and controlled from the control room which shall be equipped with an operator workstation.

All alarms and events shall be presented in the alarm- and event-lists of the operator workstation.

Video-based surveillance of the facility can be established to control the operation of the plant and the building. The screens are located in the central control room.

The process-oriented tasks include monitoring of:
- Waste Hopper (inlet to furnace)
- Furnace (combustion)
- Transport of bottom ash
- Other process areas (operation is optimized through video surveillance)

Electrical and Grid Connection
The plant should be connected to the public electrical 3 phase grid.

Emergency Power and UPS (Uninterrupted Power Supply)
Emergency power and UPS can be included to protect the plant from damage and failure during failure of the grid. This shall be decided during the design stage of the project.

An emergency power and UPS system can ensure that a power failure does not result in either damage to the plant or in excessive emissions to the atmosphere.

An emergency power and UPS system consists of an emergency diesel generator used to slowly run-down the plant at failure of the grid. The UPS (battery pack) will only supply power for smaller components - primarily the DCS.

3.5 Alternative Waste Treatment Scenario
The SPN have asked Ramboll to evaluate the impact of integrating used oil and tires in the waste treatment facility.

As mentioned in section 2.2, the current waste levels in Kuujjuaq are 1,860 tonnes. With an average assumed calorific value of 10.5 GJ/t this results in 19,530 GJ/y (5.425 MWh/y).
If waste amounts rise to 2,600 tons of waste in 2035, this will provide 27,300 GJ/y (7,583 MWh/y) assuming that the average calorific value remains the same.

Most of the waste will need to be treated/incinerated immediately for health reasons. However, adding used tires and used oil to the WtE plant can provide a bit of flexibility in heat load, seeing as they can be safely stored for longer periods of time, as is the case at the moment.

Used tires

In order to include used tires in the combustion, it is required that the tires are shredded before being transferred to the waste bunker. Due to a high calorific value of shredded tires, it is vital that they are mixed thoroughly with the rest of the waste before being fed to the WtE to avoid peaks in the calorific value. If the tires are shredded and mixed with the rest of the waste, the WtE will not have problems treating this additional waste fraction.
Shredded tires can be used to boost the calorific value in periods with low calorific value of the waste or as a means of producing more heat.

As a shredder is already planned to be part of the plant, no additional equipment is foreseen. The size of the plant itself and particularly the boiler should be able to accommodate the additional energy production.

If the tires are included in the design of the plant, the additional energy content can be taken into consideration.
Introducing the shredded tires after design completion is still possible without changing any components of the system. However, the requirement of maximum 100% thermal load of the boiler shall be kept and will thus not lead to more energy being produced in the given hour but only over the year.

The used tires (48 tonnes per year) have an estimated CV of 32.87 MJ/kg (LHV) and will produce an additional 1,578 GJ of heat per year (438 MWh/y). This represents roughly 8% of the energy content of the current waste amounts and should thus be included in the design if possible, noting that the values presented are averages, and as such more than 8% could potentially be included in some periods.

Adding shredded tires to the waste mainly results in the generation of SO_2, which is handled by the lime injection. With the expected amounts of tires added evenly over the year, REIMR emission limits are not foreseen to be exceeded with the bag house filter in place. However, if large amounts of tires are added to the waste, emissions need to be closely monitored.

Used tires have the advantage that they are easy to store so they can be incinerate during winter where the energy demand is high and this again insures that all energy coming from the tires is utilized and substitutes virgin oil burning.

Used oil

Integrating used oil in the WtE is also an option worth considering as an alternative to shipping the used oil south every year. The used oil can be added either in or after the secondary combustion chamber.
Used oil can be used to boost the calorific value in periods with low calorific value of the waste or as a means of producing more heat.

If it is added in the secondary combustion chamber it could be installed as a separate burner complementing the existing virgin oil burner or the two types of oil could be handled by the same burner. The additional energy will be provided directly to the flue gas, and the heat would be transferred to the water system in the boiler, same as for the normal flue gas. Placing the used oil burner in the secondary combustion chamber will provide additional assurance that the 1000°C for 1 second is complied with the burner in operation.

If the used oil is added after the secondary combustion chamber (before the boiler or in the boiler), it will need a separate burner. The energy outcome will be the same as above, but the used oil cannot be used for ensuring the 1000°C for one second requirement.

As long as the existing burner in the secondary chamber is designed to handle virgin and used oil, no additional equipment is necessary. The size of the plant itself and particularly the boiler should be able to accommodate the additional energy production.

The used oil (19,000 litres per year) have an estimated CV of 37.65 MJ/kg (LHV) and will produce an additional 682 GJ of heat per year (190 MWh/y). This represents roughly 3.5% of the energy content of the current waste amounts and should thus be included in the design if possible, noting that the values presented are averages, and as such more than 3.5% could potentially be included in some periods.

When adding used oil to the combustion process during the cold months only (more per month than if distributed evenly throughout the year), REIMR emission limits are not foreseen to be exceeded with the bag house filter in place.

Due to the additional heat demands, the boiler size needs to be increased to cope with the additional heat production along with feed water pumps, DH exchanger and air coolers, if this is not taken into account during the design stage.
A retrofit is possible without increasing the other components of the system, if the used oil is only used when the plant is operating below 100% thermal load being careful not to exceed the 100% thermal load limit.

Caution should be taken in handling and maintenance of the flue gas treatment system and residue in particular when adding used oil to the combustion process, as used oil ash is known to contain nickel, which may result in nickel allergy.

3.6 Energy Balance of the WtE

In order to estimate the generated heat from a waste fired boiler supplied by 500 kg per hour of MSW, an energy balance model was built using Ramboll's internal WtE modelling tool RAMsteam. It is based on the main layout showed in Figure 9 and assumptions shown in Table 8.

Parameter	Value	Comment
Waste amount	500 kg/h	
Waste composition	23% ash 26% moisture	
Waste energy content	10.5 kJ/kg (LHV) (12.0 kJ/kg HHV)	Based on data from Greenland
Boiler excess O_2 in flue gas	11%(dry) / 9.7%(wet)	Plausible value for small units
Boiler flue gas temperature	170 °C	
Flue gas treatment	Dry system with baghouse	
Air preheating	None	
Ambient air temperature	-5 °C	

Table 8 - Main assumptions for heat production modelling

Based on this, the boiler efficiency was estimated to 80.8% and the fuel feed to 1.46 MW (LHV). This results in a nominal heat production of 1.18 MW.

This requires a flow through the boiler of around 560 kg/min with 80°C going into the boiler and 110°C exiting.

The 1.18 MW will be available for the district heating network as is also shown in Figure 9.

Raising the temperature in the exit of the boiler to 180°C through fouling of the boiler will decrease the produced heat by about 0.01 MW, which also reduces the boiler efficiency.

The flue gas temperature will drop roughly 10 degrees through the bag house filter and gain roughly 10 degrees again after passing through the ID fan, meaning that the flue gas temperature coming out of the stack will be fairly similar to that coming out of the boiler.

3.7 Conceptual Design, Civil

The following sections describes the civil works required to construct the plant. Actual description of civil works needed, will be provided by a local civil firm according to SPN.

3.7.1 General

The design shall include complete, fully functional buildings and civil works consisting of following main elements:

- Site access (access roads, fire truck hard standings, car park, etc.)
- Site utilities, incl. pipe racks and trenches
- Landscaping and security, fencing and gates;
- Entrance/weighbridge (if required, alternatively crane weight can be used)
- Waste Incineration Building
- Tipping Hall
- Waste Bunker
- Flue Gas Treatment Area
- Auxiliary Rooms
- Control room /Staff facilities
- Storage Facility for bottom ash, residues and potentially recovered materials
- Stack
- Air Coolers
- Miscellaneous process equipment
- Tanks and silos

The design and construction shall accommodate for the actual site conditions including connections to the external utilities.

The design shall optimize the site layout and areas within the buildings to provide a high level of maintainability and access. The design must allow for the required escape routes according to local legislation and requirements.

The entire building complex shall be designed in such a way that it would allow for future replacement of major systems, including the boiler and flue gas cleaning equipment. This shall be possible without the need for any major dismantling of the main structures and could be achieved by the provision of removable roof panels, side panels etc. of the waste incineration building.

The building shall be suitable for the local climate conditions.

All vibrating and/or rotating equipment shall be dynamically balanced. Structural dynamic principals shall be employed in the design of the support structure to minimize the transference of vibrations, unacceptable deflections or loads to the support structure. Noise attenuation shall be employed as required to minimize the propagation of unacceptable levels of noise.
It shall be considered whether the plant shall be equipped with a weighbridge.

All roadways shall be designed for heavy trucks and container trucks to fully manoeuvre and successfully deliver materials to designated areas within the facility. Consideration shall be given to the design and construction of roads given the heavy traffic and cold ambient temperature conditions.

3.7.2 Design Basis, Structures

The design shall be in accordance with the applicable Canadian norms, standards, regulations, guidelines and etc.

The buildings shall have a design working life of 50 years. To prevent damage, concrete bollards shall be installed at all building corners and access doorways (inside and outside) subject to truck traffic.

Raised floor areas and supports shall be protected from vehicular impact with concrete bollards and/or protective steel barriers.

All live loads arising from traffic, cranes, users of facilities, water storage, waste storage etc. shall be calculated using relevant codes. Placing of and reactions from machinery, silos, filter, boiler, hopper, turbine plate etc. shall be developed from the contractor's mechanical design.

3.7.3 Building Services

The design shall provide building services, as to meet the applicable building codes and meet the requirements set out by the equipment. Interior and exterior lighting has to meet the applicable building codes and to meet the requirements for around the clock operation and maintenance. All lighting points shall be accessible for the purposes of maintenance.

<u>Mechanical Building Services</u>
The scope of works for mechanical building services comprises the following:

- HVAC
- Plumbing and Drainage

The mechanical systems shall be designed to operate in the ambient temperature and surrounding environment. The systems are expected to have a design working life of 30 years before they are due for replacement. All flexibility in design shall be included to enable the relevant replacement works to be conducted.
All floors shall be fully drained to floor drains or grated trenches using a 2% slope.

The design shall provide fire protection and fire-fighting systems in accordance with Canadian requirements. The design shall indicate the various fire rated areas of the facility according to national codes and regulations.

The waste bunker shall be covered by fire-fighting equipment consisting of minimum one remote controlled water spraying cannons at a strategic point above the bunker. The cannon shall be of foam/water type. The cannons shall cover all areas of the bunkers including hopper deck, hopper and shredder. Remote control shall be possible from the crane operator's chair. The firefighting equipment shall be protected against collision by the waste cranes.

Electrical Building Services

The electrical building services comprise the following:

- Low voltage systems, excl. process
- Lighting systems
- Life safety systems (fire detection, emergency exit etc.)
- Lightning protection
- Access control and intruder detection system (if relevant)
- CCTV system (Closed Circuit Television, if relevant)

3.8 Site Location and Layout suggestion

In the following section a potential site will be selected based on a short evaluation, and the consequences of the chosen site location and related recommendations will be listed.

A preliminary layout of the building has been created and the recommended footprint settled.

For the civil works the main dimensions of the required building volume will be illustrated. A local consultant will be engaged separately by Sociète du Plan Nord Quebec.

Site selection

It is important when selecting a site, that the WtE facility;

- is placed close to the village in order to utilise the heat produced
- is placed close to the main heat consumers of the village
- is placed high or features a tall stack in order to ensure the residual emissions coming out of the stack after being cleaned are diluted sufficiently. The higher the facility is placed (or the higher the stack) the better the dilution.
- Is accessible by truck for waste deliveries and residue collection

During the fact-finding mission a number of potential sites were identified. Not all sites complied with the above requirements however.

1. Potential site no 1 is the current landfill. The main drawback of this location is the distance to Kuujjuaq village as it is close to 7 km, and thus a lot of heat would be lost through a district heating pipeline due to the distance and the cost of the districting heating network would increase substantially.

2. Potential site no 2 is west of the village about halfway up towards the Hydro Quebec Power Station. This location is placed high up, close to the village (6-700m as the crow flies) where large heat consumers can be found e.g. the hospital. Located close to the industrial area of Kuujjuaq.

3. Potential site no 3 is next to the new water building. This site is not too far from heat consumers, but it is not located high up, and would as such require a very tall stack in order to comply with plume dispersion models.

4. Potential site no 4 is east of the village. This site is favourable to the prevailing wind direction but is also located low in the terrain and would as such also require a very tall stack, which may not be favourable very close to residential areas.

Potential site no 2 has been evaluated as the best option at the moment. Information from maps (Appendix 10, 11 and 12) and Hydro Quebec report (Appendix 13) informs the following about the site:

- Surface: Bedrock, bare rock outcrop or with a scattered cover of loose deposits
- The active layer reaches a thickness of between 4.5 and 6m. Only its joint and joint structure is likely to contain a small amount of ice
- No natural hazards have been located.
- Nordic Foundation of all types are recommended. Adaptation to rugged topography is often necessary (the area features slopes of 7.5 – 15 degrees).

<u>Layout</u>

In the following section the suggested site, building site, key plan, longitudinal section etc. can be observed. For full size drawings reference is made to Appendix 3.

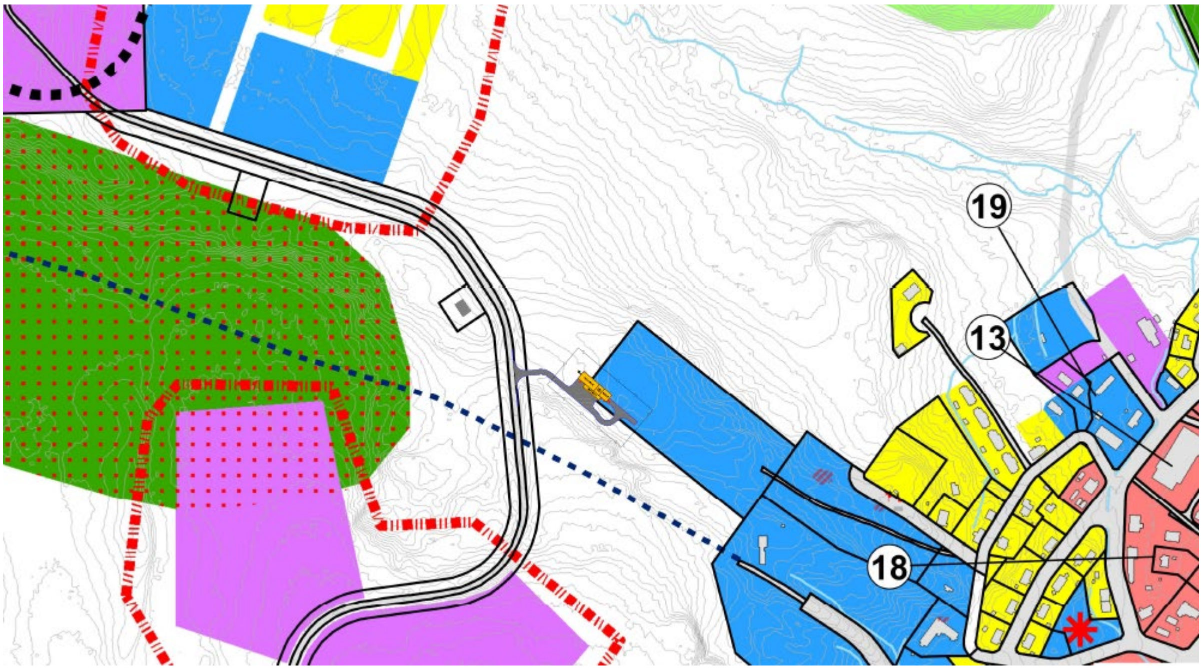


Figure 10 - Suggested site location

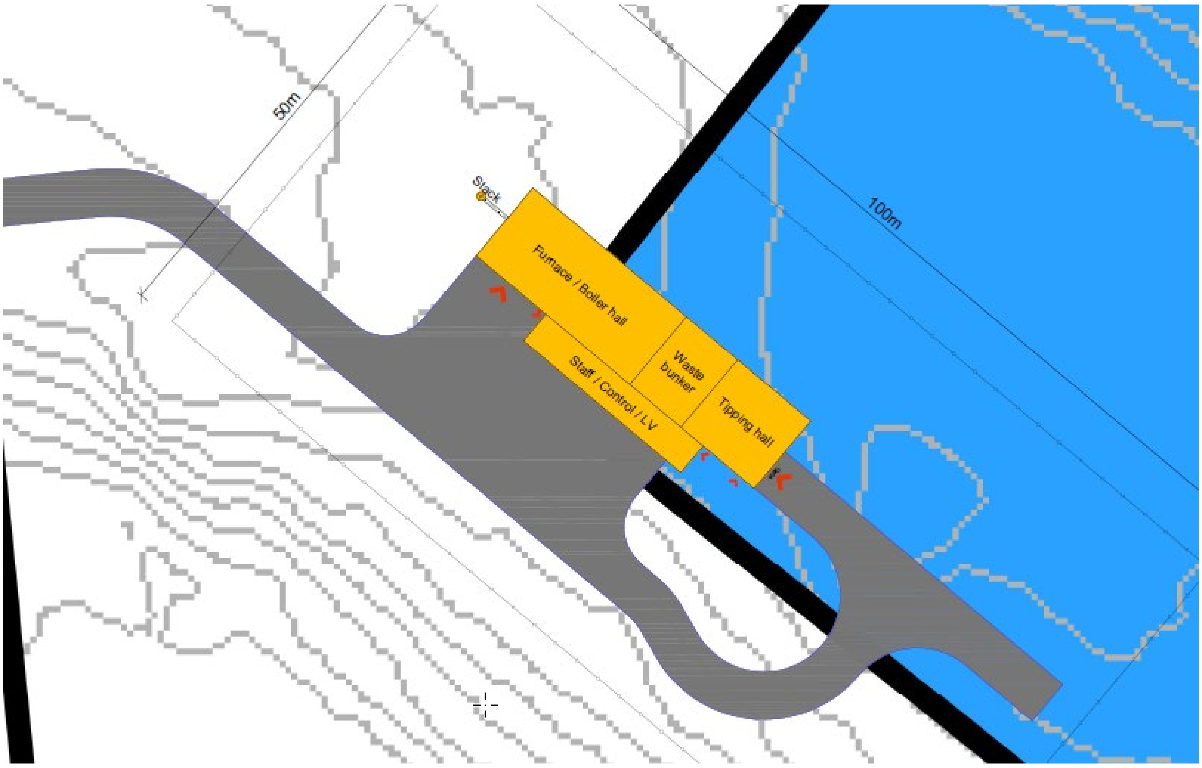


Figure 11 - Closeup of the site showing the individual sections of the building

As can be seen from the figure below Ramboll have suggested to use a layout that has a proven track record in Greenland with a plant section and a staff section. The tipping hall allows for trucks to unload the waste with the roller shutters leading into the tipping hall closed, greatly reducing the odour outside the plant.

The main components of the WtE have been showed below.

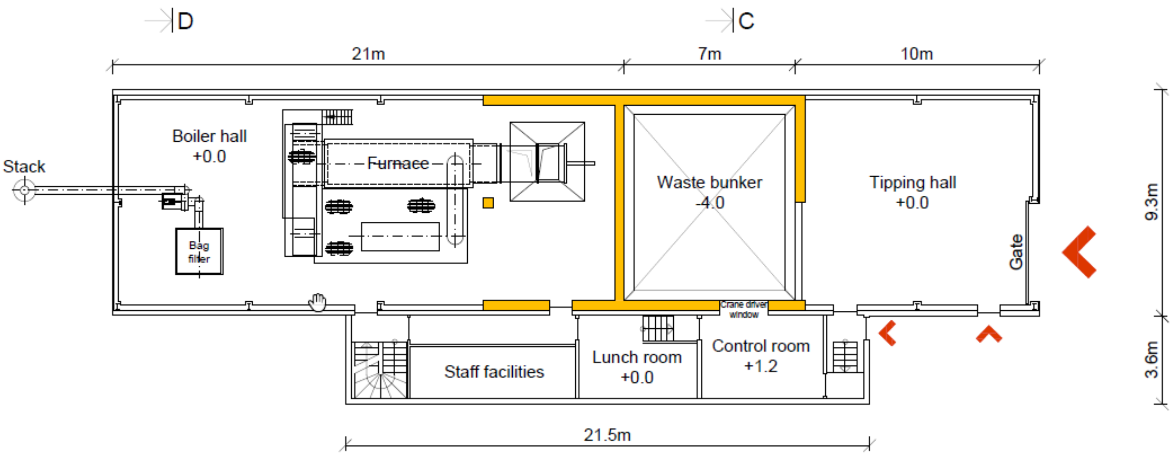


Figure 12 - Top view of the upper terrain level

The lower terrain level shows the bottom ash handling, electrical rooms and the lower part of the waste bunker.

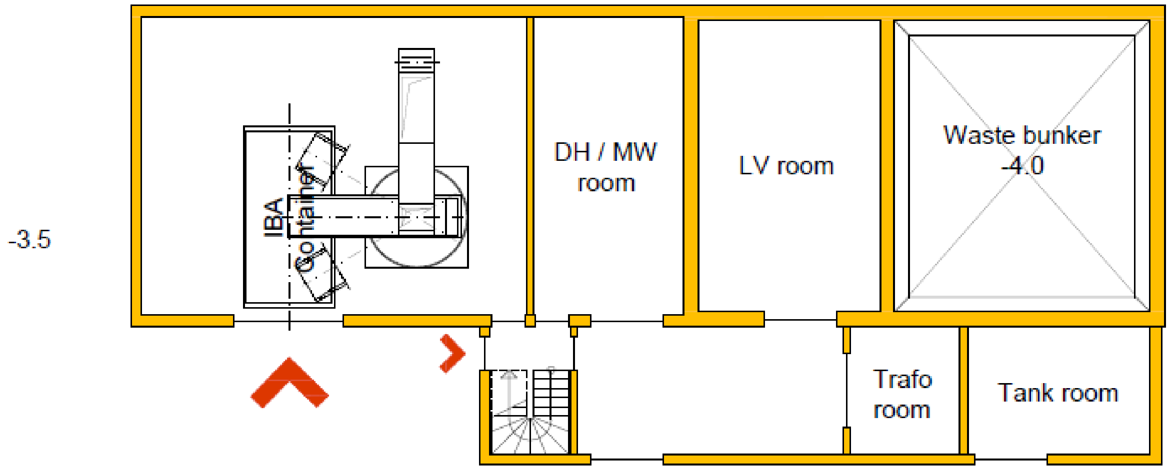


Figure 13 - Top view of the lower terrain level

The longitudinal section demonstrates the possible layout of the WtE plant as viewed from the side. The building volume has been sized in order to allow for various design from various suppliers and using Ramboll's experience for equipment layout. The layout may still be tweaked, and it should noted, that the height of the stack indicated is preliminary, as the actual stack height will need to be settled through dispersion models specific for the chosen site in Kuujjuaq.

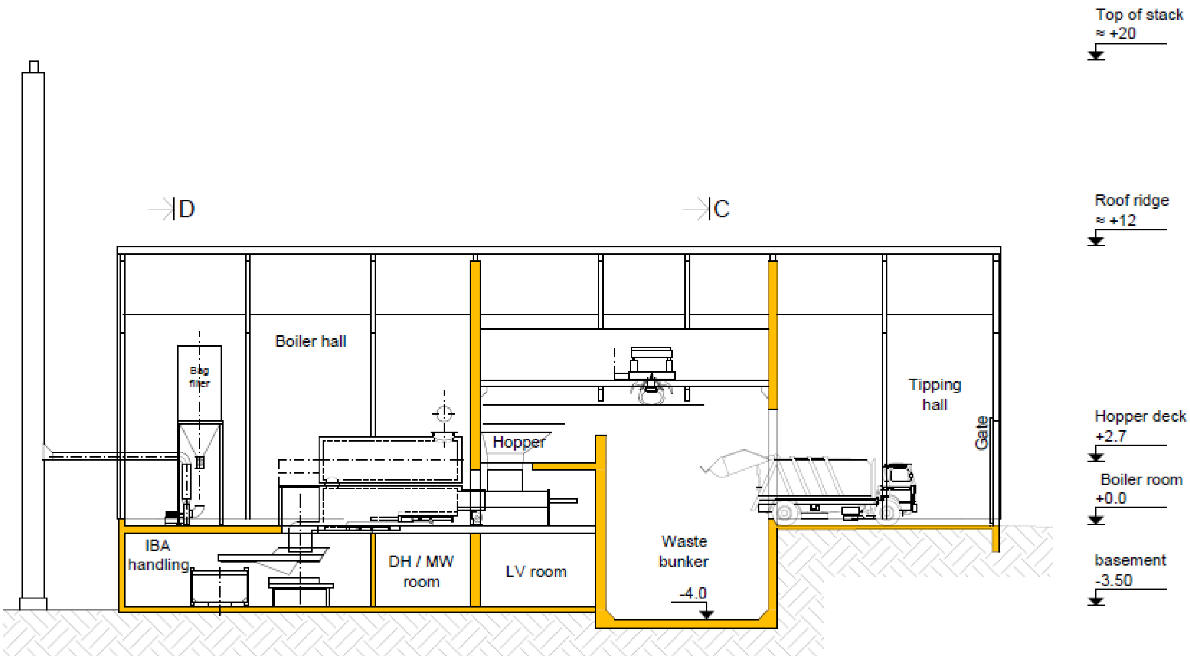


Figure 14 - Longitudinal section of the WtE plant showing the individual components

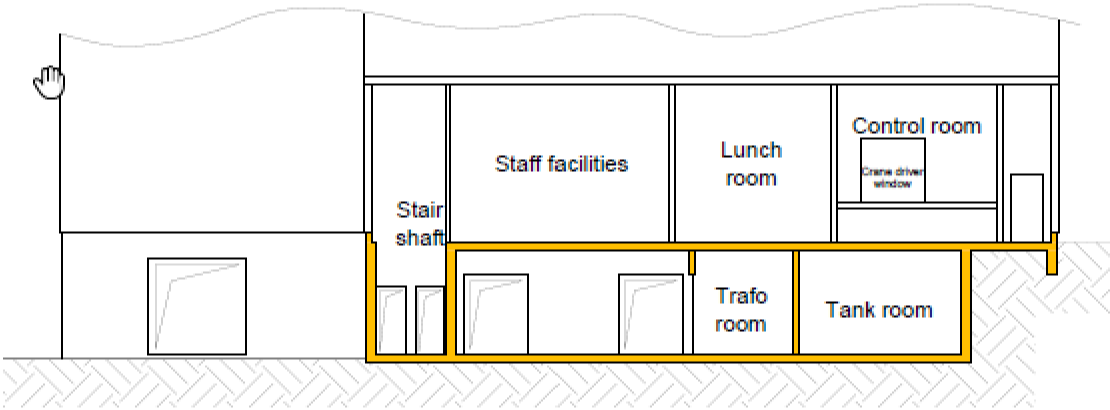


Figure 15 - Longitudinal section of the WtE plant showing staff facilities

The two cross sections below show the proposed layout for section D-D and C-C.

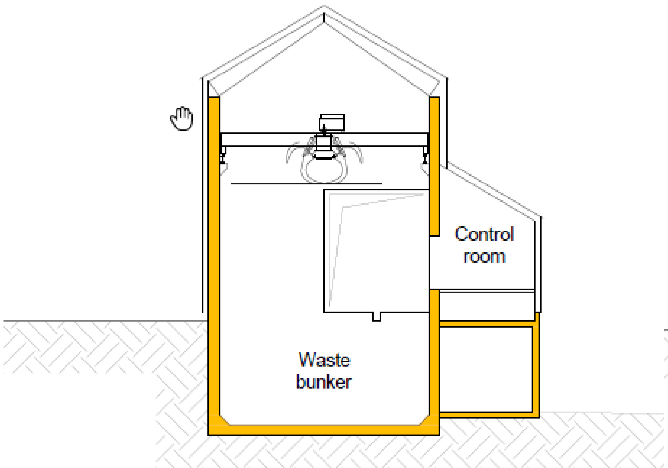


Figure 16 - Section D-D

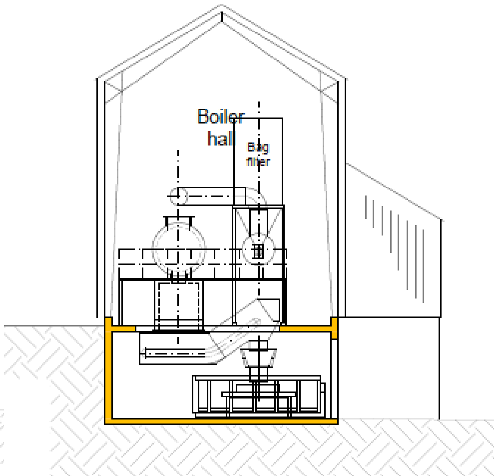


Figure 17 - Section C-C

3.9 District Heating

With Ramboll's experience from numerous District Heating systems in Nordic and Arctic regions we see a huge saving potential by minimizing unnecessary import of Arctic Grade Oil for the diesel motor powered generators and heating of buildings. This will not only cut costs for importing arctic fuel to Kuujjuaq but also significantly reduce the CO2 footprint of the village.

The below section will look into the possibilities for a district heating network in Kuujjuaq, how and why it should be implemented and how it could be supplied.

<u>Equipment:</u>
A district heating network is basically transporting hot water in pipes. The water temperature can vary in the supply between 60°C and 110°C. The pressure likewise, depending on topography,

load and piping size. The water is heated from one or many sources. Important to be noted here is that if there is only one source this source must be based on a far cheaper fuel than Fossil arctic grade oil. The supplier could be a WtE plant. From the waste boiler the heat is delivered the District Heating network through heat exchanger(es). The heat is circulated by main pumps around the network and distributed to the consumers that are attached to the network and has a demand. The consumers can be connected through a heat exchanger or without depending again on the systems pressure conditions. The heat input and the heat output from the system will be more or less in balance with a few hours variation. If no storage facility is built into the system, the consumers demand will set the input from the utility(ies). To some extent the system can have a certain limited time of accumulation by itself when the supply temperature is raised to a higher level than needed.

The District heating network impose a heat loss to the energy system (therefore the need for cheaper fuels). If the network is well designed in terms of optimal flow, temperature and insulation conditions the annual heat loss should not exceed more than 15%. In the following, Ramboll assumes that this percentage can be used in a case study for new DH-system in Kuujjuaq.

A first stage DH-system in Kuujjuaq utilizing the heat from a newly established WtE plant is described below.

3.9.1 First stage DH system

2 pcs 100% main heat exchangers, 2 pcs 100% pumps and an expansion facility is usually all it takes to make the utility ready to deliver heat to the network. It will be beneficial to have the pumps and control equipment located close to skilled personnel. An obvious choice will be to place the pumps etc. in a separate room in the WtE or a building close by, as skilled personnel is already present.

Normally WtE plants are operated with a steady load as waste on a grate provides inertia in the system and improves the emissions. This steady heat load doesn't correspond well to the demand in the DH network. If the WtE should be utilized optimal in a DH system it shall run as a baseload unit where the output is not exceeding the minimum demand of the network. That puts a limit to the size of the WtE. If the WtE is bigger than what can be used in the network the waste energy is refused and energy is cooled off to the atmosphere or through cooling water. The economic benefits of the DH system will then strive to get more consumers attached to the network or temporarily store waste to periods where it can be used to meet the demand of the system.

The demand of a DH system can thus be difficult to handle by only one source. Therefore, peak load boilers must be in place to take over the supply when the WtE heat is insufficient. These peak load boilers will typically use fossil fuels (Arctic Grade Oil). The boilers could be new boilers placed at the WtE or the newest and best of the current boilers at the DH-consumers. The boilers located at the consumers are typically taken over by the company that owns and operates the DH network. Using these boilers will free the necessary energy resources to cover the heat demand in the DH-system.

At each consumer an individual heat substations (IHS) is substituting the current oil boiler (it is far less space demanding and more clean) The IHS is a term for the plant at the consumer and it consist of all necessary equipment for transferring the right amount of energy both for space heating and domestic hot water, that the consumer needs. The efficiency for the IHS can be set to 100%.

3.9.2 Distribution network possibility (basis model)

In order to utilise the heat produced at the WtE plant, the following proposed district heating network could be a possibility. However, it should be underlined that to fully reap the benefits of a district heating network an overall heat plan for Kuujjuaq is highly recommended. This is to allow for future expansion as more producers and consumers will be connected. This bit is also discussed in the district heating recommendations section below.

For the initial network, the following buildings have been included, as they represent some of the largest buildings in the vicinity of the WtE plant. Heat demands have been informed by the SPN.

- Tulattavik Hospital
- High School
- Primary School
- Fire Station
- KRG's Building
- NV townhouse
- Municipal Garage

Figure 18 - Map of Kuujuaq with district heating connections (basis model) 2 MW heat demand

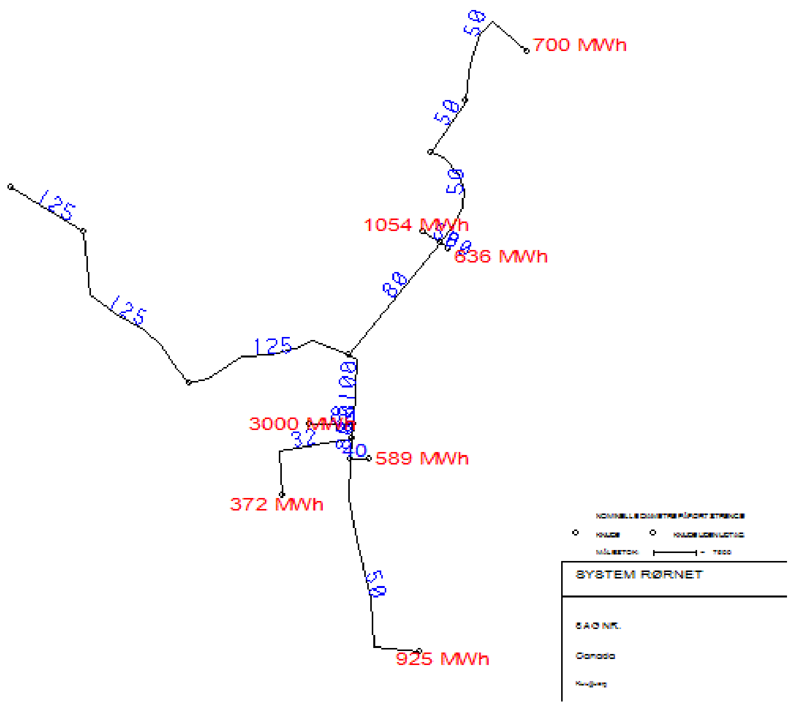


Figure 19 - View of the basic model (view from Ramboll DH software, netop)

It is anticipated that DH-pipes can be placed in the roads or beside the roads either in ground or visible fully or partly. At all crossings the pipes are buried. The trench price depends heavily on whether pipes are buried in trenches that can be dug or if it has to be blasted.

The showed network consists of roughly 3,000 m of DH pipes. WtE coverage is estimated to 60% annual heat demand (3,400 MWh). Remaining heat demand (2,200 MWh) must still be covered by arctic grade oil. This also means that introducing a simple district heating network for the buildings included will result in savings of 60% of arctic grade oil. The payback time for this system will be around 10-11 years.

3.9.3 Distribution network possibility (basis model+)

The following section looks into adding a few more of the large buildings in Kuujjuaq, effectively expanding the network from 2.0 to 2.5 MW heat.

The heat demand of the added buildings has been estimated using the footprints of the individual buildings. It should be noted that the figures will need to be verified at a later stage.

Figure 20 - Map of Kuujjuaq with district heating connections (basis model+) 2.5 MW heat demand

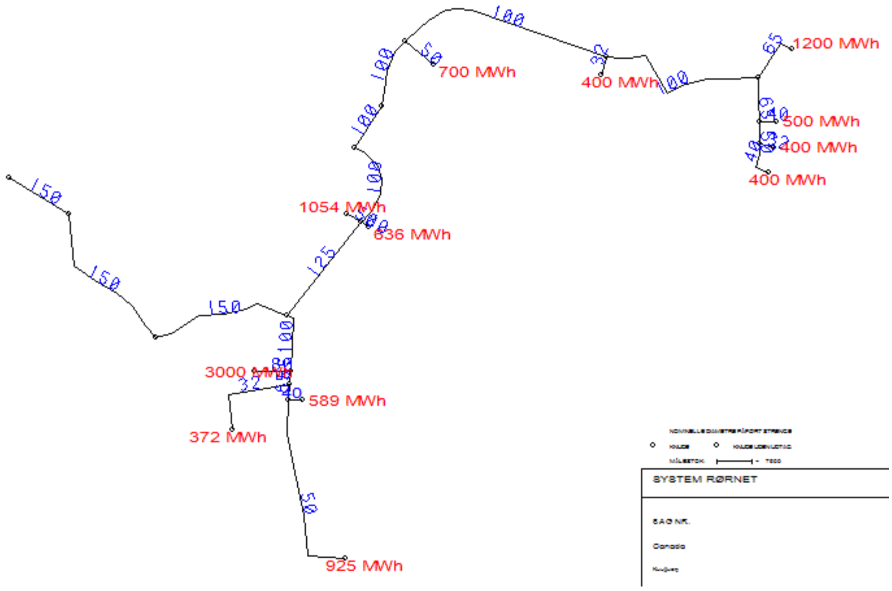


Figure 21 - View of the basic model+ (view from Ramboll DH software, netop)

It is anticipated that DH-pipes can be placed in the roads or beside the roads either in ground or visible fully or partly. At all crossings the pipes are buried. The trench price depends heavily on whether pipes are buried in trenches that can be dug or if it has to be blasted.

The showed network consists of roughly 4,000 m of DH pipes. Compared to the "basic model" WtE coverage lower as the total demand is higher. However, the WtE plant will be able to supply more heat to the DH network (less needs to be cooled away). The remaining heat demand must still be covered by arctic grade oil. As such more arctic grade oil will be saved per year. However, as the network starts to grow, the need for more suppliers becomes apparent. As such, the payback time will go down significant if the Hydro Quebec Power Station can deliver Surplus heat from Power production.

3.9.4 Balancing the district heating network

The above mentioned estimates are conservative. It is important that the network is balanced (that input matches the demand) to the best feasible extent and also taking into account that the system will be inefficient to a certain level in the beginning. In this simple isolated system, the WtE will provide the heat into the system. Contributions from the WtE depends on the amount of waste fed into the WtE and the calorific value of the waste. In the figures below a number of heat input curves have been included. A 15% transmission and distribution loss has been included in the energy input.

The "WtE heat, 100% thermal load" demonstrates the maximum amount of heat the WtE can produce and distribute each month.
"WtE heat, max, present, realistic" shows the realistic heat input into the system with the current waste amounts available in Kuujjuaq taking into account the necessary stops to clean the plant when needed. The realistic heat input (total) that can be provided to consumers for the present scenario is roughly 4,000 MWh/yr.
"WtE heat, max, future, realistic" shows the realistic heat input into the system with the projected future waste amounts available in Kuujjuaq taking into account the necessary stops to clean the plant when needed. The realistic heat input (total) that can be provided to consumers for the future scenario is roughly 5,500 MWh/yr.

The consumers will provide the heat demand (offtake). As the outdoor temperature drops during the winter months, the heat requirement is increased to maintain a comfortable indoor temperature.

For the heat demand profile (from the buildings) a figure provided from the KRG building has been used (diesel consumption). It should be noted that the heat profile does not look like a "standard bathtub heat curve" possibly due to the KRG building being closed during Christmas with people leaving. A higher heat demand for December is expected and possibly also for November.

The heat distribution curve from the KRG building has been used to calculate the heat demand for each month. The percentage distribution curve has then been used on the other possible heat consumers. As such, inherent errors in the KRG curve will affect the overall result. Another comment to be made is that the heat demand for the hospital has been reduced compared to the stated demand, as a lot of the current diesel is used for producing steam at the hospital. This cannot be achieved with the DH network. As such, the heat demand for the hospital has been reduced to a number close to the high schools demand.

The total heat consumption required by the buildings below is roughly 5,800 MWh/y. This figure is not far from the possible future heat input scenario from the WtE plant. However, as can be seen from the calculations above and the figures below, the heat is not being produced exactly when it is needed. In winter it is hard to produce enough heat, and in the summer months, too much heat is produced. The excess heat produced during the summer months will be cooled by the air coolers at the WtE plant, which is inefficient use of the heat.

It should be stressed that the figures provided below are based on rough calculations and will need to be verified at a later stage. They do however provide a look into what the heat produced at a WtE can be used for. As such large multiple buildings can be heated during winter, and even more during the summer months.

The line for 100% thermal load describes the upper theoretical limit of heat that could be produced (maximum load, no stops, etc).

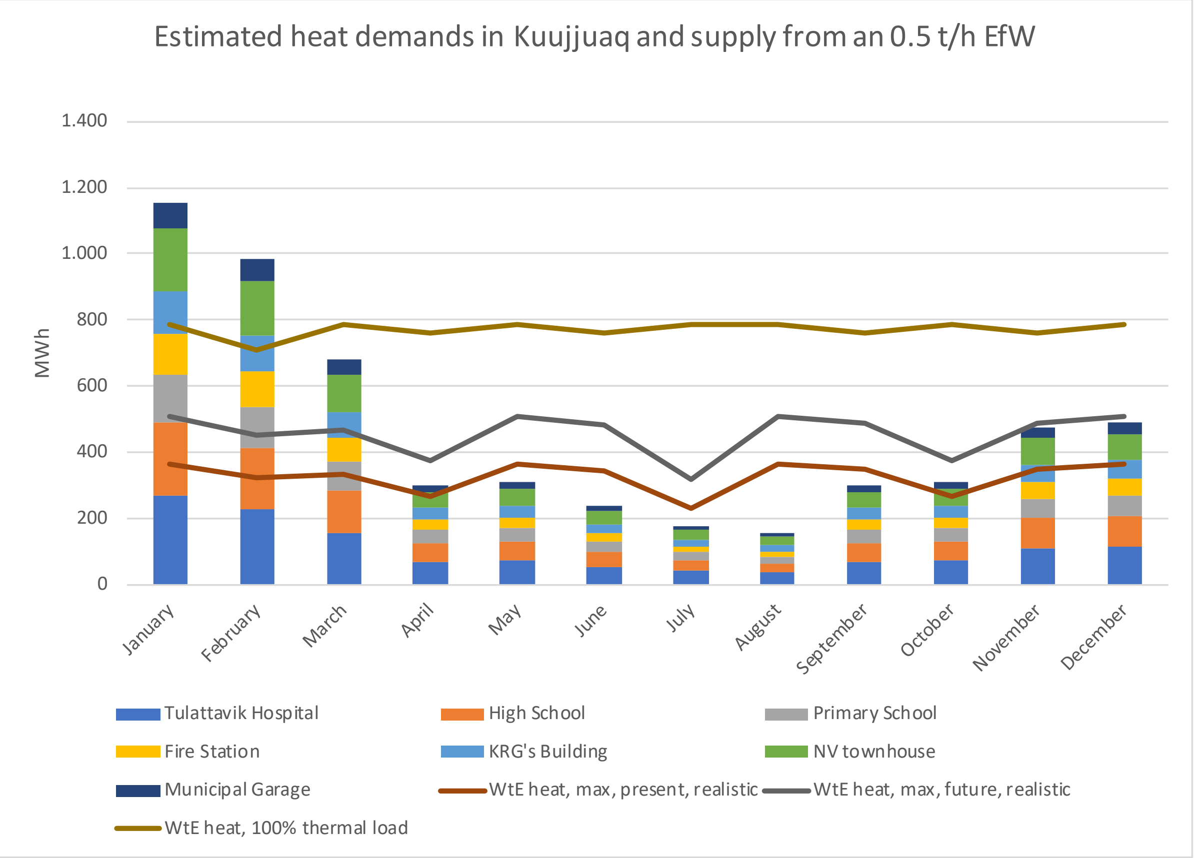


Figure 22 - Heat curves for reference scenario (only waste), basic model

The figure shows that the WtE can produce enough heat during the summer months to cover the heat demand for all the buildings included above. During winter additional heat is required from peak load boilers or other suppliers connected to the network.

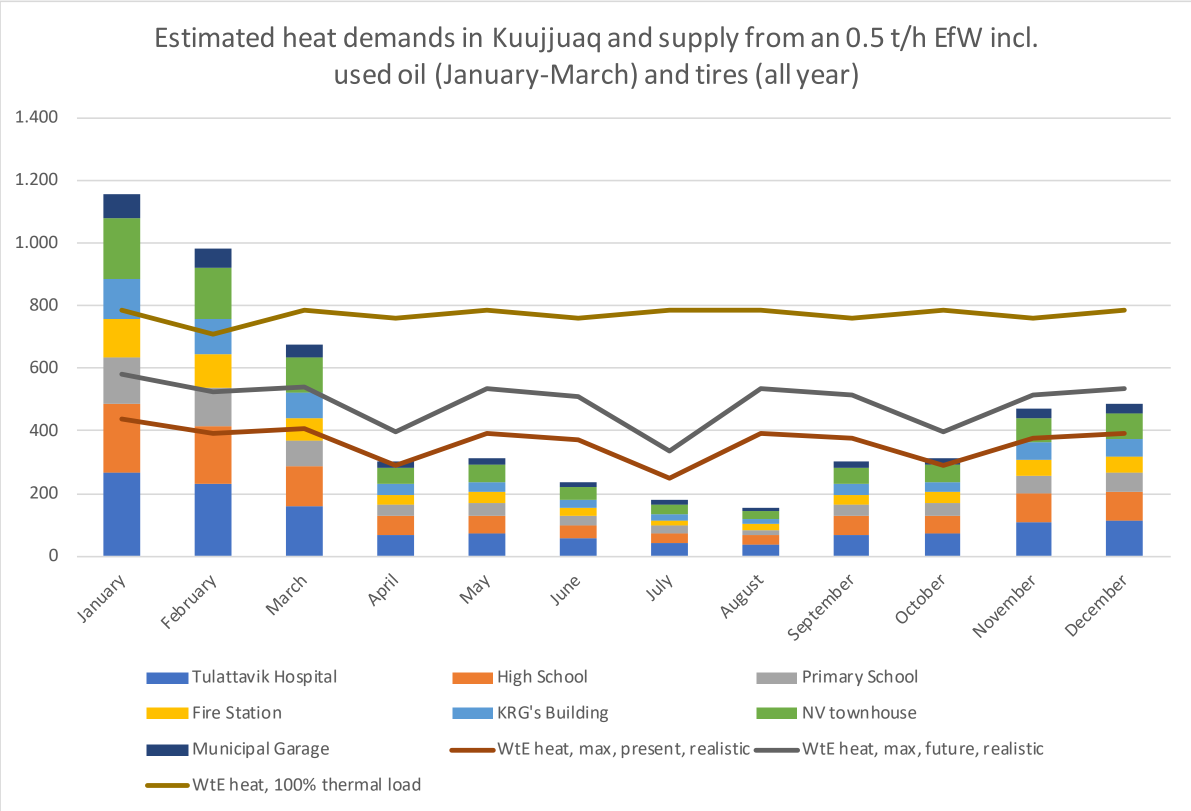


Figure 23 - Heat curves for alternative scenario (waste + used oil + used tires), basic model

The figure above covering the alternative scenario shows that the WtE can produce more than enough heat during the summer months to cover the heat demand for all the buildings included above. During winter additional heat is still required from peak load boilers or other suppliers connected to the network.

In the above it has been assumed that the used tires will be fed continuously throughout the year in order to increase the calorific value during periods of low calorific waste being received. The used oil is used solely from January to March in order to boost the heat production.

3.9.5 Recommendations on the implementation of a district heating system

Heat mapping and planning of a district heating network for Kuujjuaq goes beyond this project. District heating is the most cost-effective way to reduce the amount of imported arctic oil. It is anticipated that 90% of the arctic fuel in the basic+ network (725.000 litres per yr.) or more could be saved, and thus requires a completely separate project in order to ensure that all aspects of the energy optimisation will be considered.

An obvious player in a future district heating network is Hydro Quebec Power Station, as they currently cool away excess heat of which the amounts are currently unknown to Ramboll. However, from previous experience, there is potentially enough heat produced by the WtE and Hydro Quebec Power Station to heat 60% or more of the buildings in all of Kuujjuaq. The savings in not having to pay for Arctic Fuel are significant and the implementation of a district heating network will pay for itself quickly. Experience from Greenland suggests that the payback period is between 5-10 years.

If the buildings in the figures above were to be heated by district heating, there would be a yearly budget to establish the network almost equal to the Arctic fuel cost for that year. For the buildings included in the "basic model+" above, the estimated fuel cost is 1.5 million CAD per year. If the buildings can be 100% heated by surplus heat from the WtE (and Hydro Quebec Power Station), 1.5 million CAD in Arctic fuel will be saved every year, and the CO2-footprint would be reduced accordingly as 833,000 litres of arctic fuel would be saved every year (equal to 1 barrel every 1½ hours).

It is vital that the district heating network project takes into account the future expansions of the village. If new housing is built, it can be equipped with district heating, removing the need for a separate boiler.

Ramboll suggests that the SPN initiates a heat plan of Kuujjuaq (heat demand, heated sqm, build yr. purpose etc. for each individual building) and an overall plan for the implementation and expansion of a district heating network in Kuujjuaq. Also, the possibility of including hydro power (large or small) must be surveyed if it has not been done jet.

As described above the financial gains in establishing a district heating network are easy to see in Arctic regions. Based on Ramboll's previous DH experience in similar regions such as Greenland and the Nordics, the project would be able to pay for all installations (even with heat producers such as Hydro Quebec) and still be able to have a short payback period if planned correctly from the beginning. Hydro Quebec's income from heat sales could be settled to the savings of the electricity to the cooling fans or pumps. The DH-net operator will bear the cost for operation of the DH-pumps etc. Necessary equipment to capture the surplus heat on the Hydro Quebec Power Station should be incorporated in the total financing model.

4. COST EVALUATION FOR THE FUTURE WTE PLANT

Prices given in this section are based on the suggested conceptual design described in section 3.4. A waste to Energy facility based on the mass burn of waste on a grate, with heat recovery in a flue gas to water type boiler, flue gas treatment based on a bag filter with injection of lime and activated carbon and waste management based on a bunker with an overhead crane.

4.1 Construction cost of Waste to Energy technology

Prices in the following table are based on prices known from projects where Ramboll have participated in the design and construction of the plants. All the plants are based either in Greenland or the Faroe Islands, both remote and Greenland also arctic areas.

Construction cost	Thousand CAD
Mechanical and electrical: design, manufacturing, erection and commissioning	3,500 – 4,000
Owners Engineer: Specification of requirements (White Book), tendering and contracting, design review, inspections and supervision on site during erection, commissioning and performance testing and contract management	600
Contingency (normally app. 30%)	1500
Total	**5,600-6,100**

Table 9: Construction Cost for the M&E side

The Mechanical and electrical design includes all process equipment from waste crane to stack; crane for waste management, waste feeding, incinerator, boiler, FGT, control system, electric system, instrumentation, ash handling, summer cooler, stack and any other minor components.

ECO Waste Solution (EWS), who has supported Société Plan du Nord through the project with various information, have also supplied Ramboll with a price estimate of 3,000,000 CAD for a plant supplied by them. The price from EWS is for the M&E services but does not include any type of waste handling and/or management. EWS are suggesting a tip bin/skip or front loader solution as described in section 2.5.2. No civil works or District Heating is included in the EWS price estimate.
Furthermore, it is unclear what is included in the interface to district heating and for cooling of surplus heat in the summer period.
It is therefore Ramboll’s opinion that the budget for 3,500,000 – 4,000,000 CAD is reliable and to some extent confirmed by the budget given by EWS.

The cost for the plant (M&E) can be divided into three main parts. With the following estimated division of the cost:

Package	Scope	Division
Incinerator	Waste crane, waste feeding, incinerator, bottom ash handling and boiler	50-60%
Flue gas treatment	Bag filter, lime and activated carbon dosing, residue handling	25-35%
Auxiliary	Summer cooler, stack, control system, etc.	15-25%

Table 10: Division of CAPEX

Contingency is set to 30% of the Total cost for M&E and owners engineer. At this stage there is still a fairly large uncertainty on the final cost of the plant. Later stages of the project and further investigations will reduce the uncertainty.

4.2 Building costs for Waste to Energy plant

In order to estimate the building costs a general cost for construction of simple and technical buildings per m2 has been used. Ramboll was provided with costs per m2 for constructing a building containing technical equipment such as the water plant in Kuujjuaq. The costs seem to match very well with Ramboll's experience from other arctic regions, Greenland in particular. The costs provided to Ramboll for the $CAD/m2 is 10,800 for technical buildings (like water treatment).

With an estimated building size of 430 m2 the building costs are estimated to 4.7 $MCAD. This number shall be confirmed by the civil consultant.

4.3 Costs for the District Heating network

The costs to establish a District Heating network is based on experience from Greenland. While the regions are very similar the costs will need to be verified under a separate project.

The rough estimate of "Phase 1" DH network is 6 $MCAD.

4.4 Total costs for Waste to Energy plant, building and "Phase 1" DH network

Combining the above sections provides an overview of the costs associated with establishing a Waste to Energy plant including the building works and a small scale District Heating network.

Based on the above, a very rough estimate of total cost for the combined projects is 17 $MCAD.

4.5 Operation cost for Waste to Energy plant

Operational cost of the facility depends on different aspects; the quality of the materials used during manufacturing and construction, the operator's ability to run the plant with in the design conditions, with stable parameters as well as the quality and quantity of the maintenance being performed.
Also factors like salaries, cost of consumables, cost of spare parts etc. play an important role.

Some costs are directly related to the amount of waste treated e.g. most consumables and other are fixed costs not related to waste amounts treated.

This section gives a rough estimate of the cost that should be expected. The estimate is based on Ramboll's experience and realized budgets on similar plants in operation.

	Thousand CAD/year
Manpower	460
Maintenance (materials and spare parts)	270
Consumables (power, water, FGT consumables)	65
Residue disposal (shipped south)	30
Total	**825**

Table 11: Operational Cost

4.5.1 Manpower

Manpower for a facility of the size estimated in Kuujjuaq is expected to consist of the following:

Plant operation manager

The plant operation manager is responsible for the operation of the plant, scheduling maintenance, day to day coordination of the personnel, contact person to the responsible person in the municipal office etc.

The plant operation manager should have a formal training within a technical area, e.g. electrician, marine engineer, mechanic etc.

Will be working during day shift.

It is estimated that 1 plant manager is needed.

The yearly salary of the plant operation manager is estimated to be 60.000 CAD.

Plant Operators

The plant operators are responsible for running the plant during all hours. They operate the facility via the HMI in the Control Room and on the plant itself.

Plant Operators should have an interest in understanding the plant on an overall level, but no formal training is needed, training should be conducted by plant contractor and plant operation manager. A 5-day course offered to the operators on Greenland could be a good option for the operators in Kuujjuaq as well.

They will be working in shift, 3 shifts of 8 hour or 2 shifts of 12 hours pr. day. At all times 1 operator should be present on the plant.

It is estimated that 6 operators are needed.

The yearly salary of the plant operators is estimated to be 50.000 CAD.

Maintenance and Cleaning
The maintenance responsible should conduct the regular maintenance tasks as described in the maintenance manual as well as filling and emptying of consumables and residues.

Should have an interest in understanding the plant on an overall level but no formal training is needed, training should be conducted by plant contractor and plant operation manager.

Will be working during day shift.

It is estimated that 2 maintenance and cleaning responsible are needed.

The yearly salary of the maintenance and cleaning staff is estimated to be 50.000 CAD.

4.5.2 Maintenance

The maintenance budget is based on a percentage of the investment cost.
In Ramboll experience 5% is a conservative estimate for a plant of this size.

From first year of operation and onwards an increase in maintenance cost of 2%/year is expected.
The cost estimate given in "Table 11: Operational Cost" is based on an average over the years.

4.5.3 Consumables

Cost of consumables is based on electricity and water prices for Kuujjuaq and consumable prices as seen in Greenland.

Electricity price for the plant is calculated the basis of a max load of 80 kW and an average load of 30 kW and based on the rate system used in Kuujjuaq.

4.5.4 Cost for shipping and treatment of residues

When cleaning the flue gas for pollutants a residue amount equal to roughly 2% per weight basis of the incoming waste will be generated. This residue is considered as hazardous waste and needs to be shipped south for proper handling.
The current estimated waste amount equals 1860 t/y, which would generate roughly 37.2 t/y of residue. With the projected increase in waste for 2035 reaching 2600 t/y the residue amounts are projected to also increase to roughly 52 t/y.

With the current waste amounts SPN have estimated roughly 30,000 $CAD per year.

4.6 Income from heat sales

As described in 3.9 "District Heating" there is a great potential for implementing at district heating network in Kuujjuaq. Energy from the Waste to Energy Plant is foreseen to be sold to such a network

Depending on the size of the district heating network heat sales can cover a large part of the operational cost of the plant.
For the two networks described in 3.9.2: ”Distribution network possibility (basis model)” and 3.9.3: ”Distribution network possibility (basis model+)” a utilization of the energy procedure of respectively 60% and 75% is estimated.

To encourage the usage of district heating in buildings the price is set at app. 15% lower than the equivalent heating price on oil.

With the above assumptions the yearly income from heating sales is estimated to be as can be seen in the table below:

	Utilization of heat	Energy sold GJ/year	Income from heat sales CAD/year
District heating Basis model	60%	15,000	590,000
District heating Basis model+	75%	19,000	745,000

Table 12: Estimated heat sales

As can be seen in Table 12: Estimated heat sales” the basis+ scenario is close to that all the operational cost are covered by heat sales.

It should be noted that no taxes are included in the estimates given on either CAPEX or OPEX.

5. OVERALL TIME SCHEDULE

In the following section, Ramboll's suggestion for a preliminary overall time schedule for waste incineration in Kuujjuaq is explored. In order to make the project activities and the schedule itself easier to understand we have described the different project phases and elaborated on some of the individual activities in the following sections.

5.1 Project Phases and Flows

Ramboll has on the basis of many years of experience developed a general project execution model for the development and establishment of waste-to-energy facilities, see Figure 24.

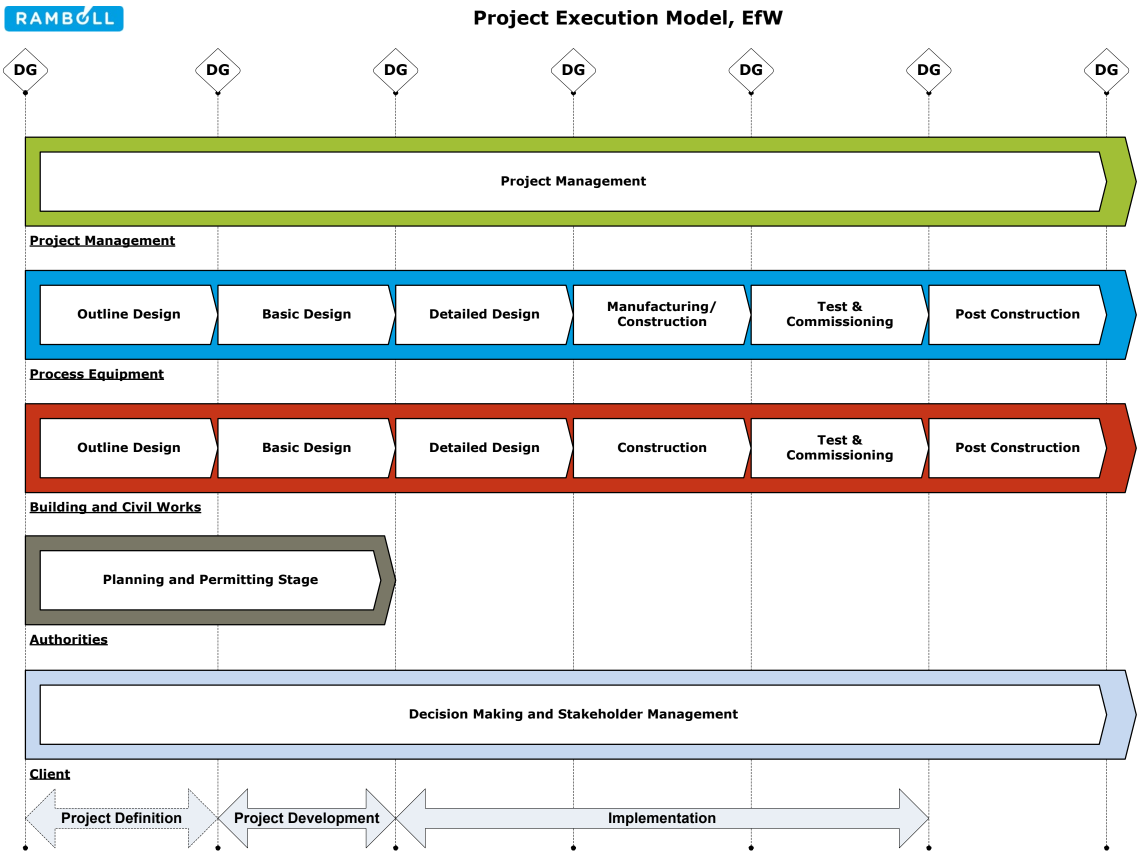


Figure 24 - Ramboll Project Execution Model (DG=Decision Gate)

As indicated in the figure above there are five overall areas/workflows (rows) which need to be addressed by the owner/operator of a WtE:

1. Overall Project Management
2. Technical management and supervision of the Waste to Energy process plant (M&E)
3. Technical management and supervision of the Building and Civil Works
4. Management of the relevant Authorities (Planning Permission)
5. Stakeholder Management

Moreover, the project is divided into project phases (columns) each with a distinct purpose and set of deliverables, and each completed with a Decision Gate (continue/re-assess/stop project).

We note that the current pre-feasibility study forms part of the Project Definition Phase. In the following sections we have described the various phases and the activities that go into them.

5.2 Project Development – Basic Design

Objective	Overall the objective of this phase is to develop a contract ready to be signed by the Client and the Contractor – Financial Close Develop Employer's Requirements for the O&M Contract. Develop an Operation and Maintenance contract ready to be signed by the Client and O&M Co.
Activities	• Layout review and development • Develop Employer's Requirements (M&E Schedules). • Develop and send out Tender Material • Receive proposals from selected suppliers • Evaluation of proposals (technical and commercial) • Contract negotiations • Contract signing • Employers Requirements, O&M Contract
Duration	We expect that this phase will be 7-8 months

The layout of the building shall be discussed and agreed between the Civil Contractor and the M&E Contractor in order to secure optimal arrangement of equipment with focus on future operation and maintenance of the facility. An important example is that sufficient room for manoeuvring and bringing equipment and spare parts in and out during maintenance as well as dust limiting provisions are often neglected during the design and will later be annoying and time consuming for the operation and maintenance staff.

The M&E Employers Requirements are a set of documents outlining the Client's requirements and serve as key documents in the M&E Tender Documents and the Contract. Based on experience derived from many WtE projects, we know the importance of the Employers Requirements comprising a combination of output based key performance requirements, and the detailed specifications required to ensure the long term performance and operability of the plant. The output based specification drives the Contractor to comply through his own good design, and yet the detailed specifications within key areas ensure that the contractor does not *cut corners* in his design that affect the (long term) performance of the facility.

Once the Tender Documents have been finalised and sent out, the potential Contractor(s) should have sufficient time to prepare the proposal. Once received, the proposal(s) shall be evaluated against the Tender Documents. The objectives of the evaluation include checking the critical aspects of the proposal against the Employers Requirements and an assessment of the suitability of the design to meet Clients (/Northern Village's) requirements, the agreed outline design and good industry practice.
It should be expected that the Contractor will submit a list of all proposed changes and deviations to the Employers Requirements, which also needs to be assessed.

After this, the negotiations with the Contractor(s) can begin. A series of short intense negotiations should be expected.

The final Contract shall include commercial conditions, technical specification (Employers Requirements) and the Contractors offer.

In this phase the Employers Requirements for the O&M Contract shall also be developed. The idea behind the requirements follow the same process as for the M&E Employers Requirements.

5.3 Project Implementation – Detailed Design

Objective	Supervise the project with a view to ensuring that the facility is established on time, on quality and on budget in accordance with the signed contracts. During this phase the objective is to ensure that designs are developed which ensures this objective.
Activities	• Final Layout • Review Detailed Design • Review Work Procedures • Review, Request for payments and changes • Risk Assessment/"What if" Hazard Analysis
Duration	Approx. 6 months (overlapping Manufacturing and Construction phase)

Shortly after signing of the contract, the Client and the Contractor must agree on the final layout. Typically, this is done through a series of workshops, collecting and combining the overall layout-requirements from all parties resulting in a design freeze. This will enable the final design of the civil structure.

A technical review and commenting on the detailed design and procurement specifications completed by the EPC Co shall be carried out. The purpose of the review is to endorse that the project has been engineered and procured in accordance with the Employers Requirements and the terms set out in the contract.

The Contractor shall conduct a Risk Assessment / "What-if" Hazard analysis of the facility. The purpose of the analysis is to provide a structured review of the process and auxiliary systems, interfaces between the systems, as well as a review of the associated control, monitoring and safety systems. The primary focus of the analysis is the operability and availability of the facility, as well as health and safety of personnel, environmental performance, and asset values, all related to the facility operation. However, the legal and contractual requirements relating to risk management rest with the Contractor, and each shall undertake and update as appropriate its own risk analysis, to meet the requirements of, inter alia, the Machine, Low voltage, EMC, ATEX and other EC/ASME and Canadian directives.

5.4 Project Implementation – Manufacturing and Construction

Objective	Inspections to verify that Manufacturing and Construction by the Contractor are in accordance with the intensions in the Contract. To make the facility ready for Testing and Commissioning

Activities	• Inspections
	    ○ Workshop inspections
	    ○ Site inspections
	    ○ Quality Management (documentation)
	    ○ Mechanical Completion

Duration	Approx. 12-18 months (overlapping Detailed Design phase and depending on delivery of the components)

Following the finalized Detailed Design by the Contractor, the Manufacturing and Construction phase commences. This phase comprises the manufacturing of components/systems by sub-contractors/vendors and the execution and construction on site. During this phase inspections should be performed to ensure the Contractor and sub-contractors/vendors are fulfilling the requirements and intention of the contracts, ensuring the various systems are ready for mechanical completion and, following this, commencement of Tests & Commissioning.

The extend of the review and inspections are for the Client to decide. Where possible we recommend that future O&M Contractor staff participates in the inspection, to gain first-hand knowledge of the relevant parts of the facility.

The time schedule takes into account that Kuujjuaq is only accessible by boat from July to October.

Workshop inspections will be carried out during Factory Acceptance Tests (FAT) at the vendors' factories. The basis for the inspection will be approved FAT-inspection plans provided by the Contractor.

Site inspections during the construction phase can be conducted as regular *spot checks* focusing on components that are critical to the execution of construction and/or operation of the facility.

The Contractor's planned Quality Management-activities will have to be reviewed and approved prior to commencement of the manufacturing and construction. It is essential to stress that the Contractor is obliged to perform thorough Quality Checks <u>and</u> supervision of their sub-contractors/vendors.

For each group of equipment/system the control of Mechanical Completion is carried out and checked against the relevant drawings and Process & Instrumentation Diagrams (P&IDs) through line walks etc. A mechanical completion report is submitted by the Contractor to certify mechanical completion before going forward to Cold Test.

5.5 Project Implementation – Test and Commissioning

Objective	Verifying that the plant is in stable operation and ready for Take Over. Take Over of the plant by Client.
Activities	• Cold tests • Hot tests • Trial Operation and Performance/Guarantee Test • Take Over • Guarantee Period
Duration	Approx. 2-3 months (+ guarantee period)

Following the finalized construction by the Contractor, the test and commissioning phase commences. This phase comprises the testing of components/systems and the commissioning of the facility performed by the Contractor.
During this phase we recommend performing inspections to ensure the Contractor is fulfilling the requirements and intention of the contracts, ensuring the various systems are fully functional and in stable operation, and being able to fulfil the guarantee requirements and Employers Requirements.
Where possible we recommend that future O&M staff to participate in the inspections, to gain first-hand knowledge of the relevant parts of the facility.

For each group of equipment/system a cold test shall be carried out without media in the equipment. During this stage power is connected and the principal function of the equipment/group is checked against the design. A Cold Test Report is submitted by the Contractor to certify the Cold Test before moving forward to Hot Test.

During Hot Test the facility operates on waste and for each group of equipment a Hot Test is carried out. The function of the equipment group is checked against the functional description and it is determined if the equipment functions as planned. A Hot Test Report is provided by the Contractor to certify that Hot Test is completed. When all equipment/groups are certified the Trial Run and Performance Test can be initiated.

After completion of the Hot Test the Trial Run/Performance Test will be conducted. The duration of the Trial Run/Performance Test will depend on the specifications stated in the Contract. Typically, we recommend six weeks Trial Run for a facility of this size. During this Trial Run a Performance Test shall be carried out by the Contractor and where required monitored by a 3rd party independent certifier.

When the Trial Run has been successfully completed the facility is taken over and the Guarantee Period is initiated, normally with a duration of 2 years.

5.6 The overall time schedule

The schedule for implementing a WtE facility in Kuujjuaq is based on the information in the sections above. The figure below shows the suggested time line for the project. The time line and the accompanying Gantt Chart can be found in Appendix 5.

Figure 25 - Suggested overall time schedule (time line)

Notes: Delivery (by boat) is only allowed from July – mid October. Construction is only scheduled from April – November.

The schedule suggests that the WtE plant and DH network could be ready to supply heat to the first consumers in early 2022, provided that the project moves ahead without substantial hold up.

Ramboll recommends that the Client receives technical input on the civil schedule in order to account for specific knowledge on local conditions.

Scheduled time for District Heating is also indicative and should be confirmed at a later stage of the project.

6. DIFFERENT FORMS OF TENDERING

When procuring a WtE facility several ways for tendering can be adopted each with varying degrees of responsibility being placed on the Client and the Contractor.
In terms of time scheduling it will make little difference, provided that the Client has a suitable organisation.

In the following, two options will be discussed:

- Tendering can be done as a turn-key supply including all electrical/mechanical equipment and all civil works; or
- The plant can be purchased in separate lots and be coordinated by the Client.

6.1 Turn key

The turn key solution is often preferred by Clients that are reluctant to accept responsibility and risks for part of the project delivery. A contract is signed with one Contractor (EPC Co) only and this EPC Contractor will then have to manage the entire process for M&E, Civil and Planning Permissions etc. incl. all interfaces. This obviously places a larger risk on the EPC Contractor which leads to a higher overall price for a turn key contract.

This approach requires less resources from the client's organisation (incl. owners engineer) but also provides less influence and control.

6.2 LOT based

A LOT based approach of buying and managing the project delivery is often preferred by Clients willing to accept more responsibility and part of the risk. This will lead to lower overall project costs as each Contractor will deliver what they do best and leave the coordination of interfaces etc. to the Client. As the Client is one step closer to each Contractor this method of tendering usually provides the Client with more insight into the facility and a cheaper plant.

This approach requires more resources from the client's organisation (incl. owners engineer) but also provide more influence and control.

Generally, it is Ramboll's experience that it is important to tender out a WtE facility based on clear technical requirements as well as well-defined commercial conditions as it is hereby possible to avoid unforeseen extra costs during implementation, and conflicts with the supplier can be avoided, regardless of which model that will be adopted.
Both models are valid and recommendable depending on the capabilities of the client organisation and the risk willingness.

7. CONCLUSION

Ramboll have been appointed by the SPN to assess whether or not a Waste to Energy Plant with a positive energy output is feasible for the village of Kuujjuaq.

A Fact Finding Mission was conducted and various sites and buildings were visited in Kuujjuaq and Ramboll spoke to a number of key people and organisations in Kuujjuaq. On top of this the SPN has been able to supply Ramboll with a range of additional documents including waste characteristics, drawings of Kuujjuaq and previous studies.
Kuujjuaq resembles similar villages in the Arctic region facing harsh weather conditions and challenges in retaining skilled workforce. Experiences from Greenland dictates that technologies implemented in these regions shall be robust and easy to operate.

The prefeasibility study has found that a WtE facility with a positive energy output is a good way for Kuujjuaq to treat their waste and recover energy from the process. In Arctic regions utilising the energy for heat production is deemed the best course of action. By implementing a District Heating network, that can transmit the heat from the WtE facility to the consumers, large amounts of arctic diesel (and corresponding CO_2 emissions) can be saved each year.

Ramboll have performed a study of various ways to thermally treat the waste in Kuujjuaq and have found that a continuously operated waste incinerator is the preferred option based on the waste amounts and characteristics. A continuously operated waste incinerator is the same technology which has been employed on Greenland with great success. The plant shall be fitted with a boiler to recover the heat from the combustion and a flue gas treatment system to lower the emissions and conform to the Province of Quebec's emission regulations.

Compared to the current method of open burn the new plant will dramatically reduce the emissions from burning waste and return a positive energy output by providing heat for several of the largest buildings in Kuujjuaq.

Used oil and used tires can be safely treated in the WtE facility providing extra heat for the District Heating network, although the regulation does not currently allow for incineration of these fuels in a municipal solid waste incinerator.

The nominal load point for the WtE facility shall be finally decided in the design stage and shall be based on the future expectations for waste levels and operational philosophy.

It is recommended to start up a separate project on the District Heating network as the scope falls outside this report. However, from the initial studies performed in the report it is clear that the potential savings (both economic and environmentally) are substantial but more importantly that there are significant benefits in extending the network to include the residual heat found at the Hydro Quebec Power Station and consumers in the rest of the city. There is potentially enough heat produced by the WtE and Hydro Quebec Power Station to heat 60% or more of the buildings in all of Kuujjuaq. The savings in Arctic Fuel are noteworthy, and the implementation of a district heating network will pay for itself quickly. Experience from Greenland suggests that the payback period is between 5-10 years.

The CAPEX for a WtE facility (M&E) will be around 5,6 – 6,100,000 CAD including services for an owner's engineer and 30% contingency.
The OPEX for operating the facility will be around 825,000 CAD per year covering manpower, maintenance, consumables and treatment of residues.

Income from heat sales can depending on the size of the network established cover from 70% up to all of the operational cost of the WtE plant.

No taxes are included in the estimates given on either CAPEX or OPEX.

Implementation of a WtE facility and DH network in Kuujjuaq requires careful planning as the Arctic climate in Kuujjuaq imposes restrictions on delivery and construction times. Ramboll have provided a suggested Time Schedule which indicates that the WtE plant and DH network could be ready to supply heat to the first consumers in early 2022, provided that the project moves ahead without substantial hold up.

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