Integrating a Cogeneration System in Food Process Manufacturing

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Abstract

The goal of the project is to determine the benefits and drawbacks of implementing a combined heat and power (CHP) unit in a food processing plant. CHP system is an integrated energy system that produces electrical and thermal energy from a single fuel source. Different CHP technologies and vendors available were identified. The studied CHP technologies included steam and gas turbines, micro-turbines, reciprocating engines, and fuel cells. Of these technologies a 400 kW range reciprocating engine was deemed optimal due to physical size constraints, voltage output requirements (600 VAC), and costs. The plant's thermally intensive units were studied at the tunnel heating system and the boiler unit system as potential places to recover the waste heat. Simulations of these two units were conducted with based case and each of the three vendor specified CHP units. Based on the data, it was found that the optimal recovery process is the boiler unit system that provides a higher increase in temperature and mitigates the risk of potential errors in calculations. Rigorous economic analyses show the payback period of the CHP unit to be 2 years and 1 month. Furthermore, there is no significant increase in GHG emissions through the implementation of the CHP unit and potential hazardous noise exposure can be mitigated through a sound attenuated enclosure.

Keywords

Cogeneration system, food processing, greenhouse gas, economic analysis.

1. Introduction

1.1 Problem & Opportunity

Nitta Gelatin Canada (NGC) Inc. wants to reduce their electrical power dependence from the public grid, and is interested in a combined heat and power (CHP) system as an alternative solution. NGC is a manufacturing plant located in Toronto that operates 24/7, and therefore reliable source of electrical power is critical. It is also committed to making continuous improvements to protect the environment through product and process innovation. NGC must tackle the concerns of growing electricity rates, service interruptions, and climate change in order to maintain a sustainable and competitive business. Enbridge Gas Distribution (EGD) Inc. is a natural gas distributor, and offers services for demand-side management initiatives to help their customers (which include NGC) adopt energy-saving equipment. Here, there is an opportunity to collaborate with both stakeholders to design a natural gas-fired cogeneration system to provide a more reliable, cost effective, and greener solution.

1.2 Goals & Objectives

The overall goal of the study is to conduct a qualification and feasibility analysis for the development of a CHP system which includes determining whether the facility is a good candidate for a CHP system, identifying potential barriers, quantifying technical and economic opportunities, and optimizing a CHP system design. The specific objectives of the project as per request from NGC include:

- CHP technologies must be screened and turnkey packages from various vendors must be evaluated to determine a final recommendation.
- Potential uses of waste heat from CHP must be identified.

1.3 Constraints

NGC posed the following constraints on the CHP system and design:

- CHP unit must be natural gas driven and rated 400 kW, 60 Hz, 600 VAC.
- Fit within 6.7 m x 3.0 m x 2.5 m (L x W x H) allocated space in the electrical panel room (adjacent to 3 phase transformer).

1.4 Success Criteria

The success of the project will be evaluated against the following basis:

- CHP unit must meet electrical equipment specifications and size constraint.
- CHP system must achieve overall energy efficiency of greater than 80%.
- CHP design and operation is in compliance with Ontario's Environmental Protection Act, Occupational Health and Safety Act etc.
- Capital project must be proven economically feasible and offer cost savings.
- CHP system should provide environmental benefits (such as reduction in air pollutant emissions).

2. Methodology

In order to achieve the project goals and objectives, the following steps were taken to complete the CHP design for Nitta Gelatin:

- CHP System Qualification: The goal here is to determine if there is technical and economic potential such that CHP system is worth considering at NGC.
- Literature Review: Various CHP technologies and CHP unit suppliers will be investigated to determine suitable CHP unit for recommendation.
- Heat Recovery Options: The potential uses of the recovered heat will be identified and simulated to quantify technical opportunities at NGC.
- Economic Analysis: The economic potential of implementing CHP system will be evaluated to determine its feasibility and to quantify cost benefits.
- Environment, Health & Safety Assessment: The environmental impact will be quantified and potential health and safety concerns of the CHP design will be addressed.
- Optimization of Design Parameters: The results from the previous steps will be analyzed to design an optimal CHP system for NGC.

The following engineering tools were used for the analysis:

- Aspen Plus will be used to validate the plant's current process and model the heat recovery options.
- MATLAB and Microsoft Excel will be used for the economic and feasibility analysis.
- GHGenius software will be used to estimate air pollutant emissions.

3. Background

3.1 Nitta Gelatin Canada Inc.

Nitta Gelatin is a gelatin manufacturing plant composed of energy intensive units for raw material processing and final product manufacturing. In 2012, NGC purchased 60.72 GWh of energy of which 13% from electricity and 87% from natural gas sources. It is equivalent to over \$1.8 million in annual utility costs and over 5 million cubic meters of natural gas purchased at \$0.25/m^3 (or \$0.024/kWh) and about 7.9 million kWh of electrical power purchased at \$0.07/kWh. It can be seen that natural gas is almost 3 times cheaper than electricity (on a per unit of energy basis) and as such the possible opportunity to utilize energy more efficiently and shift the energy source even more towards natural gas that significant cost savings are easily realized.

3.2 CHP Technology

Combined heat and power (CHP) systems is an integrated energy system that produces electrical and thermal energy from a single fuel source. The purpose of CHP systems are to harness the excess heat generated by an electrical generator and utilize it elsewhere in a productive manner in another part of the plant. Therefore, CHP systems can achieve overall efficiency of greater than 80% with combined electrical (ranges from 22-40%) and thermal efficiencies (remaining %) (U.S. EPA Combined Heat and Power Partnership, 2008). CHP units are similar to traditional electric generators in utilizing fossil fuels to generate electrical energy. In traditional steam electrical generation systems, water is heated and converted to steam. This steam is then used to rotate a turbine that converts the mechanical energy into useable electrical energy (Figure 1).

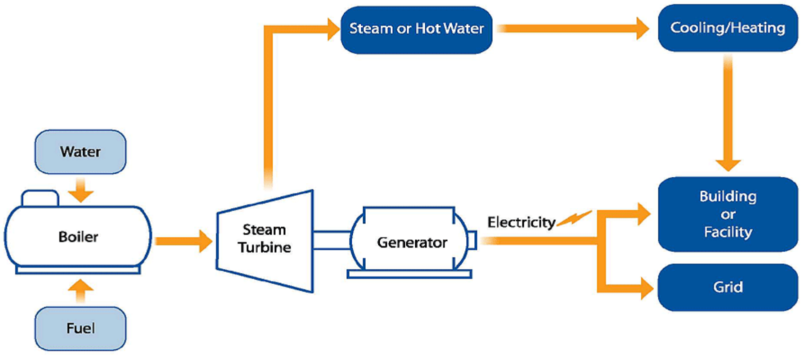


Figure 1: Traditional steam and electrical generating system.

CHP technologies include gas turbines, steam turbines, microturbines, reciprocating engines, and fuel cells. The most common being either the gas turbine (or engine) with heat recovery unit or steam boiler and turbine (U.S. EPA Combined Heat and Power Partnership 2008).

3.3 Benefits of CHP

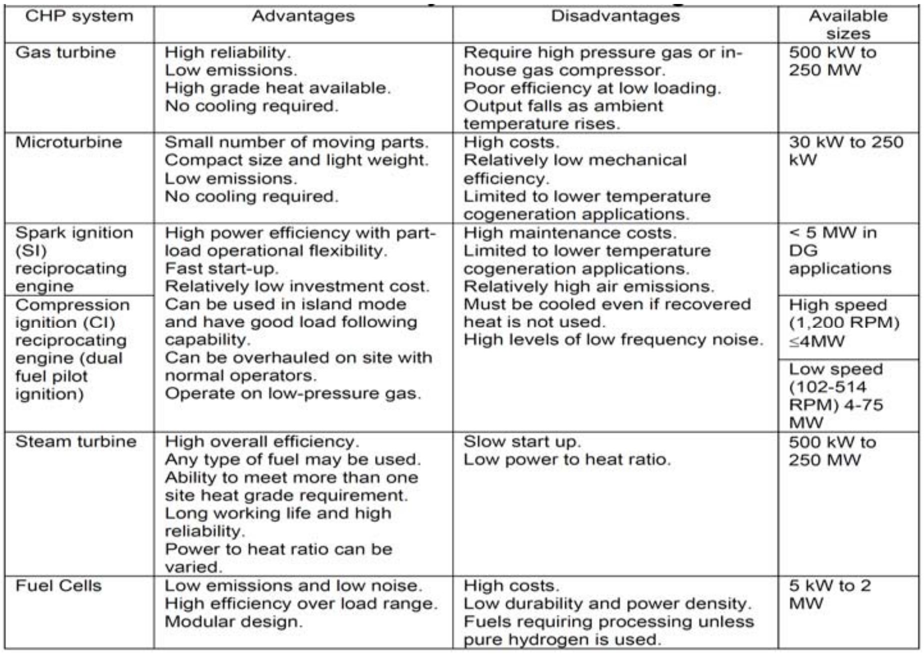
CHP systems offer significant efficiency, reliability, environmental and economic benefits which include but not limited to the following (U.S. EPA Combined Heat and Power Partnership 2008):

- More energy efficient, and avoids transmission and distribution (T&D) losses
- Provides high quality power that is less susceptible to power outages
- Reduces greenhouse gas emissions
- Results in significant utility savings and can provide a hedge against unstable energy costs

4. Selection of CHP Technology

The cost, size and performance of CHP technologies were investigated to determine the most suitable unit for Nitta Gelatin's purpose (as shown in Table 1).

Table 1: Summary of CHP Technologies.



CHP system	Advantages	Disadvantages	Available sizes
Gas turbine	High reliability. Low emissions. High grade heat available. No cooling required.	Require high pressure gas or in-house gas compressor. Poor efficiency at low loading. Output falls as ambient temperature rises.	500 kW to 250 MW
Microturbine	Small number of moving parts. Compact size and light weight. Low emissions. No cooling required.	High costs. Relatively low mechanical efficiency. Limited to lower temperature cogeneration applications.	30 kW to 250 kW
Spark ignition (SI) reciprocating engine	High power efficiency with part-load operational flexibility. Fast start-up. Relatively low investment cost. Can be used in island mode and have good load following capability. Can be overhauled on site with normal operators. Operate on low-pressure gas.	High maintenance costs. Limited to lower temperature cogeneration applications. Relatively high air emissions. Must be cooled even if recovered heat is not used. High levels of low frequency noise.	< 5 MW in DG applications
Compression ignition (CI) reciprocating engine (dual fuel pilot ignition)			High speed (1,200 RPM) ≤4MW Low speed (102-514 RPM) 4-75 MW
Steam turbine	High overall efficiency. Any type of fuel may be used. Ability to meet more than one site heat grade requirement. Long working life and high reliability. Power to heat ratio can be varied.	Slow start up. Low power to heat ratio.	500 kW to 250 MW
Fuel Cells	Low emissions and low noise. High efficiency over load range. Modular design.	High costs. Low durability and power density. Fuels requiring processing unless pure hydrogen is used.	5 kW to 2 MW

Keeping in mind the fuel source, electrical specifications and size constraints, the reciprocating engine was selected to be the optimal choice. Reciprocating engines also offers high power-to-heat ratio, requires lower investment cost, and can operate on low pressure gas that makes it ideal for NGC's application. Other CHP technologies that include gas turbines, steam turbines, microturbines, and fuel cells were rejected for the following reasons:

- Gas and steam turbines too large in size and limited to higher capacities of greater than 500 kW.
- Microturbines and fuel cells require module set up (with multiple units) and are unable to reach 600 VAC rating without a step up transformer (more expensive).
- Microturbines require a compressor which adds to the cost.

4.1 CHP Vendor Comparison

NGC requested to look into CHP suppliers and existing turnkey packages available for purchasing in the local area. Three companies, namely Caterpillar Inc, EPS Energy and Wajaks Power Systems, provide CHP units that meet the electrical specification and size constraints (as shown in Table 2). Based on the specifications given, the Wajax MTU-GC358N6 module was selected as the optimal choice as it met the size constraints even with the added sound attenuated enclosure (for conservative measure).

Table 2: CHP turnkeys package comparison.

Distributer	**Caterpillar Inc.**	**EPS Energy**	**Wajax Power Systems**
Manufacturer and Model	**CG132-08 CHP**	**2G-CHP-380NG**	**MTU-GC358N6**
CHP Unit Properties	**Values**	**Values**	**Values**
Voltage Output (VAC)	600	600	600
Electric Power Output (kW)	400	380	358
Thermal Output (kW)	447	508	535
Exhaust Heated Water Temp. (˚C)	92	94	90
Natural Gas Input (kW)	970	1009	981
Heat to Power Ratio	1.12	1.33	1.49
Size (L x W x H) (inches) **Constraint: 6.7 x 3.0 x 2.5**	Generator: 3.1x1.5x2.2 Enclosure: 6.0x2.6x3.2	Generator: 4.0x1.5x2.3 Enclosure: 9x3.0x3.0	Generator: 3.8x1.8x2.3 Enclosure: 6.1x3.7x2.4

Unit Cost Quote	Base Unit: $580,085 Add SA Enclosure: $144,985 Add SCR Unit: $138,145 (TBD)	Base Unit : $370,000 Add SA Enclosure: $88,000 Add SCR Unit: $102,000 (Hug Engineering AG)	Base Unit: $323,453 Add SA Enclosure: $60,000 Add SCR Unit: $90,000 (ecoCUBE)
Shipping Cost to NGC Facility (Toronto)	Included in base cost ($20,000)	Included in base cost	Included in base cost
Installation & Commissioning Costs	Included in base cost ($60,000)	Included in base cost	TBD
Total Cost	$580,085 – $863215	$458,000 – $560,000	$323,453.00 – $490,253
Manufacturing Location	Lafeyette, Indiana, USA	Orange Park, Florida, USA	Augsburg, Germany
Lead Time (weeks)	24	16 to 24 (ARO)	TBD
Additional Comments			• SCR unit will require clean dry air at 10 SCFM at 80-100 psi supplied by a 5HP air compressor ($16,800)

5. Unit Selection and Aspen Modeling

Several processes in the NGC plant require the use of heat transfer as a fundamental element in their process. These include the centrifuge heating system, the acid dosing system, the evaporation process unit, the tunnel heating system, and the boiler units. Of these available unit operations, only the tunnel heating system (THS) and the boiler units are continuous processes with the others being batch or semi-batch operations. Therefore these two continuous processes were chosen to study waste heat recovery. In order to determine the optimal placement of the two waste heat recovery options, four sets of simulations were created using Aspen Plus software in order to determine the reduction in heat duty on the respective heat sources between the THS (Tunnel Heating System) and the boiler system by adding the CHP system. The city water inlet stream varies with the season and is an average of 2°C in the winter and an average of 10°C in the summer. To account for this difference, a winter and summer simulation were made for the base cases for each process as well as for the cases including the CHP unit.

5.1 Aspen Model Creation and Rationale

Aspen models was created for both the THS and the boiler unit system. Separate models were created to mimic the winter and summer conditions in the base and three CHP cases of each vendor's CHP units were used to compare units and processes. There are three property methods suitable for only water and steam such as in both the boiler unit system and the THS. They are STEAM-TA, STEAMNBS/STMNBS2 and IAPWS-95. Each of these uses different steam tables to calculate water and steam properties. The IAPWS-95 property method utilizes the most recently available steam tables (circa 1995) and is the current standard from the International Association for the Properties of Water and Steam (Aspen Technology Inc. 2010). This model covers temperature ranges from 251.2K to 1273K and is deemed to be the most accurate of the three models by Aspen. For this reason the IAPWS-95 property model was chosen for the modeling of the two processes. If not given all pressures were assumed to be 1 atm. The heat transfer fouling factor was set to 1 for all heat exchangers.

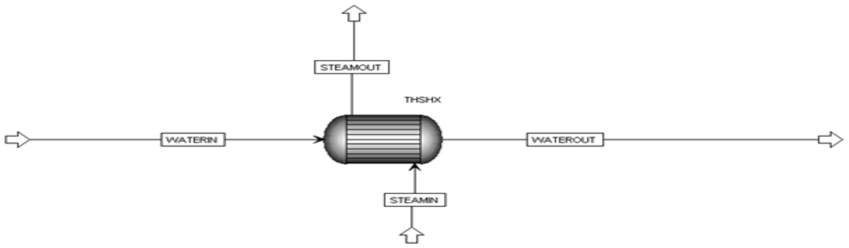
5.2 Tunnel Heating System

Since the objective of the simulation was to evaluate the heat load required by the process by examining the heat duty of the steam-water heat exchange operation in the process, the process model was simplified to focus directly on this part of the process. Since the drying process requires that water exit the system's heat exchanger (tube side) at a temperature of 87.7 °C and the air heating part of the process cools this water stream to 74.4 °C, modeling the air heating part of the process along with the water heating part of the process was necessary. Figure 2a) below shows a PFD of the base case simulation.

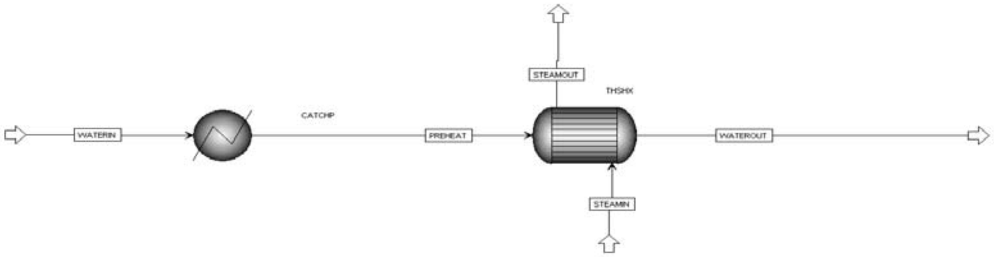
The "WATERIN" stream was set to enter the exchanger at temperature and pressure conditions of 74.4 °C and 1 atm and a mass flow rate of 21.866 kg/s (75.24 m^3/hr). The "STEAMIN" stream was set to enter the exchanger at temperature and pressure conditions of 110 °C and 1 atm and a mass flow rate of 0.516 kg/s as calculated. Aspen Plus' solver was set to simulate the heat exchange properties and process conditions by which the "WATEROUT" stream of the exchanger would reach the required 87.7 °C.

A simulation was built with one of the CHP units being considered for this study integrated into the Tunnel Heating System in this example: the Wajax CHP unit. The simulation places emphasis on the ability of the CHP to recover waste heat from its generator’s operation, and then used to preheat the water being pumped from the storage tank to the tube side of the heat exchanger. Therefore, the CHP unit was integrated into the THS simulation as a preheater for the water feed to the system’s heat exchanger’s tube side. The integrated system simulation can be seen in Figure 2b).

From the Wajax unit’s technical specifications it was determined that the CHP’s recoverable waste heat was approximately 535 kW. So, along with the process conditions implemented in the base case, this heat duty was specified as that used to preheat the “WATERIN” stream. Aspen Plus’ solver was set to simulate the heat exchange properties and process conditions by which the “WATERIN” stream was first preheated by the CHP’s exhaust heat prior to entering the system’s exchanger. The key properties that were to be assessed from the simulation results were what temperature the water was preheated to by the CHP and the consequential lowering of the heat duty between the steam-water heat exchange processes to reach the required 87.7 °C due to the higher water inlet temperature to the system’s exchanger. The temperature of the “PREHEAT” stream in this case was raised to 79°C and the difference in heat duty around the cross exchanger was, as expected, the 535 kW that was added by the CHP unit.



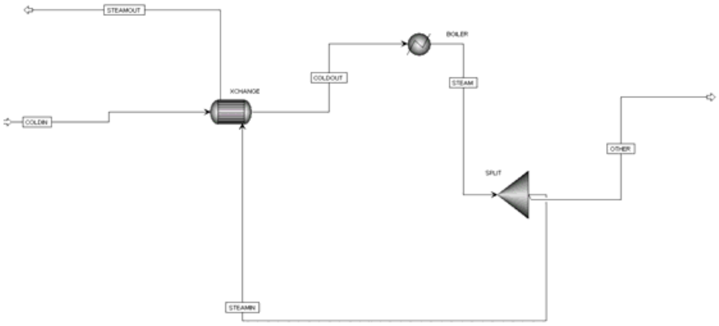
a) Tunnel heating system base case simulation PFD



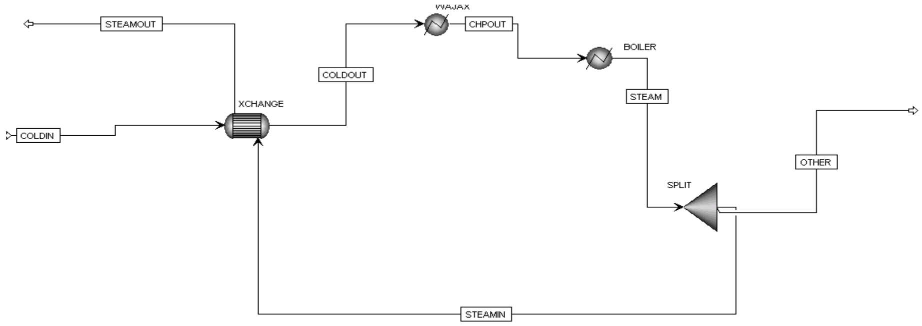
b) Tunnel heating system CHP case simulation PFD
Figure 2: Tunnel Heating System Simulation PFD

5.3 Boiler Unit System

Figure 3a) and Figure 3b) below show the simulations generated in Aspen for the boiler unit base case operation and the boiler unit with the addition of the CHP heat recovery:



a) Boiler unit system base case simulation PFD



b)Boiler unit system CHP case simulation PFD

Figure 3: Boiler unit system simulation PFD

The heat duties on the boiler units were determined in each case with the CHP unit represented by a single heat exchanger in the model. The heat duty for the CHP unit heater was provided in the vendor specification sheets for each particular model, and that for the Wajax model the thermal output is 535 kW which is equivalent to the reduction in the heat duty across the boiler unit. However, the temperature increases across the CHP unit from 30°C to around 95°C.

5.4 Selecting the Optimal Process

Because the reduction in heat duty across the respective heat exchangers is the same in each case, a different selection criterion was necessary. Both units are approximately 60 meters from the chosen location to install the CHP unit and any difference in terms of location is negligible. The amount of potential error in each model is then considered assuming a loss of 1°C in each case:

$$E_{THS} = \frac{1}{75-70} * 100\% = 20\% \tag{1}$$

$$E_{Boiler} = \frac{1}{95-30} * 100\% = 1.5\% \tag{2}$$

Where E_{THS} and E_{Boiler} represent the percent error in losing 1°C from the predicted result. From the error calculations, it is shown that a loss of 1°C from the THS will result in a 20% loss in efficiency of the process whereas the same 1°C loss in the boiler unit system will result in a 1.5% loss. Because of this *the boiler unit system is the preferred location to recover the waste heat.*

6. CHP System Design Feasibility and Economic Analysis

In order to be able to confidently recommend that the CHP unit be installed in the plant, the economic analysis should present/consider/include the following:

- Implementing the CHP will result in a reduction of operational costs associated with supplying the plant with electrical power.
- The total initial investment of the CHP will be recouped in a short period of time after the installation and commissioning of the unit (typically several years but not to exceed half of the operational life of the CHP). This investment should include all of the items listed in the CHP vendor comparison (see Table 1). The investment should also include the piping and pump costs associated with the heat recovery section of the CHP system.
- Variable electricity supply prices (from the grid) and variable natural gas prices should be considered over the operational life of the CHP to ensure that the CHP the most cost effective means by which to supply electrical power to the plant throughout that period of time.
- Maintenance and operational costs associated with ensuring reliable CHP operation should be taken into account.
- A return-on-investment calculation should be presented. A net present value (NPV) calculation should be included to show the present value of accumulated cost savings due to implementing a CHP in the plant over its operational life.
- The costs associated with implementing a CHP should be compared to the costs associated with implementing a generator over the operational life of the CHP/generator to ensure that the CHP is the most cost effective solution.

The most effective way to assess the feasibility of the three project options (retrofitting NGC's plant with a CHP, retrofitting the plant with a generator or choose neither option and continue to draw electrical power from the grid). The reason for this is because cumulative cost graphs allow one to visually interpret the total initial capital costs of all three project options, the cumulative operational and project costs over the operational life of a CHP/generator engine and the cumulative cost savings realized between all three options at the end of the CHP/generator's operational life. All the details analysis mentioned above was written in MATLAB. Table 3 summarizes the economics of the CHP and generator options for supplying the plant with electrical power where no government incentives are considered (Bank of Canada 2013; Fraser 2009). From the summary it can be seen that the cost savings accumulated by retrofitting an one of the CHPs into NGC's plant will result in comparable cost savings compared to the base case (approximately $3.8 million dollars). The justification for selecting the CHP unit over a standalone generator is best seen with the Wajax CHP unit, which shows the highest difference for cumulative cost savings between the two options. Both the simple payback and net present value numbers for the Wajax and EPS are very comparable while the Caterpillar CHPs high initial total capital cost makes it the lease attractive option out of the three CHPs as far as investment risk is concerned. In light of this analysis, and coupled with the fact that the Wajax CHP had met all of the required preliminary constraints that NGC imposed on this project, the Wajax CHP would be the most feasible option with which to implement a CHP system design in the NGC plant.

Table 3: CHP project economics summary

Economic Analysis Property	**Wajax**	**EPS**	**Caterpillar**
Savings from CHP System Design as compared to Base Case	$3,726,294.62	$3,866,697.15	$3,896,087.04
Savings from Generator System Design as compared to Base Case	$3,192,673.46	$3,364,095.73	$3,575,901.96
Savings from CHP System Design as compared to Generator Case	$533,621.16	$502,601.42	$320,185.08
Simple Payback - CHP	2 years and 1 month	2 years, 2 months	2 years, 11 months
Simple Payback - Generator	1 years and 11 months	1 years, 11 months	2 years, 6 months
NPV – CHP (@ MARR = 18%)	$3,455,165.59	$3,563,628.84	$2,070,466.10

NPV – Generator (@ MARR = 18%)	$3,254,908.35	$3,442,834.64	$2,594,889.95

7. Environmental Impact and Safety Consideration

The environmental impacts of the design cases were evaluated and compared to the base case, in particular with respect to greenhouse gas (GHG) emissions (Figure 4). The GHG emissions were calculated based on electrical power and natural gas usage, and using emission factors from GHGenius software based on Ontario's power generation mix, and CO2 equivalency factors (CEFs) ((S&T)2 Consultants Inc. 2012). In 2012, NGC's total GHG emission was 12,718 tonnes of CO2 eq. while the CHP design and standalone EG design would produce 12,819 tonnes of CO2 eq (0.80% increase), and 13,855 tonnes of CO2 eq (8.94% increase) respectively.

The selected engine-generator module of the CHP is manufactured by MTU Onsite energy. The generator is to be located indoors in the electrical panel room. To keep worker's safety a priority it is important to consider the potential hazard of loud noises from the module that can result in permanent hearing damage. In the Regulation for Industrial Establishments & Oil and Gas-Offshore permits a maximum continuous exposure of 8 hours per day for noise levels of 85 dB(A) (CCOHS 2011). The regulation allows for greater noise levels with shorter exposure time however, a typical working duration was considered to be a conservative and takes into account of possible long-term scheduled maintenance in the control room. The selected MTU-GC358N6 module can reach a sound power up to 112 dB(A), which is above regulation limits therefore adequate hearing protection must be considered. There are two options to attenuate the noise either by purchasing a sound attenuated enclosure at $60,000 that is guaranteed noise reduction of 25-30 dB(A), and/or the use of dual hearing protection (i.e. foam plugs and earmuff) at a retail price of $25.79 that is suitable for hazardous noise levels of greater than 105 dB(A) (Ontario Ministry of Labour, 2007). The sound attenuated enclosure was included in the economic analysis for conservative measures since it was considered to be inherently safer than dual hearing protection.

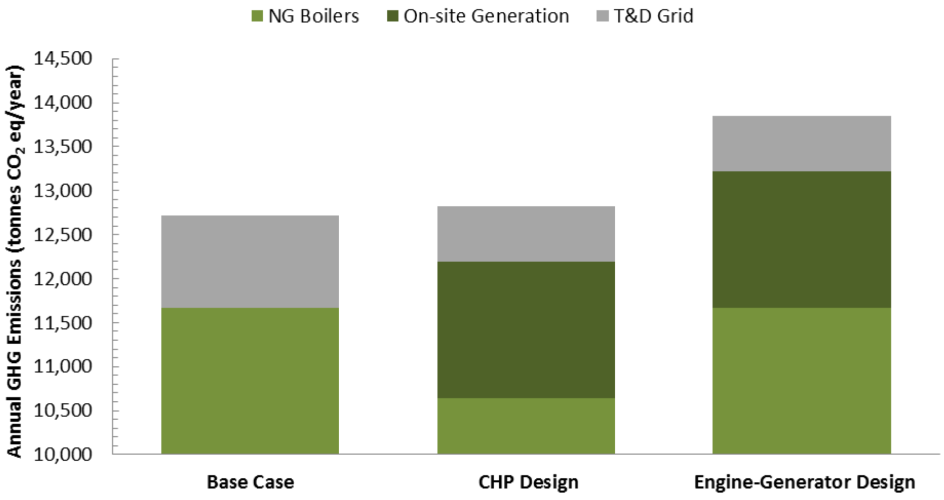


Figure 4: GHG emission

8. Conclusions

The focus of this study was to document the results of a combined heat and power system design study conducted for Nitta Gelatin Canada at their request. The results of this study were as follows:

1) Nitta Gelatin Canada’s gelatin production plant was assessed to be a viable candidate for implementing a reciprocating engine based CHP. Of the numerous vendors that were contacted to inquire about supplying this type of CHP, Wajax Power Systems, EPS Ltd. and Caterpillar Inc. were able to meet the design constraints set out by NGC at the beginning of the project (near or at th desired 400 kW power output, natural gas fuelled, 600 V rating). Of the CHP packages that were quoted by all three vendors, only the Wajax quoted CHP package included a sound attenuated enclosure that would meet the stringent space requirements set out by NGC for the potential installation site of the CHP.

2) Of the potential units in the plant that could make use of the recovered heat from the CHP unit, the plant’s boiler system and air tunnel heating system were identified as the two viable options. Heat recovery simulations were performed for both systems using Aspen plus and it was determined that the plant’s boiler system is the preferred location to recover the waste heat.

3) The project’s feasibility and economic analysis showed that retrofitting the plant’s boiler system with a CHP could result in significant cost savings accumulated over the operational life of the CHP’s engine. As compared to foregoing the CHP investment or installing a standalone generator instead of the CHP, the CHP option resulted in the highest cumulative cost savings. The cumulative cost savings and net present value assessments for each of the three CHPs considered for this project were assessed and the Wajax CHP package was determined to be the most effective cost savings solution for this project with cumulative cost savings exceeding $3.7 million, a simple payback period of just over 2 years and a net present value of almost $3.5 million.

4) There is no significant increase in GHG emission through the implementation of CHP unit (0.80% increase in GHG emissions) and a potential hazardous noise exposure can be mitigated through a sound attenuated enclosure.

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Biography

W. Wongrat holds a Bachelor degree in Food Engineering and a Master degree in Chemical Engineering from Kasetsart University and a Ph.D. degree in Chemical Engineering from the University of Waterloo. At Waterloo, she conducted research on the mathematical programming based synthesis of rice drying processes. She is currently a lecturer and Assistant Dean for Administration at Faculty of Engineering at Kamphaeng Sean, Kasetsart University, Kamphaeng Sean Campus, Thailand. Her research interests are in process systems engineering and optimization with applications to waste and energy minimization in the food processing industry and also logistic management for agricultural product.

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A. Elkamel is a professor of Chemical Engineering at the University of Waterloo, Canada. He holds a B.S. in Chemical and Petroleum Refining Engineering and a B.S. in Mathematics from Colorado School of Mines, an M.S. in Chemical Engineering from the University of Colorado-Boulder, and a Ph.D. in Chemical Engineering from Purdue University. His specific research interests are in computer-aided modeling, optimization, and simulation with applications to the petroleum and petrochemical industry. He has contributed more than 250 publications in refereed journals and international conference proceedings and serves on the editorial board of several journals, including the International Journal of Process Systems Engineering, Engineering Optimization, International Journal of Oil, Gas, Coal Technology, and the Open Fuels & Energy Science Journal.

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