Ontario Engineering Competition 2024

A.D.E.P.T.
Anaerobic Digestion and Ethanol Pulp Treatment

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Problem:

Rural Indigenous communities across Canada are facing severe energy poverty due to their lack of access to main power grids, along with the high cost of importing fuels, like diesel, into the community [1]. This inaccessibility results in very high energy costs for Indigenous families, in addition to susceptibility to power outages, which limits the growth and development opportunities for communities [2]. As this is a very widespread and important problem, there already exist a number of programs and solutions working to address the issue. These include things such as an Energy Affordability Program in Ontario, which works to provide homes with more energy efficient products [3], or a project in British Columbia that replaces expensive electric heaters with heat pumps in communities on-reserves [4]. While these programs are helping to address the issue, for the specific case of Ontario, the program fails to actually address the problem of inaccessibility and negative environmental impact of using fossil fuel and diesel as a sole energy source.

Approach:

The use of biofuels has been suggested as one of the best possible solutions for this problem due to two main reasons [5]. The first reason is its alignment with Indigenous values regarding the use of natural resources. Most, if not all, of the many Indigenous cultures across the country have core values that stem from a deep respect and appreciation for their environment, and is based around having a net neutral to net positive impact on their surrounding environment and resources [6]. The pollution created by diesel fuel obviously contradicts these values, while using biofuels is based on reusing what would otherwise be thrown away as waste. The second reason biofuels are an ideal solution is due to its local nature. While diesel fuel has to be imported from far away, driving up cost and leaving communities vulnerable to supply issues, the resources used for biofuels are sourced from directly in the community, eliminating the aforementioned issues.

Limitations:

With biofuels established as the preferred solution, the limitations regarding biofuels themselves must also be established. The main limitation with using biofuels is that they are much less efficient in terms of the amount of energy they produce per volume of fuel compared to other fuels such as diesel.

To completely replace the use of fossil fuels with biofuels in Indigenous communities would require either a massive amount of farmland to cultivate enough corn, or amounts of compost that are simply not attainable by the size of the community. As importing the compost from big cities that may have enough materials, that is not a local option. Thus, the biofuel that the community is able to produce must be offset with some fossil fuels. The specifics of how much fossil fuels, and how much the biofuels reduce the cost for families will be further analysed. Additionally, current furnaces that families in this community have cannot run off of 100% ethanol, so using only biofuel would require completely replacing everyone's furnaces, which is not entirely economically feasible in a short period of time.

An additional limitation to take into consideration is the acceptance from communities to go ahead with any possible solutions. While it is likely that they will be open to methods that are more environmentally friendly and reduce their costs, there is still a possibility that the solution does not

fully address social/cultural concerns, which could not be established without working with communities directly to find the best solution.

Proposal (High Level Design):

The proposed best solution to this problem is a two-stage process for some of the communities around Terrace Bay in Northern Ontario. The two main stages which will be implemented are anaerobic digestion and ethanol refinement. The solution will optimise the use of biomaterials and existing by-products to optimise the production of compounds that can be used in heating, an issue that is a specific problem in some Indigenous communities across Canada [4]. The process, as shown in Figure 1 will use food waste from within the community, along with waste from local paper mills, which is a large ecological pollutant in natural areas [7]. All of this biomass will be placed into anaerobic digesters which through the use of microbiological organisms will release methane gas and carbon rich bio-sludge [8]. The methane gas can then be sold, or used as a heat source for local homes [9].

The bio-sludge by-product is then used as the primary resource to be refined using a wet milling ethanol refinement process to create a biofuel ethanol. This is done by mixing the bio-sludge with yeast and enzymes and letting it sit (ferment) for approximately 48 hours, producing ethanol and carbon dioxide. From there, the mixture is heated to separate the ethanol and the remaining byproducts [10]. The biofuel ethanol will then be mixed with gasoline to create a 20% ethanol 80% gasoline mixture known as B20 [11], a mixture which is compatible with all current furnaces. By-products of ethanol refinement processes have been shown to be able to be recycled for practical uses in a variety of different applications [12], however as this is a third-level by-product, it will not be explained in further detail.

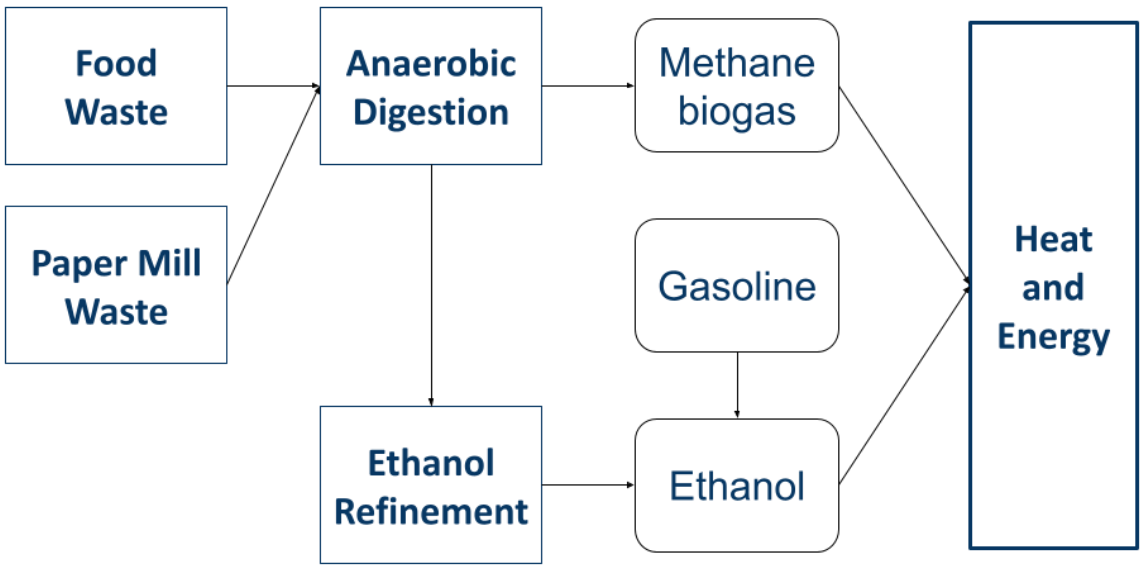

Figure 1: Visualisation of the waste management and biofuel generation system.

Detailed Design:

Anaerobic Digesters:

The first phase of the biofuel processing involves harvesting biogas from an anaerobic digester. Anaerobic digesters work by following a four successive step process the steps are as follows [13]:

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis
4. Methanogenesis

The first step that occurs within an anaerobic digester is the hydrolysis process during this step a set of microorganisms breaks down large compounds into smaller molecules (carbohydrates, proteins and lipids). The second main process is acidogenesis, in this process the smaller molecules are further broken down into base molecules like amino acids, sugar and long fatty acids. The third step is acetogenesis during this step the final unsuitable products are made viable for the final step of methanogenesis. The final step, involves creating methane with the decomposed by-product being turned into methane thanks to micro-organisms like *Methanococcus voltae* and *Methanococcus vannielli*, both of which die in the presence of oxygen, hence the need for an "anaerobic" digester [13]. These four processes all occur in all types of anaerobic digesters and can be shown in a simplified diagram in figure 2. For this specific design a plug digester was selected as they can be attempted to accommodate multiple different types of waste (i.e. food waste, a paper mill waste) [14]. A plug digester can accommodate up to 20% solid material making it suitable for the waste that needs to be treated. The digester contains a mass of microorganisms that allow for the four key processes to take place, with a plug digester the amount of biomass added to the digester directly correlates to the biogas output from the system [15].

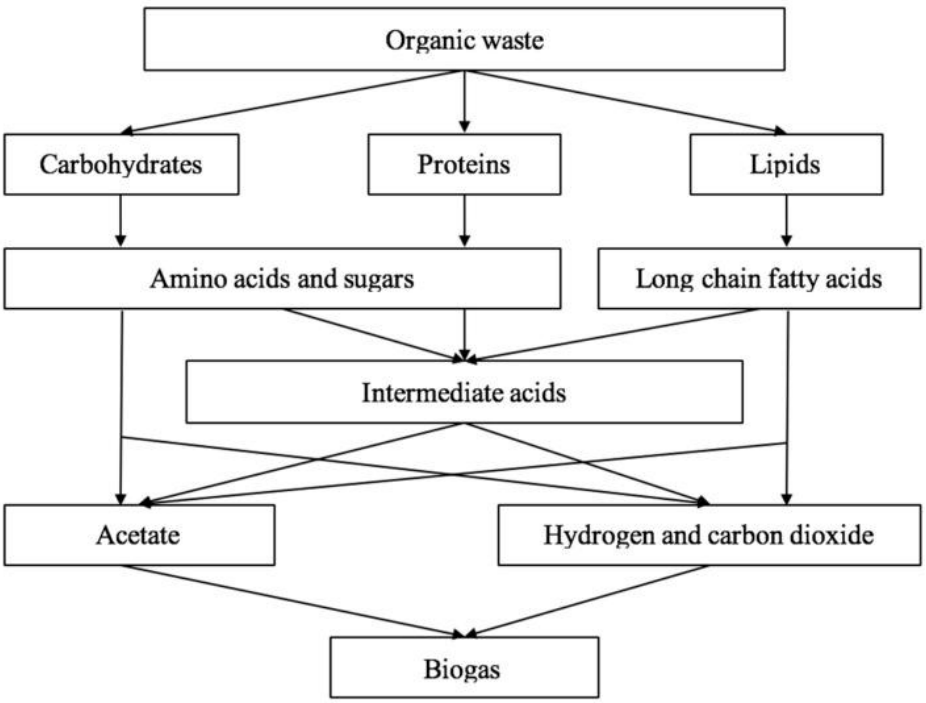

Figure 2: Simplified main steps of anaerobic digestion [13].

Ethanol Refinement:

There are two main types of ethanol refinement: dry mill ethanol processing, and wet mill ethanol processing [16]. The wet mill method will be used as the product from anaerobic digestion is a wet-like sludge (carbon digestate). The ethanol refinement process was first designed by refining bushels of corn (corn stover), however, it has also been shown that anaerobic digestate can be used in replacement of corn bushels. It has half the hemicellulose content compared to corn stover, which reduces the amount of pentose that is fermented, which is beneficial to the overall process. Anaerobic digestate that has been pre-treated at 130°C for three hours and has 2% sodium hydroxide (NaOH) was shown to have a conversion percentage of 80.3% ± 3.2, compared to 78.0% ± 2.1 of corn stover [17]. The mixture is then mixed with some more enzymes and yeast, and let sit for around 48 hours. This 48 hours is when the fermentation of the ethanol occurs, which is then collected afterwards by heating the mixture.

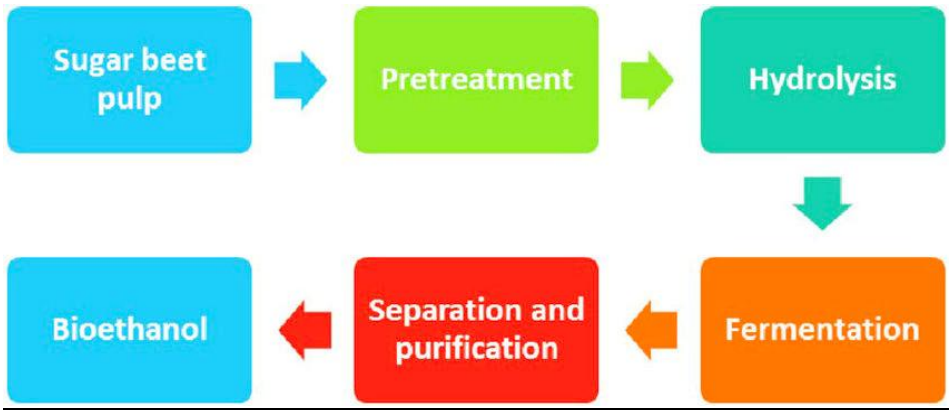

Figure 3: Process for ethanol refinement using sugar beet pulp.

Application of Biofuels:

The methane produced by the anaerobic digestion has multiple possible uses. Methane itself is only classified as a greenhouse gas when it is released into the atmosphere unburned, however when it is combusted it is one of the cleaner energy generation methods [18]. Because methane contains such high energy it is extremely effective as a heating gas, which provides two options for what to do with the produced methane. The first would be to sell it to energy generation companies and increase the reliability of surrounding energy plants. The second option would be to use it as fuel to satisfy local requirements such as fuel for certain furnaces, water heaters, stoves, barbecues and fireplaces as well [18].

The ethanol produced by the refinement process will be used in the community's furnaces as a cleaner and slightly cheaper source of heating [11]. The typical five person household uses roughly 150 GJ of energy per year [19]. This works out to roughly 3900 L of gasoline every year [20], when 20% of that gasoline is replaced with ethanol, roughly 780 L of gasoline is saved per household per year. With the average cost of gasoline being ~$1.5 [21], this saves each family over $1,100 per year. Additionally,

B20 does not require any furnace modification as most North American furnaces are compatible with the fuel, and it has even been shown to decrease the required service of some furnaces [22].

Logistics:

The location and construction/refurbishment of anaerobic digesters and ethanol refineries can be approached in two ways; depending on the system's location. The proposed location for this specific project is Terrace Bay, Ontario [23], which is within an hour of both Pays Plat First Nations and Biigtigong Nishnaabeg (Ojibways of the Pic River First Nation) communities [24]. This location was chosen due to the existing mill that can be refurbished into the ethanol refinery, which will then have the anaerobic digester built beside it. The towns close proximity to two different Indigenou communities ensures that the whole process remains local and small scale.

The whole process will be run by garbage trucks transporting compost from the communities to the plant in Terrace Bay, where the materials will be dropped off to be processed, with tank trucks then returning the final product back to the communities.

Cost Analysis:

There are some overhead costs that need to be considered when setting up the initial plants and systems. In total they work out to be roughly 1,800,000 USD. There are also associated running costs for the operation, they however are not as significant as they amount to less than 250,000 USD a month on operational costs. Based on current Ontario government funding there should be sufficient funds to initiate this project as Indigenous communities have been given close to 15 million CAD in the past year towards energy initiatives [25].

Table 1: Set Up and Running Costs

Set-Up Costs	
Item	Cost
Anaerobic digester construction - Includes microorganisms	roughly 1,200,00 USD [26]
Small scale ethanol refinery plant refurbishment - (~200 homes, 156,000 Gal of ethanol)	roughly 400,000 USD [19], [27]
Operational Costs	
Item	Cost
Anaerobic digester costs	180,000 to 300,000 USD per year [28]
Ethanol refinement costs	0.50 to 0.60 USD per gallon of ethanol [29]

Material transportation	4-5 USD per mile [30]

Conclusion:

To conclude, the proposed solution allows for the generation of energy via both anaerobic digestion and ethanol refinement. Food waste will be sourced from Indigenous communities, and will be anaerobically digested. The methane produced by this will be either sold to power companies as a source of income for the community, or used to power stoves, barbecues, etc. The carbon digestate produced by the anaerobic digestion will then go through an ethanol refinement process, which will produce a biofuel that is used primarily to heat homes. This system also provides an opportunity to connect industry to Indigenous communities, allowing for collaborative growth and projects.

Next steps for this system include integrating better furnaces that are compatible with 100% ethanol. It is also likely that biofuel technology will continue to improve with more research and technological developments, thus reducing/eliminating the amount of fossil fuels used, along with reducing the cost of producing fossil fuels.

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