ENERGY
MANAGEMENT

Biomass CHP Optimisation

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DECLARATION

I declare that this thesis is entirely my own work, except where otherwise stated and has not been previously submitted to any Institute or University.

Signed______________________ Date 18th May 2011

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ABSTRACT

Ever increasing competition in the energy market place is driving companies to revaluate their current operation and develop means of delivering their product in a more cost effective manner. Electricity generation is a prime mover in the Irish market and with the open market there is a drive for fuel efficiency where companies are looking to indigenous fuel sources, such as biomass.

In biomass power plant the use of dry fuel provides significant benefits over wet biomass fuels. Utilisation of dry biomass fuel can increase system efficiency, lower air emissions, and deliver improved operation. The provision of installing heat recovery systems to reuse rejected heat in order to dry biomass fuel can reduce the moisture of the fuel, which can have a significantly positive affect on the operation of the system.

The results of this study clearly indicate for the case of Grainger's Sawmill and IBS that the recovery of heat from the condensers to be used for the purpose of drying the biomass fuel will results in a optimizing the system. However, further study is required to fully ascertain the exact affect of operating the plant with a consistent fuel size and moisture content of 50%. The two areas of heat recovery which were inspected for their viability are the condensers and flue stack. The latter was an unviable option due to the low amount of thermal energy that can be recovered safely. Where as there is ample capacity in recovering heat from the condensers to meet the fuel moisture reduction requirements of the system. As part of the study, in-depth analysis of the fuel streams were analysed against European standards and best practice, mainly focusing on IEA Bioenergy Task 32 studies. Results yielded that a reduction in the fuel moisture content from the 2009 average of 60.43% per kg of biomass fuel to the lowest acceptable plant limit of 50% per kg would equate to a reduction in fuel requirements of 20% per year.

1 INTRODUCTION

1.1 GRAINGERS SAWMILL

Grainger's Sawmills was founded in 1977 and is one of Ireland's largest and most technologically developed sawmills in Ireland, with a number of advanced manufacturing technologies. Grainger's Sawmill is located in the West Cork town of Enniskeane and is located on a 20 acre site. The site is segregated into a number of different sections; each section outlines the core part of the process. Stage I –processing. stripping raw lumber, Stage II - Cutting and segregation of lumber, Stage III – Drying of processed lumber in drying kilns and Stage IV – dispatch preparation.

The Grainger's Sawmill site operates five days a week (Monday to Friday) and has a recorded lumber processing capacity of 250,000m^3 per annum. The site management team over the years have endeavoured to be at the forefront of sawmill technology and have continued to diversify the range of deliverables to include construction timber, fencing, garden products, pallet and packaging crates.

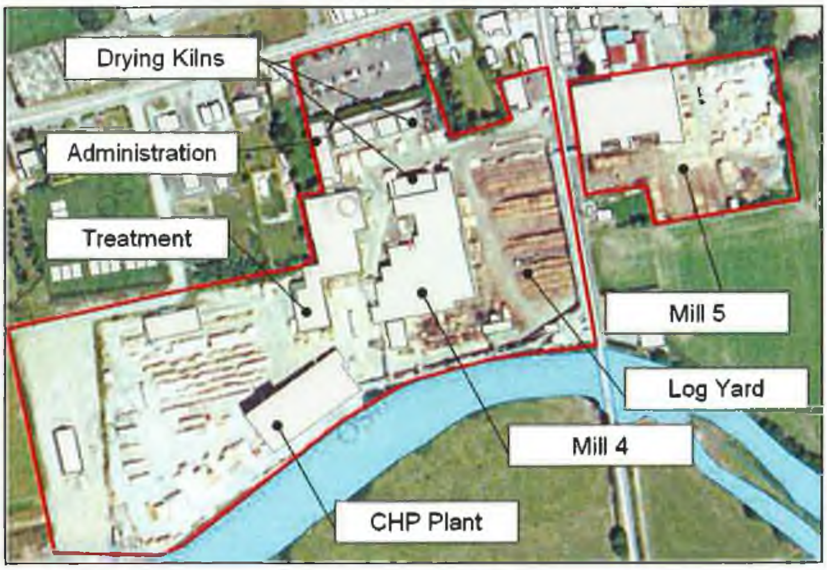


Figure 1 - Grainger's Sawmills plant layout, Osi Maps 2008

The site is well spread out over two different plants areas, Mill 4 and Mill 5, bisected by the R588. Mill 5 is utilised for lumber processing and finishing before being prepared to be introduced to the drying kilns. Mill 4 is the main production area of the plant and this is where the raw lumber is processed after entering the site, and being stripped of unnecessary waste. This waste by-product was traditionally exported from site but is now reutilised and used as a biomass fuel in the CHP plant, operated by the separate entity, Irish Biomass Systems (IBS).

1.2 IRISH BIOMASS SYSTEMS (IBS)

The Combined Heat and Power (CHP) operation and control is registered and operated under IBS, but is located on the Grainger's Sawmill site. The company was setup and formed so that the electricity produced could be sold on to an electricity supplier, and the thermal energy is sold to Grainger's Sawmill.

Although the companies are inherently linked as the CHP plant utilises the waste from the lumber process for a biomass fuel, and the steam from the CHP plant is utilised to heat water for the drying kilns, they are still separate companies.

Currently the steam from the CHP is exported to the drying kilns but the main driver of the CHP plant is electricity export to the grid. Therefore, if the thermal demand of the kilns is greater than that which the CHP plant can provide while still maintaining maximum electricity output, then the sawmill kilns will be at a reduced capacity. The steam supplied to the kilns is paid for by a fixed agreement calculated on the volume of wood which requires drying on regular intervals.

Similarly, the import of the waste product (biomass fuel) from the Grainger Sawmill used as biomass fuel is tracked and purchased from Grainger's Sawmill by IBS. This removes a number of complications relating to financial arrangements and ensures clarity for auditing if required. All information between the plants is routinely monitored and tracked, and is authenticated by both system owners from IBS and Grainger's Sawmill.

1.3 SITE LOCALITY INTRODUCTION

The village of Enniskean (Irish: *Inis Céin*, meaning "the island of Cian") in West Cork, Ireland is located 43 km southwest of Cork City, on the R586 road. Enniskeane takes its name from Cian Maol Muadh (later O'Mahony) a local chieftain and has a strong connection with Brian Boru, once the High King of Ireland. Cian married Sabh, Brian's daughter, and resided at Castlelands, Enniskeane.

Figure 2 - Enniskeane & Grainger's Sawmills, Aerial Picture, 2007

Grainger's Sawmill is the primary employer in the village and contributes a significant amount to the local trade and community. The sawmill is second only to the nearby Carbery plant which produce a variety of dairy produce There is a population of 2,000 people in the immediate catchment area of the town as it is relatively remote and off the main national roads.

The town is accessible by a number of alternative routes, and it is possible to join a number of major national road arteries within only a 15 minute journey. With a number of historical attractions nearby, the town has an increase in passing trade during peak Summer time demands.

Grainger's Sawmills is a family run business and has been operated by a family member living in the locality from inception. Similarly the personnel from the plant are indigenous to the area and this provides for a large degree of interaction between the plant and the local populace and businesses.

1.4 SITE DEVELOPMENT

The CHP plant was designed to burn sawmill by-products, using a Wartsila BioPower 2 Hot Water CHP plant with a Bio Grate bio fuel combustion chamber, steam boiler and steam turbine. The system also encapsulates an extensive 450 metres long fuel conveyor system for the transportation of the fuel in the form of wood by products (e.g. bark mulch, wood chips and residue from the stripping process) from the sawmill.

The plant was originally and primarily designed to ensure the sawmill's own thermal requirements in the form of kiln drying capacity are met, whereby the electricity produced is exported and sold to the national grid. By reusing these by-products the site is offsetting the transportation and external disposal, costs and the CO_2 footprint of the plant is reduced significantly. The use of local bio-fuels increases energy independency of the plant and minimizes environmental emissions due to large scale transportation of fuel.

The incoming raw lumber is stripped with the bark and peelings processed using a crusher before feeding into the conveyer system. This system is an enclosed belt conveyor line, taking the fuel to the covered active fuel storage area. The capacity of the main fuel storage is $600m^3$

and from the fuel storage area it is fed to the boiler using a drag chain conveyor and stoker screw. The plant has an enclosed passive storage area located beside the main storage, making it possible to store the additional fuel when required during times when the sawmill is not in operation.

1.5 CHP PLANT OVERVIEW

Through intelligent planning and investment in the biomass CHP plant, Grainger's Sawmill has added value to the timber processed from the mill, by keeping the cost base as low as possible and improving environmental performance. In May 2003 IBS entered into a contract with Wärtsilä Finland Oy for the engineering, procurement and construction (EPC) of a power plant to generate 2.4MW_E of electricity via a steam driven turbine, utilising the raw lumber by-products as fuel for the CHP boiler.

The initial agreement with Wartsila was based upon thermal load delivery of high pressure steam to the turbine to generate onsite electricity and utilise the heat for the drying kiln operation. The original agreement to install and operate the plant was based upon thermal and electrical load delivery guarantees from the plant, with an agreed efficiency and uptime period per year.

The CHP plant at Grainger Sawmills, Enniskeane, Co. Cork was at the time a landmark development in the search for renewable solutions and as such one of the first large scale biomass CHP plants in Ireland. The project was a joint venture between two companies - Grainger Sawmills Limited and SWS Group who have came together to develop the project from concept to an operational plant generating green energy (heat and electricity). The plant was ideal as it could be fuelled by the wood by-products such as sawdust, bark, peelings and forest thinnings, from the sawmill plant. The development meant that in addition to having a plentiful supply of thermal energy at a fixed cost to the sawmill, also ensures that the need for its low-grade residue, provides protection from fluctuating energy market costs.

As the CHP plant generates greener electricity and exports it directly to the national grid, it has decreased its carbon footprint dramatically by reusing the processed wood by-products onsite. Traditional CHP plants of this size and capacity are normally met by fossil fuels. Although it cannot be said that the site is carbon neutral from an electrical standpoint, the offset of a large portion of transport carbon emissions has been achieved.

From historical data by-product exportation has been reduced by up to 1,500 truck loads annually. This is achieved by the reduction in site exportation of by-products from the sawmill to the CHP plant.

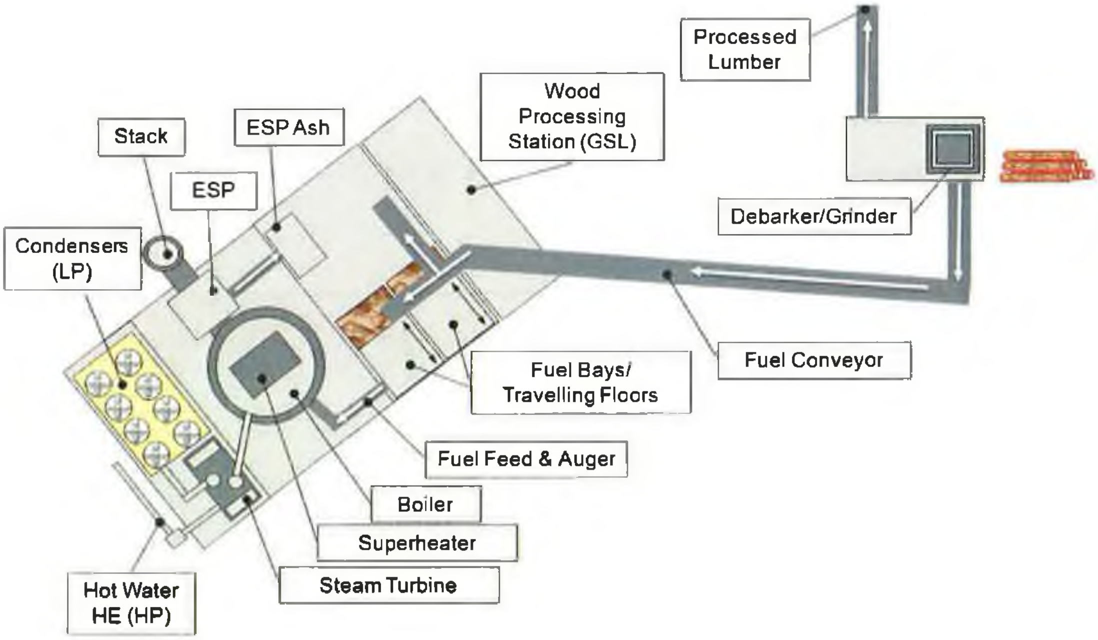


Figure 3 – Current CHP Plant operational flow [plan view]

The CHP plant was initially designed upon thermal load requirements of the sawmill for the drying capacity of the finished wood in the drying kilns. The amount of by-products was fundamentally essential to the Return on Investment (ROI) of the project, in terms of waste reutilisation and energy delivered. The CHP plants energy delivery was sized and matched to the historic by-product quantities produced from the sawmill plant.

As the site metrics have diversified over the years, so has the primary focus of the operation and dynamics of the CHP plant. Currently the primary driver of the CHP plant is the exporting of electricity to the national grid and the thermal energy for the drying kilns has taken a secondary role. This is not to say that the thermal requirements of the sawmill are ignored or reduced, but when full capacity of the drying kilns is required, then the management team must be notified of the possibility of increased thermal load requirements.

The increased thermal load requirements have a direct impact on the performance of the extract steam turbine and results in the system having to 'spill steam' from the electricity generation. This is due to the nature and operation of the extract turbine design and where the heat demand of the drying kilns.

1.6 CHP SUPPLIER WÄRTSILÄ

Wärtsilä Ireland was formed in 1994 and first established a small operation based in Dublin and then subsequently a second new workshop in Killybegs, Donegal. They are a global leader in complete lifecycle power solutions and were therefore approached to submit a proposal for the full EPC of the CHP plant in Grainger's Sawmill. With a large presence already in Ireland through their base in Donegal, servicing gas turbines, primarily on merchant shipping, they offered an indigenous service solution.

Wärtsilä provides an extensive range of turnkey solutions for the installation of a biomass CHP plant in Grainger's Sawmill, which was underpinned by a large portfolio of projects completed in Europe. With a dedicated Wärtsilä Biopower division delivering 2-10MW_E biomass CHP solutions across the world they proved to be an ideal EPC.

1.7 OVERVIEW OF PROPOSAL

Independent Biomass Systems (IBS), the company setup by the Grainger's Sawmill as the operation & electricity exporter, operate the biofuel power generation plant. The plant operates continuously over the course of the year, 24 hours a day, only ceasing operation for plant shutdown and repairs. The onsite management have continued in their search to increase system efficiencies and maintain a high level of plant optimisation, with system add-ons and energy recovery systems.

It is proposed to complete a full system review of the Biomass CHP system, identifying optimisation initiatives from the fuel supply/ quality /handling generation system, utilising the low grade waste heat and system by-products.

Management of the plant will have a keen interest in maximizing the potential of the plant and in increasing fuel efficiency while mitigating waste by-products, where economically viable. Operational personnel will also benefit from this process due to the fact that equipment will be operating efficiently, increase uptime and mitigate unforeseen downtime. Also any increase in efficiencies within power of thermal generation will have a direct impact by educing CO_2 emissions associated with fuel delivery and ash disposal.

The moisture content of wood-based biofuel (bark, forest residues, and waste wood) used by the forest industry typically varies between 55 and 65 % by weight. The high moisture content considerably decreases the power production capacity of the fuel and increase the amount of fuel required. As further study to the viability of the project it is proposed that comparison of drying costs of two alternative drying systems be undertaken once the concept proven is proven feasible

- multi-stage drying, and
- Single-stage drying with multi-stage heating.

Utilise heated air as a drying medium in both systems and where the air is heated using indirect heat exchangers. Secondary heat, back pressure steam, and extraction steam are available for heating the drying air.

1.8 RATIONAL / JUSTIFICATION

Currently the steam from the turbine at the high pressure side is passed through a first stage heat exchanger to generate hot water to dry timber in the sawmill kilns. The heat requirement of the kilns is variable and is considerably less than the heat available from the turbine when it is operating at full power. A second stage condenser transfers heat from the turbine at the low pressure side to a condenser radiator circuit via a heat exchanger to reject the remaining excess heat to atmosphere.

The ability of the cooling system to reject heat has a direct relationship with the ability of the plant to produce electrical energy. During any period when the heat requirements of the kilns together with the heat rejected by the radiators is less than the design value, typically on a hot day, the turbine output has to be reduced such that the heat generated does not exceed the capability of the radiator system to reject that heat to atmosphere.

On a cooler day, heat rejection at the radiators is more efficient and the speed of the radiator fans is reduced to limit the amount of heat rejected to match the requirements for electrical generation. As the temperature of the cooling water fluctuates its hydraulic properties change and to compensate for these changes the pressure across the cooling water pump is monitored and the pump's variable speed drive is adjusted to maintain the pump flow rate.

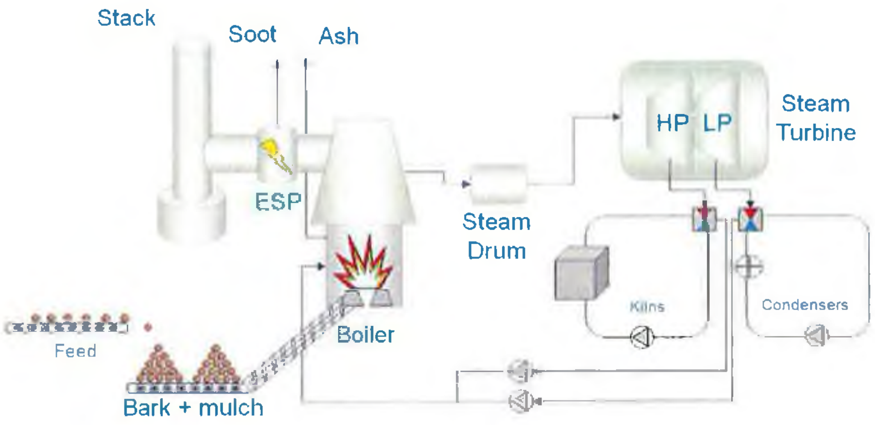


Figure 4 –CHP operational overview

It is proposed to integrate this 'redetected' low grade heat and re-utilise it in a more efficient manner and allow the incoming fuel to be dried using the waste heat. This will maintain the required load on the low pressure side of the steam output from the turbine for balancing, while reducing the electrical power required operating the condenser fans, and also utilising the heat to dry the incoming fuel.

2 SCOPE

The purpose of the project is to determine methods for improving the optimisation of the CHP plant in IBS, Enniskeane, Co. Cork. It has long been recognised in the plant that the moisture content of the fuel is high, and although the system is capable of operating with a fuel that has moisture content of up to 70% which is not ideal. The current average fuel moisture content is 55-65% approximately and the management of the site are looking the possible benefits and justification for installing drying technology for the fuel feed.

As the site has an indigenous fuel supply through Grainger's Sawmill, via the by-products from the lumber debarking, it was ideal to install a CHP plant on the site. Over the course of the pervious years, the plant dynamics have changed and the indigenous fuel supply can no longer facilitate the total fuel requirements of the CHP system. Therefore, a number of alternative fuel sources had to be sourced in order to maintain maximum operation of the CHP plant.

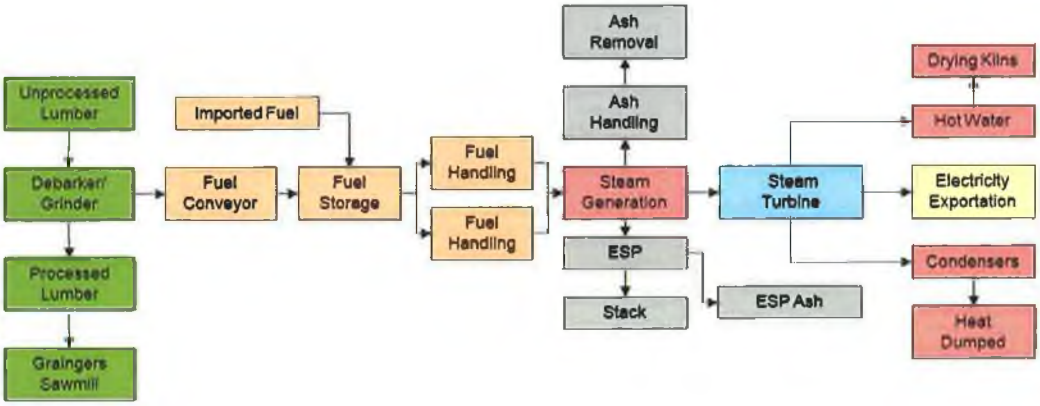


Figure 5 - Grainger's Sawmills and IBS process flow chart.

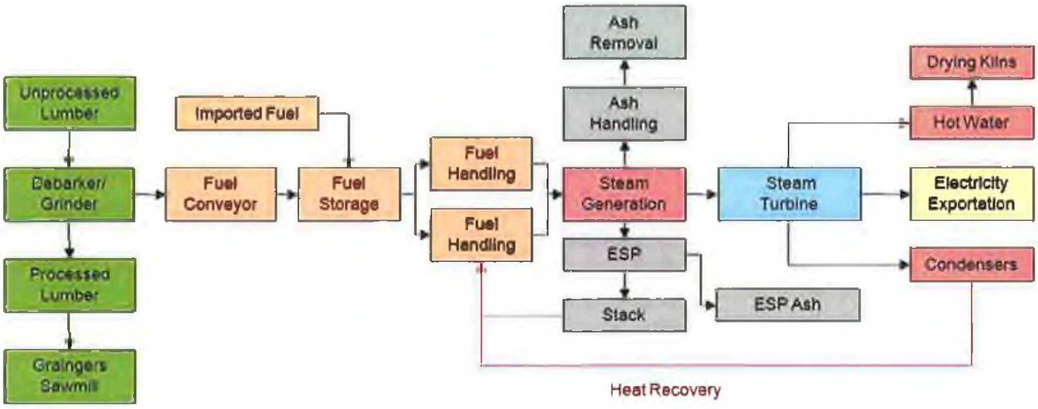
The plant also has a large thermal dissipating section that is utilised to balance the low pressure side of the steam extraction turbine. The site has had a number of operational issues with this unit in the last number of years. It has been identified as a significant source of recoverable energy and it was believed that the waste heat from this section of the plant could be used in conjunction with other waste heat recovery technologies, to provide thermal energy for the drying of the biomass fuel. Other sources, for heat recovery are the flue gas stack, which is currently operating with out a waste heat economiser.

Utilising these two heat sources for the purpose of drying biomass fuel at the plant were identified as a way of reducing the dependency on imported biomass fuels. It is hypothesized that the moisture content of the fuel will be reduced, and the calorific value of the fuel increased. This would theoretically signify that the current amount of fuel required to operate the plant would be reduced and therefore the costs incurred by importing extra fuel would be negated.

Added value incentives were also identified, including; reduced ash content from the boiler and the ESP, reduction on electrical power required for the condenser fans, improved controllability of the system overall and improved uptime of the boiler and steam turbine.

2.1 POSSIBLE OUTCOMES

By examining the areas of the plant operation where heat can possibly be recovered for alternative uses will be a determinant factor of the proposal. Outlined below is a modified block diagram of the plant operation and provides an overview of the building blocks for the proposal.



From initial research, system reusing low grade heat exist but must be accurately matched to the dynamics of each plant, such that that there is no interruption to normal plant operation. Tying into the existing fuel handling systems may be difficult to engineer but will depend on how much fuel is historically used to maximize electrical output. Also, the amount of heat energy that can be recovered and effectively utilised will affect the proposed drying air system in terms of both its drying capacity and availability dependant of fuel demand in the boiler. Site historically data has been made available for the interrogation of the information relating to the project proposal. Within the historically data is the key milestones and operational data of the plant for the year 2009.

Outlined in Figure 6 and Figure 7 is the proposed operational overview of the heat recovery, and drying air system. These illustrations provide a detailed indication of the proposed plans and how they will interact with the existing systems.

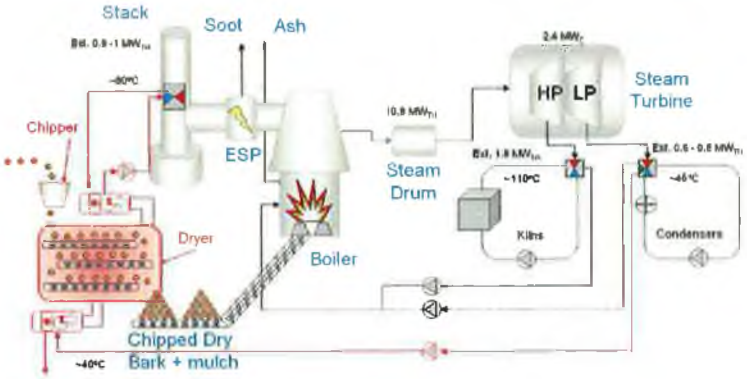


Figure 6 – Proposed CHP operational overview

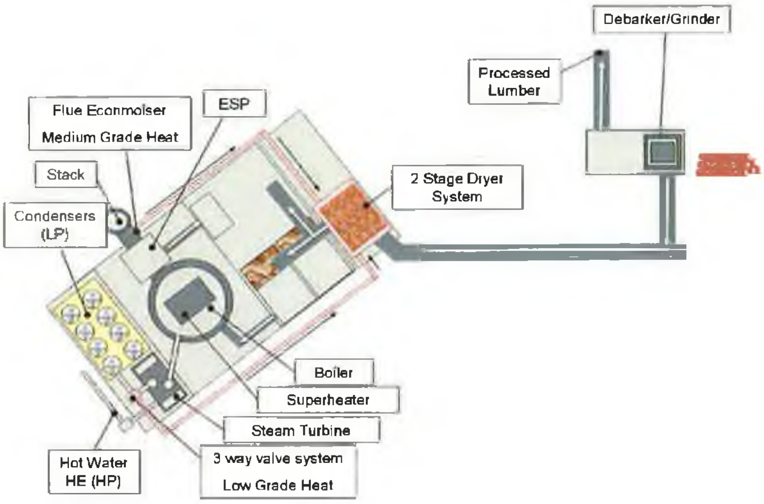


Figure 7 – Proposed CHP Plant operational flow [plan view]

The possible positive outcomes f the project include

- Lower the moisture content of the fuel (%), by using waste heat from the condenser radiators and economiser.

- Reduction of electricity requirements of the condensers fans, currently max capacity of 180kW$_e$

- Improved controllability of the system, and improving the system response time due to load fluctuations.

- Reduce waste through mitigation of ash carryover from the fuel grate in the boiler and reduce the amount of fine ash from the electrostatic precipitator (ESP) prior to the stack.

3 LITERATURE REVIEW

The purpose of this literature review is to identify appropriate information sources for the calculation and realization of the proposed project. To achieve this understanding of the technology and analysis of other similar systems is required. A traditional literature review would begin with an in-depth analysis of existing plants. For clarity, the literature review will focus upon the plant requirements and the possible means of meeting the scope of works.

3.1 RESEARCH METHODOLOGY

In order to make possible the literature review number of avenues were utilised, such as; online journals, good practice guides and papers were accessed through the IT Sligo library service databases (e.g. Science Direct, IHS, and Engineering Journals). Due to the bespoke nature of the project, research was found to be challenging and insightful with the identification of existing texts on a number of parts of this project.

3.2 BIOMASS CHARACTERISITICS

Determining the essential characteristics of certain biomass fuels for combustion and co-firing is intricate and a number of studies have been completed over Europe to centralize information and disseminate this in a constructive manner (IEA Bioenergy Task 32, 2010). The International Energy Agency – known as the have taken up this mandate and developed IEA Task 32. The objective of the Task is to collect, analyse, share, and disseminate strategic technical and non- technical information on biomass combustion and co-firing applications, leading to increased acceptance and performance in terms of environment, costs, and reliability.

Numerous methodologies and case studies have been developed as part of Task 32 and a reservoir of information is delivered through there online databases and handbooks relating to characteristics of specific biomass fuel types. The information found as part of Task 32 and a series of calculations to factor in the site specific information will be utilized as part of the project.

3.2.1 Introduction

Drying of biomass for use in a combustion chamber has a series of benefits and detriments, and the technology has to be adequately match to that of the fuel and the thermal conversion system (Robert Samuelssona, Biomass and Bioenergy 30 2006, P1)

With a number of various technologies and methodologies being utilised for drying biomass fuels, there is significant benefits to the thermal system operation. These benefits must be carefully balanced against the capital, additional energy required for drying, and the operating costs, such as; operation & maintenance.

3.2.2 Benefits

Drying biomass fuel for direct use in direct combustion boiler's similar to IBS, have been noted to increased efficiency of steam production, improved boiler operation/controllability, reduction in fuel volumes, lower emissions, and reduced ancillary power requirements, such as; fuel handling.

One of the most significant reasons for drying biomass fuels delivered to a direct fired combustion chamber is the temperature of the flame. Any efficiency in the maintainability of the flame temperature can lead to evaporation of the moisture content from the fuel, leading to an increase in combustion efficiency. This is as a result of the reduced energy requirement to removing the moisture content of the fuel being offset and the combustion energy going into heating the air in the chamber and biomass fuel. (P14, Report on Biomass Drying Technology, Wade A. Amos, Nov 1998)

As a result, dry fuels can have a flame temperature in the range of 1,260°C -1,370°C, while green wood has a combustion temperature of 982°C. This is directly applicable as the flame temperature in the IBS Watrsilla Biopower 2 boiler, utilised green wood that is unprocessed and has an average flame temperature of 850°C.

The increased flame temperature can be advantageous in a number of ways:

1 The higher flame temperature, the greater temperature gradient in the boiler for radiant heat transfer.

2 Increased heat transfer takes place for the same boiler tube area, increasing steam production and reducing the requirement of fuel input. .

With new boilers designed for dried fuel, the boiler can be smaller due to the reduced heat transfer area requirements, as there is less moisture content in the fuel to be evaporated. The increase in the flame temperature will ensure that there is complete combustion of the fuel, resulting in lower carbon monoxide (CO) levels and less fly ash leaving the boiler.

Complete combustion subsequently allows greater amounts of heat to be released from the fuel reducing the size of the boiler, proportionally. Therefore in a new boiler plant, the fire box can be smaller and the downstream ash handling system can be smaller, which reduces the amount of the excess air required and therefore reduce electrical energy required for combustion air fans and has the benefit of reducing the plant CO levels.

With high level moisture in biomass fuels, there is a requirement for 80% excess air to prevent smoke formation, where fuels with low moisture content only require as low as 30% excess air.

Also the reduced excess air mitigates the sensible heat losses from the system and the flue gases, which in turn increase the boiler efficiency. With lower air flow required in the combustion chamber the boiler can increase its residence duration and potentially lower the gas velocities, aiding in complete combustion. This reduces the volume of light fuel blown out of the chamber prior to combustion and increase the thermal and combustion efficient of the system.

With the reduction in excess air previously discussed, this can relate to reduced energy consumption in the forced draft fans. Similarly the secondary fan system, also referred to as the induced draft (ID) fan system, which draws the flue gas out of the boiler and through the pollution control equipment, will require less power due to the reduced lower air flow and the reduced moisture content of the fuel from the fuel.

Further rationale for increasing overall boiler efficiency is the lower flue gas temperature to the flue stack, which is in essence energy lost to the atmosphere, this however must be carefully considered, to ensure that there is enough temperature to precipitate the natural stack affect and not give rise to flue gas formations of by-products (e.g. acid buildup causing corrosion in the stack). With a boiler that does not have fuel drying, the flue gas temperature will typically be 177°C [this mimics the IBS boiler stack temperature which is approximately 180°C] or higher. With dryer biomass fuel the stack temperature can be greatly reduced down to approximately 104°C. This must be carefully considered per system, as various manufacturers stipulate a minimum stack temperature requirement and the presence of fuel gas cleansers, such as ESP or cyclone systems may add further temperature requirements. Overall thermal efficiency increases can amount to 5%-15%, with steam production increases of 50%-60%.

3.2.3 Drawbacks of Using Dried Fuel

There are a number of economic facets which must be considered when considering the utilisation of dried biomass fuel

1 Previously outlined burning dried biomass fuel results in increased combustion temperatures in the boiler, which benefits boiler operation and fuel feed required. However, as the flame temperature increases, it approaches the fusion temperature of the ash. If the ash starts to flow and form slag [clinkers], then this has the potential to be detrimental to boiler operation. Normally the flowing temperature of the ash is safely above the flame temperature, but when contaminants from construction debris or salts are mixed with the fuel, the flowing temperature can be reduced

2 Concern surrounding the boiler design to efficiently utilising dry biomass fuel also must be considered [this is vital as the IBS boiler is designed to use wet' residual fuel with moisture content up to and not exceeding 50-70%]. If the fuel is lower than the designed minimum, this may precipitate carry over or flash off the fuel in the combustion chamber. This can also lead to reduced residence time and therefore loss of thermal efficiency per ratio of fuel input to steam generation.

3 Another potential issue may arise when using dried fuel when the hot flue gases from the boiler are cooled below the dew point of the flue gas. This can lead to the formation of sulfur trioxide (SO_3) as at reduced temperature the flue gas can condense, resulting in sulfuric acid formation. This can seriously corrode downstream equipment and duct work, leading to failure of the system and also impair fume handling.

The configuration and specification of the boiler, and whether the fuel moisture content can be regulated may require expensive materials of construction and result in higher maintenance costs. The formation of nitrous oxide (NO_2) emissions may increase or decrease depending on the boiler design. Lower excess air decreases NO_2 emissions, but high flame temperatures can increase NO, formation (Katarina Rupar, Biomass and Bioenergy 30, 2006, P2)

When drying biomass fuel or wood-derived residues, it must be considered that the condensate produced from the system will contain VOCs (Volatile Organic Compounds). VOCs have a high biochemical oxygen demand and can be highly corrosive, and therefore may require treatment systems.

3.3 BIOMASS DRYING SOLUTIONS

There is a wide number of drying technologies available for the purpose of drying biomass, including direct and indirect fired rotary dryers, conveyor dryers, cascade dryers, flash or pneumatic dryers, superheated steam dryers, and microwave dryers. It is possible to categorise drying technologies in accordance with drying media, such as steam which passes through the material to be dried, indirect heating using steam, air or water.

There are a number of factors which need to be considered when selecting the appropriate dryer, including the size and characteristics of the feedstock, capital cost, operation and maintenance requirements, environmental emissions, energy efficiency, waste heat sources available, available space, and potential fire hazard.

Classification	**Alternatives**
Drying media (i.e. the stream passing through the material to be dried)	Flue gas, hot air or superheated steam
Firing	Direct- or indirect-fired
Heat source	Dryer burners, boiler (flue gas or steam),recovered waste heat from facility processes
Pressure	Atmospheric, vacuum or high pressure

Table 1 - Biomass Fuel Drying Technologies Types

With air or flue gas dryers there is a potential fire risk and emissions to be taken into consideration, while superheated steam dryers do not share these potential issues, as the steam generation technologies are normally closed loop systems. Superheated steam dryers have other potential drawbacks, such as; condensate that must be treated and this adds considerable finical and operating costs to a project. Steam dryers can vent moisture evaporated from the biomass fuel, and are therefore ideal facilities that have excess low pressure steam that must be purged.

Biomass drying systems can be classified as either direct or indirect-fired. Indirect-fired dryer systems utilise a heat transfer medium, such as; flue gas, hot air or superheated steam which is passed directly through the biomass fuel material to be dried. Where indirect-fired dryers, use heat transfer medium which is normally steam or hot water passed through tubes or a heat exchanger technology inside the dryer.

Noticeably the heat transfer media is also used as the drying media for direct-fired dryers, but not for indirect fired dryers. Direct fired drying systems are generally more efficient, as they have reduced distribution losses and are normally connected straight to the thermal energy generation system. Indirect fired system, utilise a distribution system or transportation system, to move the heat from one source to another. The only exception is when no air is utilised where an indirect-fired dryer, and therefore the moisture vented from the dryer as steam is recovered to serve process heating needs.

Direct-fired drying systems are not suitable for all materials, and are better suited for drying fine and dusty materials, which have a low flash point and where potential for ignition is possible. The drying systems can be designed to operate at atmospheric pressure or under a vacuum in order to increase the heat transfer rate and further reduce ignition or fire. Drying of biomass materials under a vacuum reduces the boiling point of water and therefore reduces the temperature required for the drying process to take place. This increases the potential for reducing waste heat and reusing it within the facility or system. There is an increased cost associated with the installation of a vacuum drying system and therefore must be weighed against energy savings as a result of increased use of heat recovery.

Superheated steam drying systems can be operate at pressures exceeding atmospheric pressure which allows for more efficient heat recovery, due to higher temperatures.

Thermal heat energy for the dying process may be recovered from the drying systems from

- burners,
- boiler flue gas,
- waste heat recovered
- exhaust of process heating in the facility,
- Steam from the boiler.

3.3.1 Drying Conveyor

When utilising conveyor drying systems, the biomass fuel is spread onto a moving perforated conveyor to dry the material in a continuous process. Within the enclosed system, fans blow the drying medium through the conveyor and biomass fuel, upward or downward to gain the maximum cross sectional exposure to the fuel.

When a series of multiple conveyors are used, the system can be stacked in series to provide multiple passes and increase the drying operation. Using conveyor drying systems can provide a highly versatile system which can handle a wide range of materials. Conveyor drying systems are suited to take advantage of waste heat recovery opportunities due to their lower operating temperatures rather that that of rotary dryers.

Rotary drying systems typically require inlet temperatures of at least 260°C for drying biomass fuel, and 425°C is recommended for optimal draying processes. Inlet temperature requirements for some specialised vacuum conveyor dryer can be as low as 20°C above ambient versus conveyor drying systems which operate at higher temperatures of between

90°C and 180°C. Due to the relatively low temperatures which conveyor drying systems can operate, they can be installed in conjunction with boiler stack economizers, to maximize the heat recovery from boiler flue gas. This is where the exhaust from the economizer is used for drying using a cross flow heat exchanger. The lower temperature outlines that the fire hazard will also be diminished and this system is a highly proven heat recovery system. Emissions of VOCs from the dryer will also be subsequently lowered as a result.

Other advantages of this system in comparison to the other types is that where other dryer systems utilise agitation to increase drying contact area, the conveyor systems does not have these requirements. This reduces particulates in its emissions and reduces environmental concerns considerably.

Another advantage of a conveyor system is the reduced footprint as a single-pass conveyor drying system can be is typically no larger than a comparably sized rotary dryer. Multi-pass conveyors, where the conveyors are stacked one above the other with material cascading down from upper conveyors to lower conveyers, save considerable space. Multi-pass dryer conveyors are very common in many industries due to their small footprint and lower operating and capital cost.

3.3.2 Rotary Dryers

Rotary drying systems feed material into a slowly rotating cylinder, with longitudinal flights inside the cylinder in order to agitate the fuel and allow it to cascade down through the drying medium. These drying systems are in wide use and have a long proven history in many industries and are the most commonly used dryer in drying biomass and the cement industry.

3.3.2.1 Direct-Fired Rotary Dryers

Continuous-feed, direct-fired rotary drying systems are the most common type of dryer for heavy biomass fuel, such as; sawdust and bark. This is as a result of high temperatures which are possible that do not scorch fuel and increasing the drying efficiency of the system.

Inlet temperatures of up to 420°C are optimum for heavy biomass fuels to be dried in a rotary drum. High intensity moisture fuels require higher temperatures than drier fuels, but it is possible to operate rotary dryers at lower temperatures as low as 260°C. These inlet temperature can result in exhaust temperatures typically found by the operation of direct fired rotary dryers these can be as high as 65°C, and can be utilised for further heat recovery system, such as; steam generation and preheated feedwater.

In comparison to rotary steam-tube indirect-fired dryers, direct-fired dryers have reduced operational and maintenance costs, with higher availability time with less associated down time for maintenance due to their robust design.

3.3.2.2 Indirect-Fired Rotary Dryers

Steam-tube dryers utilise steam directly from boilers to dry the fuel, passing the steam through tubes or other heat exchanger inside the drum. This steam could alternatively be utilised for electricity generation and therefore represents an impasse in terms of cost variability for electricity export and drying energy cost. Indirect-fired dryers are less efficient than direct-fired dryers as they have inefficiencies associated with transferring heat from the steam tubes to the material.

3.3.3 Superheated Flash Dryers

Superheated steam drying system is where the steam is fed directly into the dryer and where there are no requirements for heat exchange systems. It is critical that the temperature of the steam remains above its saturation temperature, to prevent condensation and moisture formation in the fuel.

The system is based on the principle that greater quantities of steam at a lower temperature and pressure will leave the dryer, than that which enters. This type of dyer can operate in a closed-loop, with low-pressure steam from the dryer being reheated and injected back into the dryer. It is therefore possible in the event of excess steam to be recovered for utilisation another process.

In order for the unit to work efficiently the steam exhausted will be required to be at the same pressure as inside the dyer, this is an inherent requirement due to the expansion of super heated steam. This allows heat recovery in a more efficient manner and at a higher temperature increasing the overall heat transfer. Superheated steam dryers have no air emissions, no fire hazard as the there is no combustion chamber and is essentially a wet system. These units can like all other direct steam systems, carry increased energy losses due to the nature of its operation.

3.4 WOOD PELLET PRODUCTION

Wood Pellets are traditionally comprised of clan conifer sawdust and plant shaving, and the wood must have been debarked prior to passing through the wood pelletising process. There are typically two streams of wood pellet fuel source, such as softwood and hardwood.

Due the composition and malleable properties of softwoods it makes is easier to palletize. This does not require a binding agent, often referred to as a 'binder' to hold the processed word together. Hardwood however often requires a binding agent in order to hold the processed wood particles together after the processing stage.

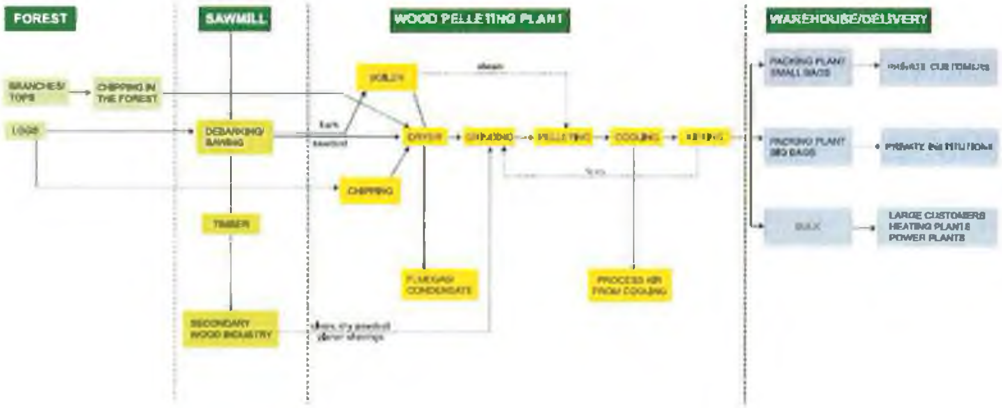


Figure 8 – Wood Pellet steps, "The production of wood pellets" *Pieter D. Kofman, Coford 2007*

The sawdust's moisture content is required to be less than <15% prior to the pelletizing stage to ensure that the binding of the wood. Wood pellets are normally comprised from clean conifer sawdust and planer shavings from either the primary or secondary stage of the sawmill process. The wood must have been debarked prior to passing through the sawmill and then only can the sawdust of hardwoods be mixed with that of softwood.

Where possible, dry sawdust and shavings (less than 15% moisture content) are used, because then the drying step can be removed from the overall process, if not the sawdust will require that so goes through drying a process before pellets can be pressed.

3.5 WOOD CHIP PRODUCTION

Wood chip quality can depend on a number of factors such as; size, distribution, moisture content, and on impurities. Quality of wood chip handling and burning properties are associated with having an influence on the combustion efficiency and on the content of harmful substances in smoke/flue gas and ash. It is therefore fundamental that the production of wood chips be of the highest quality to ensure that the maximum amount of energy can be produced for the smallest amount of fuel

The two most important factors which affect these issues are the calorific value of the wood and the moisture content. The calorific value is the number of heat units obtained either per weight or volume unit by the complete combustion of a unit mass of a fuel is termed the calorific value. There are a number of different calorific values;

Cross Calorific Value	The heat produced by combusting a specific quantity and volume of fuel.
Net Calorific Value	The heat produced by combustion of unit quantity of a solid fuel when burned, at a constant pressure, under conditions such that all the water in the products remains in the form of vapour
Actual Calorific Value	The heat per unit mass produced by complete combustion of a given substance.

When referencing the 'calorific value' of a biomass fuel it is often referring to the gross calorific value unit. This is the amount of recoverable heat from the fuel by combustion.

This s directly related to the moisture content which is the amount of water contained in wood fuel which can be evaporated during the first stage of combustion. Often referred to in terms of percentage due to the moisture content, and is given as a percentage of the total weight of a sample. This states that the amount of energy that can actually be utilised is reduced due to the evaporation of the water from the wood fuel.

3.5.1 Energy Supply Company (ESCO)

An ESCO, or Energy Service Company, is a service provider business that designs, builds, operates and finances energy projects for customers over a fixed time period. These services can also include billing, plant operation, maintenance, long-term replacement and risk management.

" ESCOs offer a range of services that can help end users buy and use energy efficiency cost effectively. They typically promote performance contracting as a financial mechanism for encouraging the use of their services, thus guaranteeing a level of savings from an improvement programme and receiving payment from those savings. The benefit for customers is that they take on minimal risk while entering into the contract, which can help overcome some barriers to implementing energy efficiency projects"

Assessment of the Potential for ESCOs in Ireland December 2005
Report prepared for Sustainable Energy Ireland by: ENVIROS

District Heating or heating ESCO companies, provide a service to the client by operating and maintaining heating equipment on the clients sites. This may cover the installation and continued operation and supply of the equipment for a contracted period. For example, companies in Ireland, such as; Johnson & Johnson (J&J) facility, contracted Sisks Engineering to deliver an ESCO solution, with a large scale steam biomass boiler and fuel supply chain. Sisks have installed the system and provided an operator and secured a deal with a local wood chip supplier for the continued fuel source of the boiler. The J&J company at Centocor contacted Sisk on the basis per kWh of heat delivered to the plant, which this is a fixed term unit cost. This removes potential issues surrounding fuel supply and quality, putting the onus on the ESCO to supply high grade fuel to reduce costs and ensure uptime of the unit. The unit costs also entails the operating and maintenance costs of the unit and allows J&J a front up cost for their steam requirements on an ongoing basis.

3.6 HEAT RECOVERY

Heat recovery through such technologies, such as a stack economiser or recuperator are through a water-to-air heat exchanger, and designed to use heat from hot boiler flue gases to preheat water for heat recovery or use in another process. Traditionally heat recovery systems such as economisers have been used on large utility steam boilers to preheat the feedwater using recovered stack heat. The heat loss from a fired boiler/heater is primary dissipated through the chimney and the amount of flue gas and the temperature of this, is proportional to the heat loss. Considerable economical advantages can be achieved by recovering heat from the flue gas, which under normal circumstances would have been released to atmosphere.

Generally a high temperature level on the heating media often means a high chimney temperature (flue gas temperature). By inserting a heat exchanger in the flue gas flow just before the stack means process, heat can be recovered economically. The heat loss through the stack can be seen by the lower flue gas temperature, which can limit the temperature level of the produced/recovered heat. Analysis of the system parameters and re-using the heat in the process can negate this limitation and often lead to an increase in the overall thermal efficiency of the system. Using the heat for another process or user may reduce the boilers thermal effectiveness. Operational consideration needs to be undertaken before any installation of a heat recovery system occurs.

4 METHODOLOGY

The energy sources with the greatest potential for biofuel drying in a CHP plant are secondary heat, back pressure steam, and extraction steam. In this connection, secondary heat (also known as waste heat) means heat recovered to a heat recovery system from energy flows leaving the main processes.

- The circulation fluid in the heat recovery system is usually water, and the temperatures of the available secondary heat flows are typically in the range of 50–90°C.
- Back pressure steam is typically 3–4 bar (ca. 133–144°C) and the pressure of extraction steam 10–12 bar (179–187°C).
- The drying temperature is usually 5–10°C lower than the temperature of the heat source, depending on the minimum temperature difference between the heat source and the drying air in the heat exchanger.

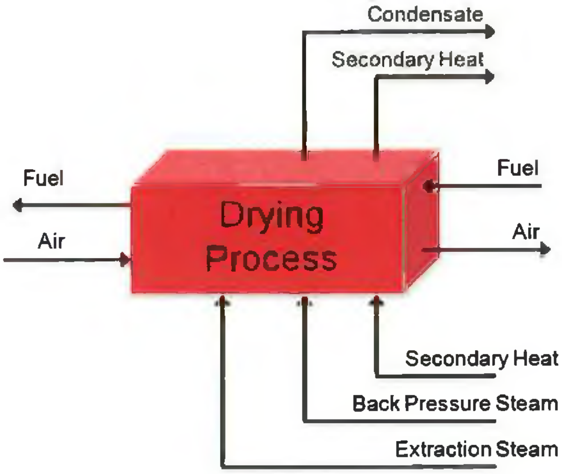


Figure 9 - Grainger's Sawmills plant layout, Site graphics, 2010

Figure 9 illustrates the mass and energy balances of the adiabatic drying process utilising these three heat sources. The drying temperatures are relatively low when secondary heat is used (approximately 60–80°C). The dimensions of the dryer become larger if higher drying temperatures are required.

Back pressure and extraction steam, is potentially more valuable energy than secondary heat. This is due to the steam expansion in the turbine which provides a higher rate of conversion to do mechanical work (generate electricity) from the steam process.

Typically in a sawmill, the cost of secondary heat is usually close to zero and the cost of steam depends on the pressure. Therefore it can be stated that in comparison to the use of steam, secondary heat increases in capital costs but decreases in operating costs.

4.1 DATA INTEROGATION

The IBS and Grainger's Sawmill have provided the data recorded for the two separate entities on the same site for the previous 12 months of 2009. This will allow a complete overview of the system operation relating to the importation of fuel [forest residue] from the sawmill plant to the steam and electricity generation from the plant. These figures have been laboriously maintained manually for verification against the automated systems on a daily, weekly and monthly basis, to ensure that the system operation can be accurately tacked and monitored.

4.1.1 Historical information

- Steam Power Output (MW)

The steam power figures are taken from a daily sum of the energy generated by the boiler after the super heater. This figure is significant as currently the boiler is at its maximum limit and cannot produce further quantities of steam, unless re-design and modifications are undertaken. This is important to remember as the project entails optimisation of the plant and this is a limiting factor which cannot be altered due to normal plant operation, with the steam turbine operating above it max capacity of $2.4MW_e$

- Hot Water (MW)

Hot water is generated using the steam taken from the high pressure side of the steam turbine after use and sent to a series of plate heat exchangers. The system operations seven days a week due to the operation of the system and the demand varies depending on the amount of drying kilns and timber which requires drying. While the plant was originally designed around the needs of the hot water, as mentioned previously, the plant dynamics have changed. To this end it is important when outlining optimisation initiatives for the system that the hot water requirements be taken into account, while not a prime driver, it is still a prerequisite to the plant operation.

- Export Electricity (KWh)

Exportation of electricity is now the current main driver for the IBS plant, due to the purchasing arrangement with the ESB. It is therefore imperative that any optimisation scheme will not affect any change in the electricity production through the operation of the steam turbine. While the project does not look at the steam turbine in any great scope, there are certain portions of the plant which are key to its operation. These include the main biomass boiler, and the condenser fans on the Low Pressure (LP) side of the extract turbine, which allows the system to balance accordingly against loads from the boiler and the hot water system.

- Fuel Consumption (m^3/h)

There are three streams fuel going to the holding pen prior to the travelling floor fuel feed system. This was outlined earlier in the introduction section, where it was explained that the site was originally designed around the thermal requirements of the site to be matched against the by-products of the Grainger's Sawmill. As the site dynamics have changed, with the increase of timber drying required and the introduction of new kilns, combined with the change to large scale electricity exportation, the fuel requirement volumes have increased.

- Grainger's Sawmill by-products

Traditionally the Grainger's Sawmill by-products fuel the system and were adequate to maintaining the feed volumes required for the steam generation. The sawmill by-products are stripped bark, mulch and off cuts from the incoming unprocessed wood. This is considered green fuel and as such has a high moisture content value of approximately 65% (taken from averages in the 2009 year) and tested by onsite personnel utilising an oven, weight scales and various measuring equipment.

- Other fuel sources

Since the change in the CHP system requirements, biomass fuels from alternative sources are required to meet the fuel demand of the system. The sources of the fuel come in three variances, and are now considered an integral part of the fuel mix for the system.

One of the streams is from the processing part of the Grainger's Sawmill in the form of wood chips that have been manufactured for use in MDF (Medium Density Fibreboard) construction. This is normally purchased by companies in its raw state form for the manufacture of MDF furniture, cabinets, and kitchens.

The plant also purchases a small portion of woodchips when no other fuel raw by-products or internal woodchips can be made available to the CHP. This arrangement is not preferred due to the high cost of the external

The alternative is to source locally from other sawmills and transport in large container trucks in order to meet the onsite fuel requirements Other arrangements such as; bringing mobile wood chippers onsite and using alternative wood sources can be utilised, but again this is not the preferred option due to the large degree or management, sourcing and lead time of fuel. These fuels however have a large advantage over the unprocessed by-products, as these are all of regular size and dimensions. These woodchips have the benefit of also having lower moisture content as they are less green wood and have been allowed to dry for standing periods.

4.1.1.1 Trending

The onsite DCS (Distributed Control System) is connected to a PLC (Programmable Logic Controller), which allows the trending of information over prolonged periods of time. The system can also be very helpful when identifying rationale and the critical path to failure modes or unforeseen issues. (E.g. temperature sensor analysis can be overlapped with fan run time and flow rates), so that high level temperature alarm can be identified. Currently there is no historian backup and the memory is only on the PLC, so that in the event of a complete system failure, potentially all legacy information could be lost. This also makes it difficult to download information to CSV format so that information can be interrogated by 3rd party software (e.g. Microsoft excel, MiniTab). This drawback, unfortunately hinders the precise information needed to actively track energy usage in some parts of the plant and therefore must be done through virtual meters, or stand alone portable metering.

4.1.1.2 Daily Logs

Daily logs of the plant are kept by the onsite operator of the CHP plant, and a daily review of the operation is undertaken in order to compare best practise in the system versus daily operation. This assists in identifying any potential issues in the plant, and can be addressed before unplanned downtime occurs.

All relevant information regarding logbooks is kept in the operator room, where the plant is controlled from and these can be scrutinised for past issues which may have occurred. The onsite personnel are proactive and have a vigil mindset for the operation of the system and utilising their experience can often system irregularities before they escalate.

4.1.1.3 Fuel Mix Reports

Daily fuel mix reports are kept by the onsite operator of the CHP and are regularly cross checked against other information, to ensure consistency and accuracy. These include, the volume of wood processed and the operation of the grinder relative to the wood delivered. The grinder removes the unwanted portions or the by-products from the raw material, which is sent to the CHP plant.

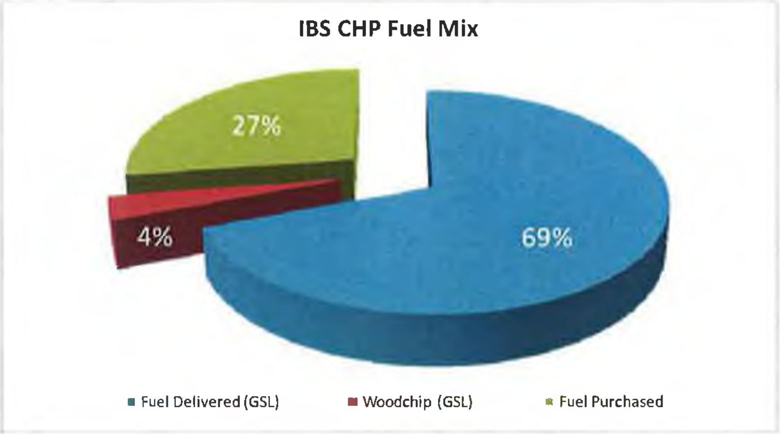


Figure 10 – IBS Fuel Mix 2009, Grainger's Sawmill & IBS Production Reports

Description	Amount (tonnes)	Percentage [%]
Fuel Delivered (GSL)	31,809.64	69.16%
Woodchip Delivered (GSL)	1,597.96	3.47%
Fuel Purchased	12,584.80	27.36%
Total	**45,992.40**	**100.00%**

Table 2 - IBS Fuel Mix information, 2009

Illustrated in Figure 10 and Table 2 are the fuel mix ratios for the plant over the 12 month period of 2009 which provides a clear understanding of the fuel mix requirements of the system. While 73% of the fuel mix is sourced from the Grainger's Sawmill plant, there is a large requirement for offsite importation of biomass fuel.

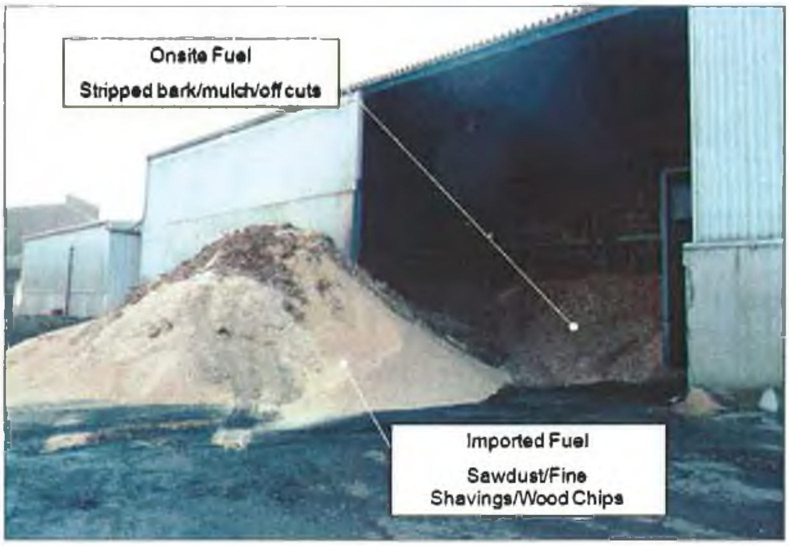


Figure 11 – IBS Fuel Store, External View, 07/01/2010

Illustrated above is the common storage area for all fuels, where the fuels are stored and processed before entering the traveling grate system which feeds the main boiler auger. The above picture is not the normal scenario as the imported fuel is normally housed inside to ensure that it is kept as dry as possible, but due to over capacity for the internal fuel supply it can be stored at the entrance of the warehouse. This means that the fuel delivered or imported can be greatly exposed to potential rainfall which may significantly alter the fuels moisture content.

4.2 FUEL INFORMATION

The biomass fuel in question is a predominantly derived from two species of tree (pine and spruce), supplied from renewable forestry. The total onsite fuel itself is a mixture of bark, saw dust and wood chip which are by- products from a saw mill processes

Important physical parameters of the biomass that influence the combustion process are particle dimensions, bulk density, energy density, gross and net calorific value and moisture content.

Particle Dimensions

The particle size is a variable but this does not have an effect on the calorific value although it does affect the combustion process as in the speed of combustion and necessary residence time within the furnace for complete combustion to take place.

Calorific Value

The gross calorific value (GCV) is defined as the heat released during combustion per mass unit of fuel under the constraints that the water vapour formed during combustion is in liquid phase and that the water and flue gas have the same temperature as the temperature of the fuel prior to combustion, measured in kJ/kg.

The net calorific value (NCV) is defined as the heat released during combustion per mass unit of fuel under the constraints that the water formed during combustion is in a gaseous phase and the water and the flue gas have the same temperature as the fuel prior to combustion. (P11 The handbook of biomass combustion and co-firing, 1998)

Bulk Density

The bulk density of biomass fuels vary with particle size, the fuel mixture, moisture content and on the compression of the material, measured in kg/m^3. The bulk density is also dependant upon the storage and settling time of the fuel before usage.

Together with the heat value and the bulk density, these determine the energy density which is the potential energy available per unit volume of the biomass. (P4) Energy from biomass: a review of combustion and gasification technologies, Peter Quaak, Harrie Knoef, Hubert E. Stassen

Energy Density

The amount of energy stored per unit volume (volume energy density) or mass (mass energy density) of a fuel and is measured in GJ/kg or KJ/kg. High energy densities generally make storage and transport of a fuel more convenient. Fossil fuels typically have higher energy density than solid or wet biomass fuels, though converted liquid biofuels and biogas are similar to those of their fossil counterparts. (www.biomassenergycentre.org.uk, Reference Library, Glossary, 2010)

Moisture Content

The proportion or ratio of water in a sample of fuel, defined as the weight of water as a percentage of the weight of biomass (i.e. – 50% wet and 50% dry fuel mix has an Moisture Content of 50%). This can be defined on either a wet basis, as a percentage of the total (wet) weight of the sample, or a dry basis, as a percentage of the oven dry weight of biomass. Wet basis is usually used for fuel purposes. The moisture content of biomass fuels varies considerably, depending on the type of biomass and the method of storage. The moisture content influences the combustion behaviour, and the energy density, and the adiabatic temperature of combustion and the volume of flue gas produced per energy unit. Wet biomass fuels need a longer residence time for drying before gasification and charcoal combustion can take place.

Moisture content is expressed as percent water of the total weight, and determines to a large degree where the wood chips can be used and if they can be stored. Freshly felled trees have a moisture content range of 40-60%. Typically softwoods such as pine and spruce have a fresh moisture content of at least 55%, in comparison to hardwoods such as oak and beech have a moisture content of around 50%. (P1, Coford, Harvesting / Transportation No. 6, 2005, Pieter D. Kofman)

4.2.1 Fuel Characteristics

The species which is processed in Grainger's Sawmill as previously outlined is principally Spruce and Pine, from which the final wood product is used for the various lumber requirements. From the debarking and grinding process is where the biomass fuel is sourced for the onsite fuel mixture comprised of bark, mulch, chips and saw dust.

The externally supplied fuel to the plant was also found to be Spruce and Pine soft wood, which maintains the consistency of the fuel supply and accommodates in less problematic calculations of the specific characteristics of the combined fuel mixture.

The biomass fuel make-up for the boiler plant is a homogeneous mixture with variable moisture content and calorific values. In order to calculate the effectiveness of the fuel in combustion going to the boiler and the process as a whole, the calorific value of the fuel must be established based upon the fuel mixture, moisture content and type. Due to the disparity in the fuel mixture over the course of the year and the exact quantities of each portion of the streams I difficult to accurately quantify a calculated a figure based over the 12 months data will be utilised.

In order to establish a value for the calorific value of the fuel for the purpose of this project an average value for the moisture content was utilised. This was completed through two mechanisms; 1) by simply averaging the monthly and weekly moisture contents recorded by the onsite personnel 2) by using frequency date to determine the most reoccurring moisture content recorded in the fuel mix.

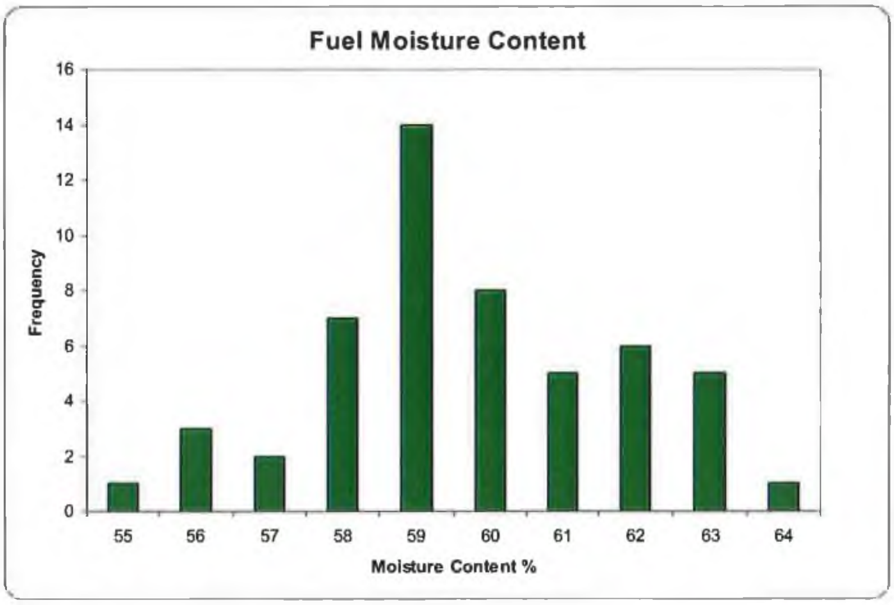


Figure 12 – Moisture Content Frequency taken weekly in 2009

The most frequent moisture content measured of the fuel makeup was found to be between 59 and 60% with majority of the fuel mix MC over 59%. Therefore, it can be assumed that the MC for calculation purposes can lie in the range of 59-61% for an accurate portrayal of the fuel characteristics.

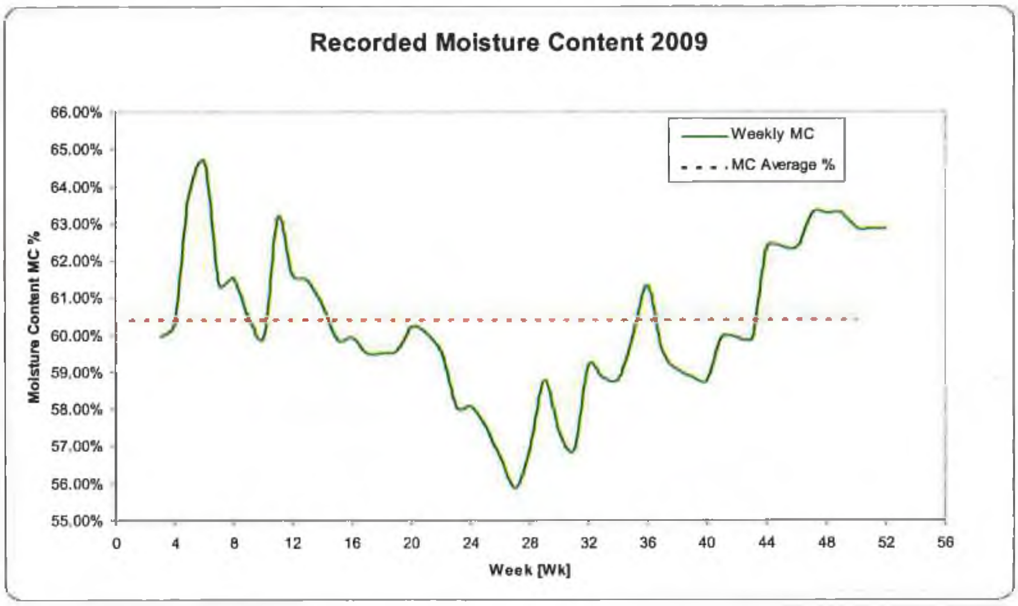


Figure 13 – Weekly Recorded Moisture Content 2009 *(Range 55%-66% MC)*

From examination of the weekly recorded and tested batches of fuel in 2009 it was found that an average reading of 60.43% was recorded over the year (50 data entries). This provides a better overall moisture content of the fuel mix and rules out any discrepancy between various fuel streams being used at any one time in the year.

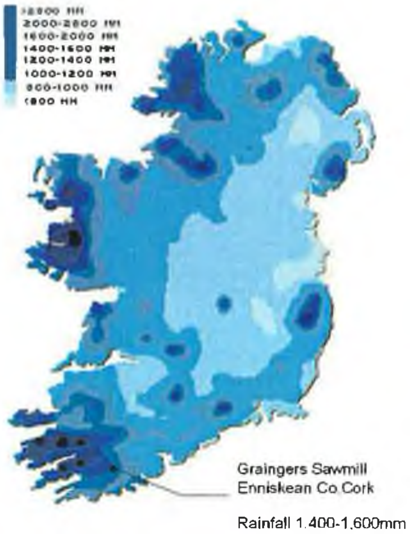
This confirms the earlier expectations from the frequency calculation approach to determining the fuel moisture content and is comparable to the recorded average value for the year.

Notably as formation of the weekly averages bare similar comparison to typical external air temperatures over the seasonal year, whereby the middle of the year May – August are warmer. This may indicate that the moisture content of the fuel is linked to the external air temperature. This is further discussed within the documents at a later stage.

4.2.2 Weather data

4.2.2.1 Rainfall

As rainfall can be a key indicator of changes moisture content and therefore have an affect on the fuel make up characteristics in Grainger's Sawmill it is important to compare and contrast historical trends in relation to the plant fuel.



Graingers Sawmill
Enniskean Co Cork

Rainfall 1.400-1.600mm

Information was garnered from the National Metrological service in Ireland (MET) for the local weather station based 40 miles from the site, at Cork International Airport.

Using the information for the rainfall in 2009 will allow for comparison to the characteristics on the fuel from 2009. This may indicate or be linked to the plant performance and may provide an insight into the key influencing features for plant operation.

4.2.2.2 Air Temperature

Similar to rainfall, temperature profiles for the immediate locality will be examined to ascertain whether the external air temperate will have any affect on the plant operation relating to the fuel and efficiencies.

Determining the average air temperature for the area will provide insight into the evaporation characteristics of the water or MC of the fuel. This will in turn form a vital part of the calculations in determining the quantity of energy required for the recovery of energy for use in reducing the fuel moisture content (MC).

4.2.2.3 Heating Degree Days

Heating degree days are used to predict heating energy consumption in buildings, but in the case of Grainger's Sawmill it may be used to determine how much energy is required to reduce the moisture content of fuel dependant on drying of the fuel. Heating degree days provide a useful measure of the variation in outside temperature, which enables energy consumption for heating or drying to be related to prevailing weather conditions. The outside air temperature is likely to be colder during January than in March. Due to this, energy consumption relates both to the degree of lower temperatures and the duration of that coldness. The degree day method allows for both these factors by setting a base outside air temperature (15.5°C for Ireland) above which most buildings do not require any heating but can be used at lower temperatures for special investigations. Therefore, by monitoring daily outside air temperature, it is possible to produce tables of monthly heating degree days for the site and the feasibility of drying the fuel mixtures prior to use allowing for estimations of drying energy requirements. Information for this purpose was sourced from the Degree Days.net database using local Cork International Airport as a reference point.

4.2.2.4 Weather Data Analysis

Collating the weather data for the locality and comparing the moisture content average values for the fuel streams may provide a greater insight into the how the plant operates in relation to weather conditions.

	Rainfall		Temperature		Heating Degree Day	
	Monthly (mm)	Mean (mm)	Monthly (oC)	Mean (oC)	Monthly HDD	Mean HDD
Jan	197.60	148.30	4.80	5.10	331.00	
Feb	21.10	115.90	5.20	5.10	288.00	
Mar	41.30	97.10	6.80	6.30	272.00	
Apr	155.00	70.20	8.30	7.90	223.00	
May	90.50	84.10	10.40	10.30	166.00	
Jun	84.50	67.70	13.80	13.00	72.00	
Jul	203.80	65.40	14.20	14.90	63.00	
Aug	157.10	89.90	14.10	14.60	63.00	
Sep	55.40	97.40	12.90	12.80	87.00	
Oct	166.60	125.80	11.70	10.40	127.00	
Nov	245.30	108.70	7.40	7.20	248.00	
Dec	160.30	136.50	3.90	6.10	353.00	
Annual	1,578.50	100.58	9.50	9.48	2,293.00	191.08

Table 3 – 2009 Weather information for Cork International Airport

Firstly linear regression analysis, which is a statistical technique which determines and quantifies the relationship between variables, was used. This is a widely used energy management tool which enables standard equations to be established for energy consumption, often from data which would otherwise be meaningless.

However, while it is clear that time-dependent analysis is a useful comparative tool, it has its limitations; it is difficult to identify why certain trends occur or indeed, if perceived trends actually exist. Regression analysis overcomes this difficulty by removing the time element from the analysis and focusing instead on the two variables which influence energy consumption. Using the linear regression analysis statistical technique will aid in identifying or removing weather dependant relationships and the moisture content.

Firstly the comparison of Heating Degree Days (HDD) and the averaged monthly moisture content of the fuel will be examined for any possible relationships.

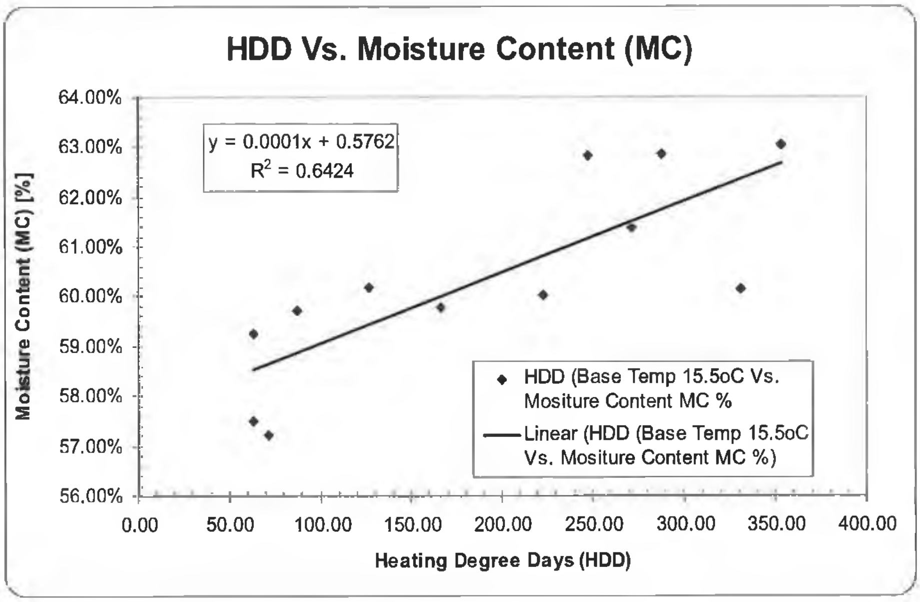


Figure 14 – Linear Regression – HDD Vs. Moisture Content (MC),

From the linear regression analysis above in Figure 14 which illustrates that there is a correlation between the HDD and the fuel. Moisture Content (MC) of $R^2 = 0.6424$ or 64.24%. While this is not a very strong correlation it does provide a valuable insight to when the external temperatures are lower in the colder months that the moisture content of the fuel is higher. This would be related to the amount of moisture in the air which will be absorbed by the fuel before going to the boiler. With the increased moisture content of the fuel, the boiler is less efficient and uses more fuel for the same amount of energy produced in comparison to months where the MC is lowest.

In the second linear regression analysis the external air temperature for the area was analysed against the moisture content of the fuel over 2009.

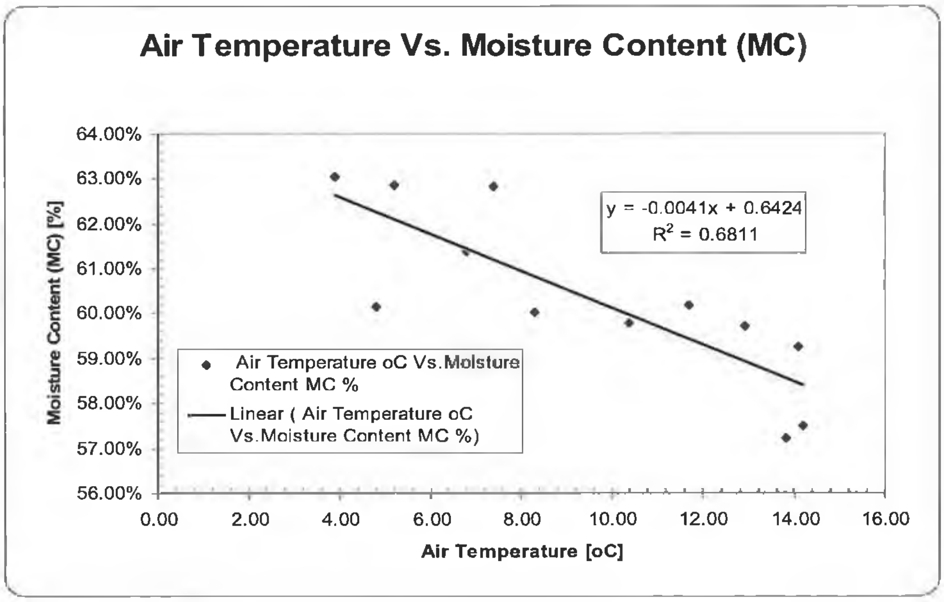


Figure 15 – Linear Regression – Air Temperature Vs. Moisture Content (MC),

From examination of the linear regression analysis in Figure 15 it can be seen that there is a correlation between the air temperature and the fuel. Moisture Content (MC) of $R^2 = 0.6811$ or 68.11%. Similar to the regression analysis with the HDD this analysis with air temperature yields an increased degree of correlation. The correlation is higher but the correlation is not as definitive as required, as above $R^2 = 0.75$ or 75% correlation is considered a strong correlation of the two data inputs. This does confirm the initial findings in Figure 14 and it can be seen that with an increase in air temperature the moisture content reduces in the fuel. This indicates that if the fuel was kept in a warmer environment, then the fuel moisture content will decrease.

Thirdly rainfall for the locality for 2009 will be compared with the moisture content of the fuel, to ascertain whether there is any correlation between the two sets of data.

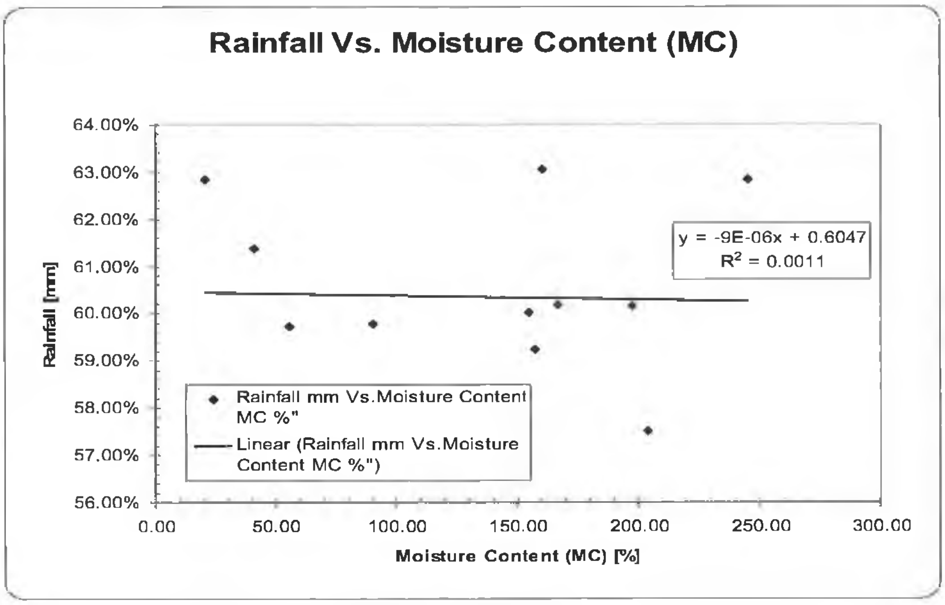


Figure 16 – Linear Regression – Rainfall Vs. Moisture Content (MC),

Analysis from the data provided in Figure 16 outlines that there is no correlation between the rainfall and the moisture content of the fuel. With a correlation factor (MC) of $R^2 = 0.0011$ or 0.11% indicating that the rainfall in the area has no bearing on the amount of moisture that is found in the fuel. Identifying that there is no correlation is both helpful and difficult to interrogate, as the fuel is wet when it enters the plant and the raw lumber after being stripped and chipped is thought to be subject to the elements. Comparatively, the onsite fuel is stored indoors when processed and rainfall does not vary the air temperature dramatically and as a result has no relationship with the moisture content of the fuel. The external fuel can be left exposed to the elements but this is thought to be infrequent and not have a determent al effect on the regression analysis.

4.3 CALCULATIONS

4.3.1 Fuel Calculations

Utilising a number of resources to attain the characteristics of the fuel mix was made possible through the databases supplied on the intent by the IEA Task 32 and EU Bionet research facilities.

Due to only initial small scale research being completed in this area on the various types of wood fuels and with varying dryness factors/moisture content, it proved difficult to confirm exact figures over varying fuels and MC ranges. Therefore, it was necessary to calculate the Net Calorific Value (NCV) of the fuel mix in order to examine the potential energy of the fuel streams using IEA Task 32 statistics published.

The formula below allows for the calculation of the net calorific value on a wet basis to be calculated from the gross calorific value derived in Table 4.

$$NCV = GCV * \left[1 - \frac{W}{100}\right] - \left[2.447 * \frac{W}{100}\right] - \left[2.447 * \frac{H}{100}\right] * 9.01 * \left[1 - \frac{W}{100}\right]$$

Eq. 1.0 - The Biomass Assessment Handbook by Frank Rosillo-Calle, Peter de Groot, Sarah L. Hemstock, and Jeremy Woods, 2007, P68)

NCV	net calorific value in MJ/kg fuel (wet basis)
GCV	gross calorific value in MJ/kg fuel (dry basis)
w	water content of fuel as percentage of weight (wet basis)
h	concentration of hydrogen as percentage of weight (dry basis).

The first term simply converts the gross calorific value to the wet basis. The second term is due to the latent heat of vaporization of the water contained in the wood. The specific latent heat of vaporization of water at 25 °C and constant pressure is 2.447 MJ/kg. The third term is due to the vaporization of the water produced when the hydrogen in the wood is combusted. The concentration of hydrogen in woody biomass is typically 5.5% (dry basis - $H_2O \div M\ H_2$ which is the molecular mass ratio between H_2O and $H_2 = 9.01$)

		GCV (kJ/kg)	Hydrogen (H2%-wt)
Spruce	Woodchip	18,800.00	5.77
	Sawdust	20,054.00	5.60
	Bark	20,525.00	5.18
Pine	Woodchip	16,071.00	5.60
	Sawdust	20,846.00	6.24
	Bark	20,431.00	5.80

Table 4 – Fuel Mixture Characteristics – Grainger's Sawmill

As there were three fuel mix types, values of each mix were averaged in order to get a more true representation of the NCV for the biomass fuels. These include the general mix for the onsite supply from the grinder:

1) Onsite - bark, offcuts, sawdust and wood chips

2) Onsite - supply of woodchips

3) External - sawdust and woodchips.

Utilising the information in the Table 4 and the known combination of each of the fuel stream, made it possible to determine the GCV and Hydrogen amount for each of the fuel streams. This was established due to the known weight of each of the fuel streams relative to the composition characterise. This is important as the known moisture content (from routine testing) will allow the NCV to be calculated for a number of streams and their varying moisture contents.

	Onsite	Woodchip	External
GCV (kJ/kg)	19,454.50	17,435.50	18,942.75
Hydrogen (H2%-wt)	5.70	5.69	5.80

Table 5 - IBS Fuel Mix information, 2009

Using the information garnered in the above table and inputted into the formula in Eq. 1.0 allowed for the determination of the NCV for the fuel streams over the varying moisture levels, as outlined in Tables 5-7

Onsite				
Moisture %	**H2O per Kg kg**	**GCV kJ/kg**	**H per Kg kg**	**NCV kJ/kg**
50	0.50	20,182.67	0.057	10,089.48
51	0.51	20,182.67	0.057	9,887.62
52	0.52	20,182.67	0.057	9,685.75
53	0.53	20,182.67	0.057	9,483.89
54	0.54	20,182.67	0.057	9,282.03
55	0.55	20,182.67	0.057	9,080.16
56	0.56	20,182.67	0.057	8,878.30
57	0.57	20,182.67	0.057	8,676.44
58	0.58	20,182.67	0.057	8,474.57
59	0.59	20,182.67	0.057	8,272.71
60	0.60	20,182.67	0.057	8,070.84
61	0.61	20,182.67	0.057	7,868.98
62	0.62	20,182.67	0.057	7,667.12
63	0.63	20,182.67	0.057	7,465.25
64	0.64	20,182.67	0.057	7,263.39
65	0.65	20,182.67	0.057	7,061.53
66	0.66	20,182.67	0.057	6,859.66

Table 6 – Onsite Fuel Mix information NCV

Woodchip				
Moisture %	**H2O per Kg kg**	**GCV kJ/kg**	**H per Kg kg**	**NCV kJ/kg**
50	0.50	19,620.00	0.057	9,808.15
51	0.51	19,620.00	0.057	9,611.91
52	0.52	19,620.00	0.057	9,415.68
53	0.53	19,620.00	0.057	9,219.44
54	0.54	19,620.00	0.057	9,023.20
55	0.55	19,620.00	0.057	8,826.96
56	0.56	19,620.00	0.057	8,630.73
57	0.57	19,620.00	0.057	8,434.49
58	0.58	19,620.00	0.057	8,238.25
59	0.59	19,620.00	0.057	8,042.02
60	0.60	19,620.00	0.057	7,845.78
61	0.61	19,620.00	0.057	7,649.54
62	0.62	19,620.00	0.057	7,453.31

63	0.63	19,620.00	0.057	7,257.07
64	0.64	19,620.00	0.057	7,060.83
65	0.65	19,620.00	0.057	6,864.59
66	0.66	19,620.00	0.057	6,668.36

Table 7 – Onsite Woodchip Mix information NCV

External				
Moisture %	**H2O per Kg kg**	**GCV kJ/kg**	**H per Kg kg**	**NCV kJ/kg**
50	0.50	20,035.00	0.058	10,015.64
51	0.51	20,035.00	0.058	9,815.25
52	0.52	20,035.00	0.058	9,614.86
53	0.53	20,035.00	0.058	9,414.48
54	0.54	20,035.00	0.058	9,214.09
55	0.55	20,035.00	0.058	9,013.70
56	0.56	20,035.00	0.058	8,813.31
57	0.57	20,035.00	0.058	8,612.93
58	0.58	20,035.00	0.058	8,412.54
59	0.59	20,035.00	0.058	8,212.15
60	0.60	20,035.00	0.058	8,011.76
61	0.61	20,035.00	0.058	7,811.38
62	0.62	20,035.00	0.058	7,610.99
63	0.63	20,035.00	0.058	7,410.60
64	0.64	20,035.00	0.058	7,210.22
65	0.65	20,035.00	0.058	7,009.83
66	0.66	20,035.00	0.058	6,809.44

Table 8 – External Delivered Fuel Mix information NCV

What is most noticeable is that variation of the moisture content across all the streams has a significant effect on the NCV and the amount of energy that can be captured over from the combustion of the fuel at different MC levels. This reinforces the requirement to reduce the MC of the fuel entering the boiler, in order to maximize the thermal efficiency and optimise the fuel loads delivered to the site to generate the optimum amount of steam and therefore electricity via the steam turbine. As the water within the fuel (MC) will evaporate at low temperatures more energy is required in the combustion process and lowers the temperature of the combustion chamber. This has an adverse affect on the system, as it requires supplementary fuel to evaporate the excess water content in the fuel, and therefore requires more fuel to do so and reduce the energy available to the boiler for steam generation.

4.3.2 Grainger's Fuel Moisture Content

From historical records over the course of 2009 an average of 60.43% moisture content (MC) was recorded. The maximum recorded value for MC over the course of the year was 64.69% and the minimum recorded value of 55.88% - this would be with a combination of all the fuel streams. Due to the nature of the fuel transportation and delivery system; to deduce accurate quantities of each fuel stream is difficult to deduce. For this reason an average or uniform value was used to determine the affects across the three fuel streams in an effort to illustrate the difference in NCV at this average value.

Therefore, information provided from Tables 5-7 was trended to illustrate the variance in NCV over the moisture content range of each of the fuel streams. Also, the average MC for 2009 across the fuel mixes was inputted and results interpolated to provide a comparison of each fuel stream for a given MC. This allows comparison of the effectives and fuel properties of the system and compare them to the heat generated from the boiler.

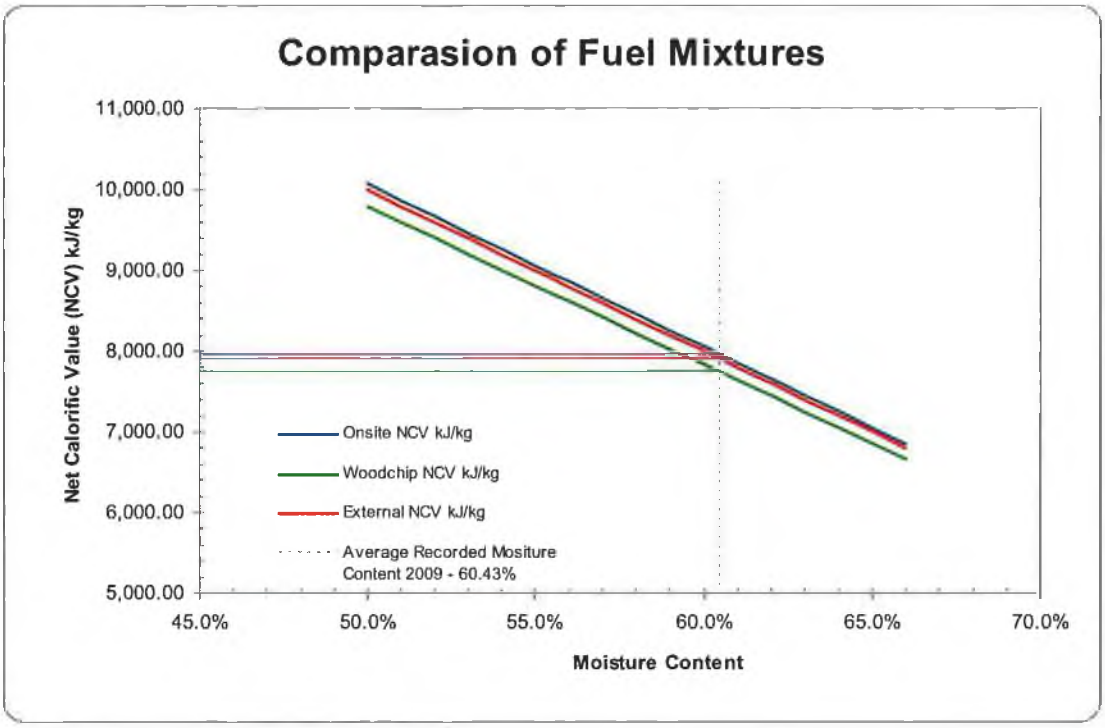


Figure 17 – NCV for the fuel mixtures at the average 2009 recorded MC

	Onsite[1]	**Woodchip**	**External**
	Onsite NCV kJ/kg	Woodchip NCV kJ/kg	External NCV kJ/kg
Average at 60.43%	7,984.04	7,761.40	7,925.60
kW/kg	2.22	2.16	2.20

Table 9 – NCV for the fuel mixtures at the average 2009 recorded MC

The graphical illustration identifies that the onsite fuel mixture has a higher combined Net Calorific Value (NCV) compared to the other two fuel streams. While the values are very similar as outlined in Table 9 the results were surprising and will require further analysis.

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[1] 1) Onsite - bark, offcuts, sawdust and wood chips

2) Woodchip - supply of woodchips

3) External - sawdust and woodchips.

4.3.3 Moisture Content Reduction

For biomass combustion systems, moisture content plays a vital role and any reduction in water content will have a positive affect on the combustion process. Water content in the fuel requires energy to remove it, thus reducing overall system efficiency and potentially reducing combustion temperature below the optimum.

Reduction in combustion temperature below the optimum may result in incomplete combustion of the fuel giving rise to combustion issues such as residence time in the combustion bed, fouling, and reduction in combustion efficiency. It may also lead to harmful emissions (due to incomplete combustion) which may condense in the flue, especially if the flue is elongated or includes changes of direction, and particulates.

The moisture content may also condense in the flue, and all these may lead to corrosion of the flue and the gradual accretion of material leading to the potential for eventual blockages or even fire. Modern, high efficiency combustion systems are designed to operate within a range of parameters to ensure that their performance meets emissions and efficiency specifications and a range of acceptable moisture content for the fuel is also usually specified. It should also be prioritised that the moisture content of the fuel be kept as low a permitted to reduce adverse affects due to moisture content of the fuel.

High moisture content biomass has a much lower net energy density by mass, owing to the weight of the water, but also by volume owing to the energy required to evaporate the water. Storage is also less efficient, with less net energy available, but also storage of high moisture content biomass brings other problems with greater risk of composting, causing loss of biomass and potentially a fire risk from elevated temperatures and mould formation. Good ventilation and air flow help to minimise these problems.

Reduction in the plant of the moisture content in the fuel can be reduced to the lowest permitted level of 50% MC due to the design and efficiency of the system. At the current average moisture content recorded over the year being 60.43% and the highest record at 64.49% there is a large capacity for the reduction in MC ,therefore a reduction in fuel required to deliver the optimum level of steam generated.

Using the average recorded air temperature of area at 9.48 °C it is possible to determine how much energy will be required to liberate the moisture from the wet fuel to achieve a moisture content of 50% in the fuel across the three fuel mixtures.

	Onsite	**Woodchip**	**External**
	Onsite NCV kJ/kg	Woodchip NCV kJ/kg	External NCV kJ/kg
Heating value of the fuel @ 60.43% MC	7,984.04	7,761.40	7,925.60

Table 10 – NCV for the fuel mixtures at the average 2009 recorded MC

$$(\text{NCV}_{\text{wood}} \text{ with \% MC} + \text{NCV}_{\text{water}} * \text{1-Wood MC}) = \text{Net Heating kJ/kg}$$

Eq. 2.0 - Mikko Helin, Joensuu, Moisturein wood fuels and drying of woodchips presentation, 2005, P3)

Sample Calculation for onsite Fuel Mix 60.43% MC compared to 50% MC

Heating value of wood = 7,984.04 kJ/kg (Onsite Mixture @ 60.43% MC)

To evaporate 1 kg of water at air temperature 9.48 °C = 2,265.00 kJ/kg H_2O (0.623 kWh/kg H_2O)

Net Heating $(7,984.04 + 2,265*0.3957) = 8,880.30 \div 2 = 4,440.15$ kJ/kg

Heating value of wood = 10,089.48 kJ/kg (Onsite Mixture @ 50% MC)

To evaporate 1 kg of water at air temperature 9.48 °C = 2,265.00 kJ/kg H_2O (0.623 kWh/kg H2O)

2 kg of woodchips, moisture content 60.43 % = 1 kg of wood at x MC + 1 kg Water

Net Heating (10,089.48 + 2,265*0.50) = 12,354.48 ÷ 2 = 5,610.99 kJ/kg

Therefore to reduce the moisture content of the onsite fuel mixture from 60.43% to 50%

5,610.99 KJ/kg - 4,440.15 kJ/kg = 1,170.84 kJ/kg or 0.325 kW/kg

Examining how much heat would be required for all the fuel mixes can now be calculated and tabulated in order to examine the heat recovery that is required from the plant.

	Onsite NCV kJ/kg	Woodchip NCV kJ/kg	External NCV kJ/kg
60.43%	7,984.04	7,761.40	7,925.60
50.00%	10,089.48	9,808.15	10,015.64
60.43%	4,440.15	4,328.83	4,410.93
50.00%	5,610.99	5,470.32	5,574.07
Extra Heat Required per kJ/kg	1,170.84	1,141.50	1,163.14
Extra Heat Required per KWh/kg	0.33	0.32	0.32

Table 11 – Energy required to reduce the MC from 60.43 – 50% MC

There is minimal difference in the heat required to reduce the moisture content of the fuel from 60.43% to the proposed 50% across the three fuel streams. This identifies that a single heating system can be used for all the fuel streams in comparison to having to dry certain fuels separately to achieve the same moisture content.

From the section 4.3.1 it is now possible to ascertain the quantity of heat that will be given off relative to changing the moisture content of the fuels from 60.43% to 50%.

	Onsite	Woodchip	External
Moisture %	NCV kJ/kg	NCV kJ/kg	NCV kJ/kg
50	10,089.48	9,808.15	10,015.64
51	9,887.62	9,611.91	9,815.25
52	9,685.75	9,415.68	9,614.86
53	9,483.89	9,219.44	9,414.48
54	9,282.03	9,023.20	9,214.09
55	9,080.16	8,826.96	9,013.70
56	8,878.30	8,630.73	8,813.31
57	8,676.44	8,434.49	8,612.93
58	8,474.57	8,238.25	8,412.54
59	8,272.71	8,042.02	8,212.15
60	8,070.84	7,845.78	8,011.76
60.43%	7,984.04	7,761.40	7,925.60
61	7,868.98	7,649.54	7,811.38
62	7,667.12	7,453.31	7,610.99
63	7,465.25	7,257.07	7,410.60
64	7,263.39	7,060.83	7,210.22
65	7,061.53	6,864.59	7,009.83
66	6,859.66	6,668.36	6,809.44

Fuel Output	NCV kJ/kg	NCV kJ/kg	NCV kJ/kg
Increase kJ/kg	2,105.44	2,046.75	2,090.04
Increase kW/kg	0.58	0.57	0.58

Table 12 – Comparison of MC for fuel streams

There is a dramatic increase in potential fuel output from changing the moisture content of the fuels from 60.43% to 50%. It is now possible to ascertain the quantity of heat that will be given off relative to changing the moisture content of the fuels. Using the annual usage figures of the plant for the fuel required, the amount of energy required to dry the fuel can be calculated, in order to determine how much energy must be recovered for the purpose of fuel drying.

	Onsite	Woodchip	External
	kg	kg	kg
2009 Weight PA	31,809,640.00	1,597,960.00	12,584,798.00
Mj/kg Required PA	37,243,965.36	1,824,064.51	14,637,873.47
MJ per kg	4,251.59	208.23	1,670.99
MWh per kg	1.18	0.06	0.46

Table 13 – Reduction in Fuel required – 60.43 to 50% MC

Therefore a heat recovery source of 4,251 MJ or 1.18 MWh_{th} is required to adequately reduce the moisture content of the fuel per kg before entering the boiler. This is a significant amount of energy but the plant has the capability of outputting significantly more at peak capacity and a factor of this is rejected to the condensers.

When the fuel input increases there will be a significant reduction of fuel required to deliver the same energy output of steam (MW) to the turbine. Comparing the annualised fuel figures as a total, and as the fuel output and drying energy inputs are comparable it is possible to quantify the reduction of fuel required, with the reduction of the moisture content.

	Onsite	**Woodchip**	**External**	**Totals**
	kg	**kg**	**kg**	**kg & kJ/Kg**
2009 Weight PA	31,809,640	1,597,960	12,584,798	45,992,398
KJ/kg @ 60.43% MC	7,984	7,761	7,926	-
Fuel potential KJ/kg	253,969,542,247	12,402,403,307	99,742,046,011	366,113,991,565
KJ/kg @ 60.43% MC	10,089	9,808	10,016	-
New Weight PA	25,171,714	1,264,500	9,958,632	36,394,846
			Overall Reduction	9,597,552
			Percentage	20.87%

Table 14 – Reduction in Fuel required – 60.43 to 50% MC

This illustrates that there will significant reduction in fuel required for the system should the system parameters in terms of moisture content (MC) be changed from the averaged 60.43% to 50.00% proposed.

4.3.4 Calculating Heat Recovery Potential

Heat recovery from the system has been identified in two areas for reuse in the drying of the fuel before the boiler system:

1) The boiler flue stack and

2) The exhaust steam flow connected to the condensers which is fed back into the boiler feed water tank.

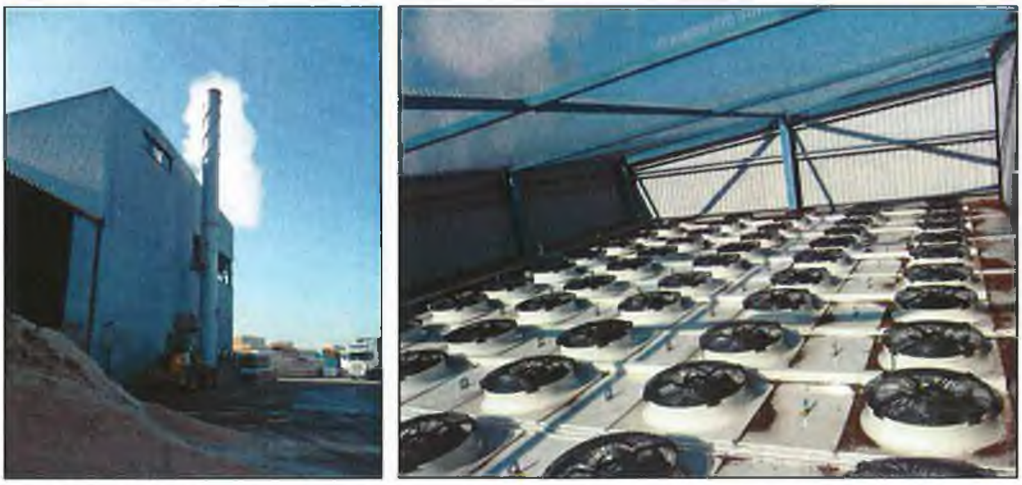

Figure 18 – Boiler Flue Stack [Left] and Steam Exhaust Condensers [Right]

The main boiler stack stands 40m high and is connected after the boiler and before the stack by the Electro Static Precipitator (ESP) which is a particle control device that uses electrical forces to move the particles out of the flowing gas stream and onto collector plates.

Each radiator has a stated surface area of 1,798.6 m^2 of which the site have 9 no. radiators resulting in a total surface area of 16,187m^2. In addition each radiator has secondary 100mm diameter flow and return headers each approximately 2.2m long.

4.3.5 Condenser Heat Recovery Potential

The diagram outlined Figure 19 is a block diagram representation of the steam turbine cycle in the CHP plant. The turbine is an extraction steam turbine, which consists of a High Pressure (HP) stage and Low Pressure (LP) stage turbines, the turbines are coupled to an alternator via a reduction gearbox.

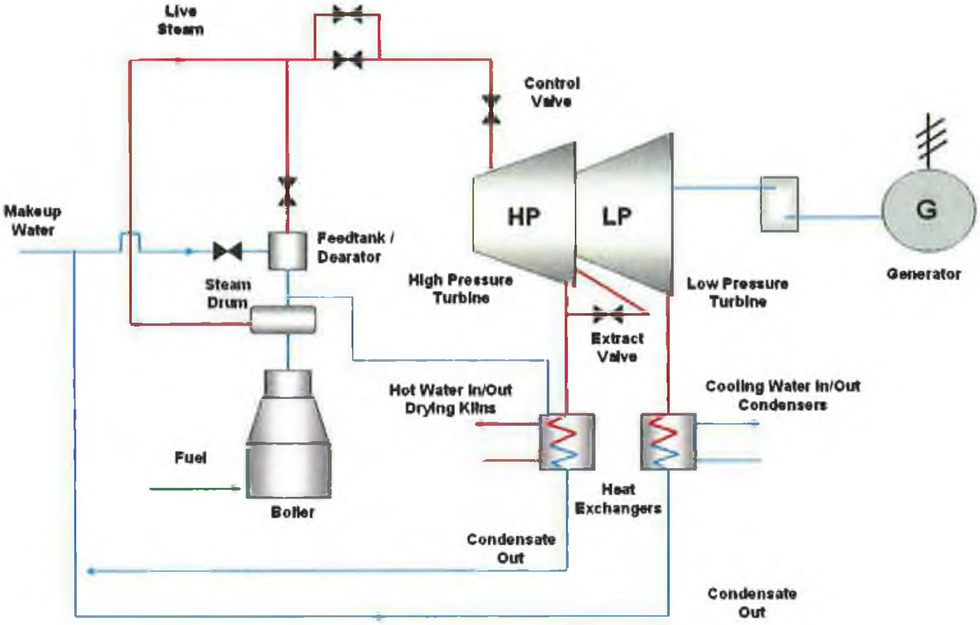

Figure 19 – Block Diagram of the IBS CHP System

The high pressure steam enters the HP stage where it is expanded through the turbine. It exits the HP stage where a proportion of the steam is extracted for use in a heat exchanger this is used to heat hot water for process. The remaining steam is then expanded through the LP stage; it then exits the LP stage into a condenser where the steam is cooled back to water.

The cooling water used in the condenser is passed through a bank of radiators where the heat gained from converting the steam to water is given up to atmosphere. This heat rejected from the system to atmosphere is by far the biggest efficiency loss within the CHP plant steam cycle and can account for between six and seven megawatts of heat being lost.

In order to determine the heat rejected by the low pressure turbine efficiency and thus the heat recovery potential between exhaust steam flow and the mass steam flow going to moving exhaust has to be calculated.

One of the major obstacles in calculating the steam flow through the system is that there is no flow meter on either the extract steam flow or exhaust steam flow so there is no direct measurement of either of these flows. The only flow meter within the system that is proportional to the flow of steam to the extract and exhaust steam flows is the flow meter that is measuring the hot water flow to the kilns.

From this the exhaust steam flow can be determined as the difference between the mass flow of steam being supplied to the turbine and the mass flow of steam that is extracted for the purpose of supplying heat for the kilns. Both the hot water heat exchanger and the exhaust steam condenser can be considered to be constant pressure, surface condensers. As such they are both operating under constant pressure; therefore energy transfer between the process fluids will take the form of changes in enthalpy.

Therefore neglecting losses,

Energy In = Energy Out

Eq. 3.0 (Basic Engineering Thermodynamics, Rayner Joel, 1998, p300)

This formula can be used to calculate the mass flow of extract steam using the following formula and known values taken from the plants DCS system.

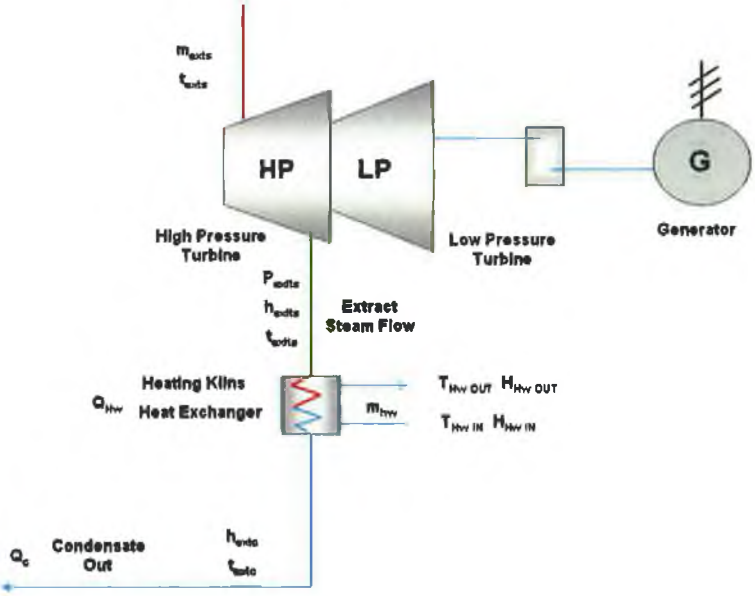

Figure 20 – High Pressure, Extract Steam System

m_{extc}	Mass flow of extraction condensate	kg/sec
m_{exts}	Mass flow of extraction steam	kg/sec
m_{HW}	Mass flow of hot water	kg/sec
h_{exts}	Specific enthalpy of extract steam	kj/kg
$_{extc}$	Specific enthalpy of extract condensate	kj/kg
$h_{HW\ IN}$	Specific enthalpy of hot water entering heat exchanger	kj/kg
$h_{HW\ OUT}$	Specific enthalpy of hot water exiting heat exchanger	kj/kg
t_{exts}	Temperature of extract steam	°C
$t_{Hw\ in}$	Temperature of hot water entering hot water heat exchanger	°C
$t_{HW\ OUT}$	Temperature of hot water exiting hot water heat exchanger	°C
t_{extc}	Temperature of condensate exiting hot water heat exchanger	°C
Q_w	Heat energy contained in hot water	kj/kg
Q_c	Heat energy contained in condensate out of hot water heat exchanger	kj/kg
p_{exts}	Pressure of extraction steam	Bar

The enthalpy of water is derived from the temperature multiplied by the specific heat capacity of water which is 4.186 kj/kg k. The mass flows for both the steam and condensate remain unchanged within the heat exchangers, although the steam undergoes a change of state from steam to water. For these the calculations the mass flow of the steam on both sides of the heat balance require for the following calculations.

$m_{extc} = m_{exts}$

Energy = Mass Flow * Enthalpy

Therefore, Energy In = Energy Out

$$m_{exts} * h_{exts} + m_{hw} * h\ hwin = m_{exts} * h\ extc + m_{hw} * h_{hw\ OUT}$$

$$m_{exts} * h_{exts} - m_{exts} * h_{extc} = m_{hw} * hw_{out} - m_{hw} * h_{hw\ IN}$$

Therefore the energy balance can be re-written as,

$$m_{exts}(h_{exts} - h_{extc}) = m_{hw}(h_{hw\ OUT} - h_{hw\ IN})$$

With this formula the quantity of extract steam entering the hot water heat exchanger can be calculated for any given load. The following example uses values that can be read directly from the plants DCS system,

$t_{hw\ IN}$ = temperature of hot water inlet temperature = 105 °C

t_{extc} = temperature of condensate out of heat exchanger = 105 °C

$t_{hw\ OUT}$ = temperature of hot water outlet temperature = 118 °C

m_{hw} = mass flow of hot water = 32.96 kg/sec

t_{exts} = 203 °C

p_{exts} = 0.8 bar

Using these values to calculate the specific enthalpy gives the following,

$h_{hw\ IN}$	105 * 4.186 = 439.53 kj/kg
$h_{hw\ OUT}$	18 * 4.186 = 493.95 kj/kg
h_{extc}	105 * 4.186 = 439.53 kj/kg
h_{exts}	2877 Kj/kg *(superheated steam @ 0.8 bar & 203 °C)*

Therefore; $m_{exts}\,(h_{exts} - h_{extc}) = m_{hw}\,(h_{hw\ OUT} - h_{hw\ IN})$

$m_{exts}\,(2877 - 439.53) = 32.96\ (493.95 - 439.53)$

$m_{exts} * 2437.5 = 1793.68$

$m_{exts} = 0.7341$ kg/sec

With the exhaust steam flow known, the quantity of heat being rejected can now be calculated. The rejected heat is the difference in enthalpy between the exhaust steam entering the condenser and the condensate exiting the condenser.

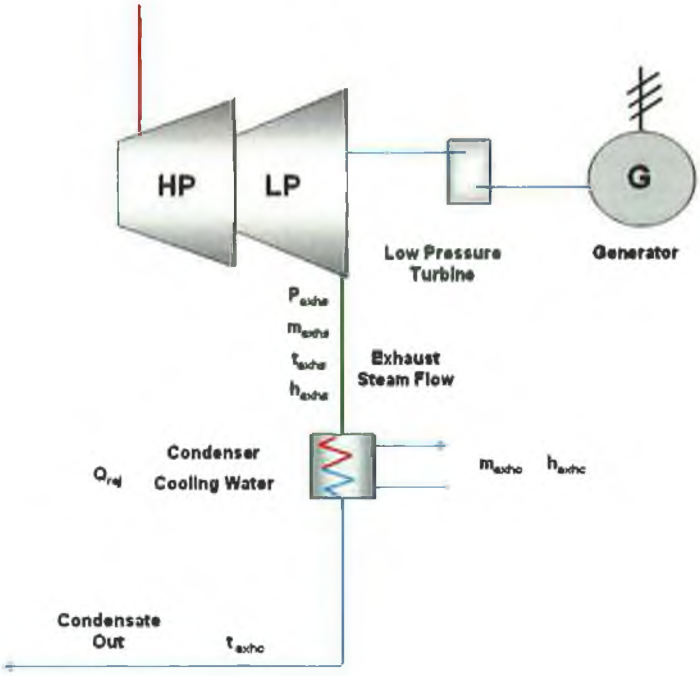

Figure 21 – Low Pressure, Extract Steam System

h_{exhs}	Specific enthalpy of exhaust steam	kj/kg
h_{exhc}	Specific enthalpy of exhaust condensate	kj/kg
t_{exhs}	Temperature of exhaust steam	°C
t_{exhc}	Temperature of exhaust condensate	°C
Q_{rej}	Heat energy rejected within the condenser	kj/kg
p_{exhs}	Pressure of exhaust steam	bar
$\dot{m}_{exhs}$	Mass flow of exhaust steam	kg/sec
$\dot{m}_{exhc}$	Mass flow of exhaust condensate	kg/sec

As the mass flow of steam entering the condenser and mass flow of condensate exiting the condenser are the same, it will use the mass flow of exhaust steam in the following calculations.

$\dot{m}_{exhs} = \dot{m}_{exhc}$

$Q_{rej} = {}^{\circ}C_{exhs} (h_{exhs} - h_{exhc})$

$\dot{m}$ exhs = 3.12 kg/sec *(calculated)*

p exhs = 0.27 bar a *(from DCS system)*

t exhs = 63.9 °C *(from DCS system)*

t exhc = 62.5 °C *(from DCS system)*

Therefore;

h_{exhc} = 62.5 * 4.186 = 261.63 Kj/kg

h_{exhs} = 2,341 Kj/kg *(from steam tables)*

Q_{rej} = 3.12 * (2341 – 261.63)

Q_{rej} = 6,487.6 Kj/sec or 6.487 MW

This outlines that there is a substantial amount of heat being rejected to the atmosphere in order to balance the turbine load. This would equate to 5 times the heat required to dry the annual fuel load for the current plant operation. Further discussion is required surrounding the effects of balancing the turbine load further by increasing the load on the high pressure, extract turbine side. This would significantly reduce the amount of heat rejected and allow a greater amount of heat to be utilised for productive purposes.

4.3.6 Stack Heat Recovery Potential

The potential for a stack economizer which is an air-to-water heat exchanger is designed to use heat from hot boiler flue gases to preheat water. Economizers have been used on large utility steam boilers to preheat the feedwater using recovered stack heat. These installations have become more economical as energy prices have risen and smaller economizers with light but durable and efficient heat exchangers have been developed.

Economizers are sized to be installed into the stack, as close to the boiler's flue outlet as practical. The interior of the stack economizer must be able to withstand the corrosive effects of condensing flue gases. Heat is typically exchanged through finned tubes that must be constructed from a high-grade stainless steel.

Prior to any installation of an economizer or other technology to recover heat (e.g. recuperator) an analysis of the potential heat recovery should be completed and any obstacles that may impact on the normal boiler operation be investigated.

These can consist of;

- Formation of condensation which will be high in corrosive nature, and essentially damage the lining of the stack,
- Pressure drop and affect which removing/recovering heat that can disrupt the natural stack effect
- Increasing energy usage of the extract fan and the comparison for heat recovery vs. electrical energy input required
- Potential for fowling and maintenance requirements

Determination of the potential energy available for heat recovery from the stack will fundamentally illustrate if the installation of a heat recovery unit, such asno semi colon here an economizer is suitable for the plant.

	Particulate	Nox	CO	Temp	O2	Vol Flow Rate
	Mg/Nm3	mg/Nm3	mg/Nm3	°C	%	m3/hr
IPPC Limit	**50**	**500**	**200**	N/A	N/A	**26,640**
Q1 2009	0	189	57	160	13	13,772
Q2 2009	4	222	43	147	13	13,394
Q3 2009	1	116	32	159	12	16,646
Q4 2009	6	146	48	175	6	14,665
2009 Averages	3	168	45	160	11	14,619

Table 15 – Emissions Data from the IBS plant in 2009

$Q = m \text{ x } Cp \text{ x } (T_o - T_i)$

Eqn 4.0 (P12 Heat Transfer 9th Edition, JP Holman, 2002)

Where;

Q = total heat transfer rate KJ/Kg

mg = gas mass flow rate, Kg/hr

cp = mean specific heat of gas, KJ/Kg K

T_i = gas temperature leaving economizer, k

T_o = ambient temperature, k

Therefore, using the information garnered from the onsite DCS stack monitoring station and properties from Appendix A

$Q = (14{,}619 m^3/hr * 0.815 kg/m^3) \text{ x } 1.017 \text{ KJ/Kg K x } ((160^oC + 273) - (10^oC + 273))$

$Q = 1{,}817{,}554.69$ KJ/hr

$Q = 504.671$ kW or 0.5 MW per hour

Note: Due to the difficulties of ascertaining the density and SHC of the flue gas, the temperature reference point was used and oxygen properties at the average temperature were utilised.

In order to verify that the units are correct a second calculation was utilised to verify the relatively low heat recovery potential from the flue stack.

$Q = V \times \rho \times Cp \times \Delta T$

Eqn 5.0 (P14, Waste Heat Recovery, Retscreen International, Energy Efficiency Asia Chapter 2006)

$Q =$ heat content in kCal

$V =$ the flow rate of the substance in m^3/hr

$\rho =$ density of the flue gas in kg/m^3

$Cp =$ the specific heat of the substance in kCal/kg °C

$\Delta T =$ the temperature difference in °C

Cp = Specific heat of flue gas = 0.24 kCal/kg/°C or 1.017 KJ/Kg K

$Q = (14{,}619 m^3/hr \times 0.815 kg/m^3 \times 0.24\ kCal/kg/^{o}C \times [160-10])$

$Q = 428{,}921.46\ kCal / hr$

Q = 498.83 kW or 0.5 MW per hour

The comparison of the two calculation methods yields a 1% deviance in the two methods which is presumed negligible. Factors that would significantly hamper the heat recovery of the stack by using a recuperator or economiser were not considered in this calculation (e.g. stack sulphur dew point corrosion of approx 104°C and also the efficiency of the heat recovery unit 80-85%). Adding these factors into the calculation would significantly reduce the delivery of potential heat recovery compared to that which is needed to dry the raw fuel to a 50% MC.

5 SUMMARY & CONSLUSIONS

Within this section, all calculations and assumptions are collated into a definitive summary and from these conclusions are drawn in relation to the viability and practicality of the project.

5.1 SUMMARY

Further analysis was undertaken on the fuel mixture, including the analysis of each fuel stream and the properties of each. From this it was ascertained that indeed reduction sounds off, maybe indeed the reduction of the moisture content of the fuel streams would significantly reduce the amount of raw fuel required to generate steam and electricity from the plant. Also, what was illustrated during the theoretical analysis was that there was no large disparity of energy content from processed and unprocessed fuels (e.g. wood residues and woodchips). This outlined that with the chipping of the fuel, that no discernable energy content would be lost,. Therefore, chipping, thinning and drying of the wood residue is feasible to ensure that the plant can operate on the thinned fuel, reducing possible issues in the combustion bed , fuel handling and ash handling systems.

Information utilised from 2009 was assumed to be for normal plant operation and was utilised to develop an understanding of the key metrics and outputs of the site, relative to fuel inputs and other variables. For the purpose of the project these parameters were assumed to be steady state for the future, even though the site dynamics are changing to maximize plant operations.

The 2009 usage figures were considered to be best benchmark for the system as there were minimal disruptions to plant operation, fuel mixtures, output requirements, in both steam and electricity.

Combining the measurements that are taken onsite for the fuel mixtures with a combination of calculations gathered from the IEA Task 32 handbooks and notes allowed for more detailed analysis of the fuel streams and how the plant reacted to each.

External information relating to climate variations were collated from a number of sources including; Met Eireann – Cork Airport and also degreedays.net website archive for Cork Airport. This information provided a number of sources for carrying out regression analysis to ascertain how the plant and fuel are impacted by climactic conditions. The analysis carried out were utilised to prove that the weather in the locality can have a significant bearing on the fuel properties, ergo the energy potential and operation of the plant.

Thermodynamic and heat transfer calculations were utilised in conjunction with information taken from the averaged and set points of plant operation over 2009. This facilitated the examination of the plant dynamics and possible means of recovering heat and increasing the optimisation of the overall system.

CONCLUSIONS

Utilizing the existing plant layout and construction, two heat recovery sources were inspected for viability and practicality for recovering heat for the purpose of drying the fuel prior to it being fed into the boiler. It was found from calculations that the heat recovery prospects from the flue gas in the stack was minimal and would not contribute greatly to the reduction of the moisture content in the fuel streams. The flue gas had only a potential of $0.5MW_{TH}$ maximum that could be recovered and this would be diminished when consideration of natural stack effect and the possible build up of acid, which may damage the stack.

Alternatively, there is a significantly increased potential for heat recovery from the condenser fans from the second stage of the turbine. This would see a considerable amount of 'low grade heat' being captured potentially for drying fuel through a belt or air drying medium prior to entering the fuel handling system. Reduction in the moisture content of the fuel from the average recorded in 2009 of 60.43% to the boilers lowest permitted rated MC of 50% would yield a reduction of up to 20% fuel requirements of the site. The heat recovery from the condensers would be maximum $6.5\ MW_{TH,}$ albeit low grade heat at an estimated $60^{o}C$, dependant on external temperatures and operational conditions of the plant. The thermal energy needed to meet the MC reduction was calculated to be $1.18\ MW_{TH,}$ outlining that there is ample capacity for drying of the fuel.

Another factor that affects the optimum operation of the plant is the weather in the local climate. It was observed from analysis that the plant' operation can be affected by external air temperature and this was proven through the correlation of fuel moisture content against heating degree days and air temperature respectively. This relates to the amount of moisture in the air which would be absorbed by the fuel before going to the boiler. With the increased moisture content (MC) of the fuel, the boiler is less efficient and requires additional fuel to generate the equivalent amount of energy produced in comparison to months where the MC is lowest.

5.2 STUDY OUTCOMES

The main driver of the study was to determine means of increasing the optimisation of a biomass CHP plant. A key part of the plant's operation was the fuel source and the properties of the fuel streams and what impacts of changing the fuel dynamics may have on the system. Outlined in Section 2.1 were the desired outcomes of the study, which will be measured against the completed study.

- Lower the moisture content of the fuel (%), by using rejected heat from the condenser radiators and economiser.
    - It was found that the reduction of the moisture content in the fuel would yield considerable savings in the fuel requirements of the fuel over an annual period (based on 2009 fuel reports).
    - The heat recovery potential from the condensers 6.5 MW_{TH}, is more that viable and more than meets the required 1.18 MW_{TH}, required to reduce the moisture content.
    - Utilisation of the stack heat recovery system was found to be unviable from a heat recovery perspective. Installation of an economiser would not deliver adequate amounts of thermal energy for drying the fuel and reducing the moisture content.

- Reduction of electricity requirements of the condensers fans, currently max capacity of $180kW_e$
    - Reduction in the operation of the condensers electrical fans would be negated or offset by the movement of the heat and the utilities required to operate drying technologies and conveying systems within.
- Improved controllability of the system, and improving the system response time due to load fluctuations.
    - Until such time that the project is implemented or that the plant operates on continuous supply of woodchips at an optimum MC of 50%, it is difficult to qualify or quantify the optimisation savings directly attributed. From onsite discussion with the management and operational department, there are noticeable merits to utilising woodchips only. This would increase the controllability of the fuel feed system, and also mitigate build-up of fuel on the grate resulting 'clinkers',which are large portions of fuel that ball together, causing issues in the combustion bed. This ensures that the plant operates more consistently, with increased uptime and plant availability.
- Reduce waste through mitigation of ash carryover from the fuel grate in the boiler and reduce the amount of fine ash from the electrostatic precipitator (ESP) prior to the stack.
    - Similarly to the previous point, without the project being implemented it will prove difficult to prove operational improvements of the plant until sustained periods of just woodchips at a low MC are utilised.

5.3 RECOMMENDATIONS

As there is a significant business case for the initiation of the heat recovery project, further studies should be undertaken to ascertain other synergies to the plant and more in-depth analysis of next steps of the study. These include:

- Examination of the layout and footprint needed to install the drying system and the heat recovery system. The plant manufacturer the plant should be consulted when examining the installation of the heat recovery system to ensure that the system is not unbalanced with detrimental affects to steam and/or electrical generation.

- It has been identified that there is more than excess heat available to dry the fuel to the lowest level of 50% MC. Therefore there is approximately 4.0 $MW_{TH,}$ of potential heat that has to be dissipated by the condensers or used in another medium. Installation of more drying kilns may be an alternative or installation of a Stirling Engine could be examined to reutilise the low grade heat.

- As there is significant drying capacity from the low grade heat currently sent to the condensers, the plant could look at processing wood pellets or wood chips for export. The fundamental equipment is installed and there is ample room for expansion on the plant. A business case should be investigated to see if this can made into a viable exportation source for the site.

- Connection of the plant to a district heating system (DHS) should not be discounted as there are considerable clustered residential properties in close proximity to the plant's location. Installation of a central Enniskeane DHS could significantly offset carbon emissions to the town.

NOMENCLATURE

A	Area (m^2)
B	Breadth (m)
AUC_E	Price of electricity (kWh)
AUC_{TH}	Price of heat (kWh)
C	Costs (€)
c	Specific heat capacity (kJ/kgK)
L	Length (m)
m_{Air}	Air mass (m/s)
m_{Fuel}	Fuel mass (kg)
p	Pressure (Pa)
t	Temperature (°C)
u	Fuel moisture (%)
v	Velocity (m/s)
x	Air moisture (kg=kgda)
Z	Height (m)
Efficiency	(%)
Density	(kg/m3)
Time	(seconds)
FD	Force Daft

ABBREVIATIONS/GLOSSARY OF TERMS

Alphabetical order, please

CHP	Combined Heat & Power
ESB	Electricity Supply Board
ESCO	Energy Supply Company
ESP	Electro Static Precipitator
EPC	Engineering, Procurement and Construction
GPG	Good Practise Guidelines
HDD	Heating Degree Days
IBS	Independent Biomass Systems
IPPC	Integrated Pollution Prevention Control
MC	Moisture Content
SWS	South Western Services
TGD	Technical Guidance Document
VOC	Volatile Organic Compounds

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