SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Biomass CHP

Operation & Maintenance Guide

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September 2020

Sustainable Energy Authority of Ireland
SEAI is Ireland's national energy authority investing in, and delivering, appropriate, effective and sustainable solutions to help Ireland's transition to a clean energy future. We work with Government, homeowners, businesses and communities to achieve this, through expertise, funding, educational programmes, policy advice, research and the development of new technologies.

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Ricardo Energy & Environment

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1. Introduction

Ireland has a long-term vision for a low-carbon energy system. It aims at reducing greenhouse gas emissions from the energy sector by between 80% and 90% (compared with 1990 levels) before 2050. Achieving this target will require a radical transformation of Ireland's energy system, a reduction in energy demand, and a move away from fossil fuels to zero- or low-carbon fuels and energy sources.

Sustainably produced biomass is a low-carbon fuel, but resources are limited. Therefore, it is important to ensure that it is used as efficiently and effectively as possible. In addition, other potential impacts from biomass use, such as emissions of pollutants that affect air quality, need to be minimised and biomass installations must be operated safely.

It is important to recognise that combined heat and power (CHP) systems that use biomass as a fuel (e.g. wood pellets, energy crops and chicken litter) differ significantly in various respects from those that use gas. To ensure a well-functioning, safe and efficient biomass CHP system, these differences need to be properly addressed in its operation and maintenance.

The guidance presented in this Operation & Maintenance Guide and the accompanying Implementation Guide and Technology Guide is intended to be a comprehensive starting point for readers wishing to better understand the biomass CHP technology, its implementation and ongoing management.

1.1 The Support Scheme for Renewable Heat

The Support Scheme for Renewable Heat is a Government-funded scheme, to encourage the installation of renewable sources of heat in non-domestic applications in the Republic of Ireland. These guidelines will help applicants identify the appropriate standards and best practice required for the Support Scheme for Renewable Heat and other relevant schemes. These guidelines provide applicants with guidance on good practice only. The Terms & Conditions, the Grant Scheme Operating Rules, Guidelines and the Tariff Scheme Operating Rules, where relevant, set out the basis on which the Support Scheme for Renewable Heat will operate.

1.2 Purpose of this guide

This Operation and Maintenance Guide is principally intended for users of biomass CHP systems such as facilities, engineering and environmental managers; and technical maintenance staff. It has two principal aims:

1. To provide the reader with a sound appreciation of the operation and maintenance requirements of biomass CHP systems, good practice and essential issues.
2. To direct the reader to further sources of more detailed information on specific aspects of the technology. There are various existing publications on biomass CHP systems. This guide and its two companion guides do not seek to duplicate existing publications; rather they are intended as a comprehensive starting point for those wishing to better understand the technology, and its implementation and management.

1.3 Scope

The guides concentrate on solid biomass CHP systems for non-domestic premises in the installed power capacity range of 20kWe to 2MWe. However, depending on the nature of the specific project, much of this guidance will also apply to smaller and larger scale systems. The guides cover combustion-based and gasification-based biomass CHP technologies that are available on the market.

The distribution of heat from a CHP system focuses on hot water systems for non-domestic space heating, water heating and process heating. Steam and thermal oil systems can be used where higher temperatures are required.

Direct air heating systems have not been covered in this set of biomass CHP guides. Systems can be designed that provide cooling as well as heat and power. These are known as combined cooling, heat and power (CCHP) systems – sometimes referred to as trigeneration. However, such systems are more common for larger scale biomass CHP systems. While trigeneration has been mentioned in these guides, it is not discussed in detail.

Regarding fuels, the focus of the guides is on wood (virgin and waste), mainly in the form of pellets and chips as these are the most commonly used. Other, less common, fuels covered are straw, chicken litter (agricultural residues), and energy crops (e.g. short rotation coppiced (SRC) willow and miscanthus (elephant grass)). Liquid and gaseous biofuels are not considered. An accompanying set of guides is available on the production and use of biogas from anaerobic digestion plant.

2. Fuel procurement

Fuel procurement

- The quality of fuel used in the boiler or gasifier of a biomass CHP system is important and substandard fuel can cause a range of issues. Therefore, conducting quality checks on the fuel is important.
- The moisture content of biomass is an important element in the operation of gasification systems. In addition, the composition of biomass affects the quality of the syngas resulting from the gasification process, which then needs to be treated and conditioned before being combusted in a syngas engine. Moisture content, calorific value, and biomass size needs to be taken into consideration when sourcing fuel for gasification systems.
- Biomass fuels should be sourced from sustainable supplies.
- There are a range of fuel supply options including self-supply, direct supply from a local site and fuel supply companies.
- Fuel costs should be reviewed regularly to ensure the price is reasonable. Determine if the cost is a fixed rate per unit or the summation of a unit rate and fixed delivery charge.
- A low-cost fuel supply may not be the best option if the fuel is sub-standard.
- Accreditation of the fuel supplier and/or products provides a degree of quality assurance.
- Records should be kept to assess fuel consumption and any quality impacts on boiler performance.

As the cost of fuel is one of the main ongoing operational costs for a biomass combined heat and power (CHP) system, it is prudent to ensure that the price paid is minimised, subject to ensuring that the quality is appropriate for the boiler or gasifier in question. The use of cheap, sub-standard fuel may well prove to be a false economy as it can decrease the performance of the biomass conversion process, increase maintenance costs and cause excessive emissions.

2.1 Sustainability of fuels

To maximise the carbon savings from bioenergy, it is important that biomass fuels are produced as sustainably as possible, with minimal greenhouse gas emissions, such as carbon dioxide (CO_2), and other environmental impacts associated with the production of biomass fuel.

There are also other aspects of sustainability to consider, including:

- Carbon stocks in forests are not reduced through harvesting wood as a biomass fuel.
- The conversion of land to produce biomass does not lead to high releases of carbon
- Biomass is not sourced from areas of high biodiversity such as primary forest.

Some fuel accreditation schemes, such as the Wood Fuel Quality Assurance (WFQA) scheme for Ireland[1] and EN*plus*®,[2] include sustainability criteria (see Section 2.3 for more information).

2.2 Identifying suppliers and market testing

Factors influencing the identification of a fuel supplier will vary according to availability of fuel and fuel type. It is generally recommended that fuel is sourced locally to reduce transport costs and help minimise carbon emissions associated with fuel delivery. As biomass fuel costs are subject to variation, it is worth conducting regular market testing to verify the competitiveness of the supplier’s current prices, as well as their customer service, fuel quality and ability to meet short-notice deliveries.

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1 http://wfqa.org/
2 https://enplus-pellets.eu/en-in/

2.3 Certification

There are two main fuel certification schemes relevant to Ireland, the Wood Fuel Quality Assurance scheme (which certifies that wood fuels are accurately described and meet a supplier's stated product specifications) and EN*plus*® (a quality certification scheme for wood pellets).

2.4 Fuel quality

Using fuels supplied under a recognised standard provides assurance regarding the quality of the fuel. Wood chip and other fuels are commonly supplied to meet a desired specification but may not be produced to meet a recognised standard. Therefore, routine sampling and fuel monitoring will be essential to ensure that delivered fuel meets the specification. The key elements to be monitored are moisture content, particle size, contamination, calorific value (CV), and, for some fuels, sulphur and chlorine levels. Fuel monitoring can range from basic on-site tests to laboratory testing. Regularly inspecting boiler ash and slag from the gasifier for changes in colour, particle size or clinkering can also highlight issues with combustion or contamination that may be fuel related.

2.5 Fuel consumption

Many larger biomass CHP systems will offer in-built monitoring of fuel consumption, and some manufacturers and/or fuel suppliers provide a remote-monitoring function that alerts the operator when fuel needs to be ordered. In smaller systems, fuel records can be kept by logging delivery notes or invoices, or by keeping records of fuel quantities loaded into the fuel store. For boilers, fuel consumption should be compared to heat output to verify the energy density of the fuel used and the efficiency of the boiler.

In the case of gasification systems, the amount of syngas produced and manufacturer's efficiency of the gasifier can be used to verify fuel consumption. Where measurements of syngas flow may not be available or not possible, the amount of electricity produced by the syngas engine, combined with the efficiencies of the engine and gasifier, can be used to verify the fuel input to the gasifier.

It is recommended fuel stores should have fuel-level sensors in several locations and viewing hatches so that fuel levels in the whole store can be seen. Regular emptying and cleaning of the fuel store and/or manual levelling of the fuel helps to reduce the risk of fuel slumping issues.

2.6 Record-keeping

It is important to keep the following records:

- Any fuel contract that may be in place;
- Fuel suppliers' specifications for fuels purchased;
- Fuel invoices;
- Fuel delivery notes;
- Fuel quality checks; and
- Stock levels taken at appropriate intervals.

3. Maintaining efficient operation

Maintaining efficient operation

- Proper planned maintenance and monitoring is vital to ensure the biomass conversion system (boiler or gasifier) functions well with minimal outages.
- Some of the ongoing manual input can be taken on by site staff, which may be less costly, but will require a certain level of training in how the system operates. Alternatively, it can be conducted by a contractor, which is likely to be more costly.
- The following should be considered when selecting contractors:
  - Their credentials;
  - Remote monitoring capabilities;
  - Helpline facilities; and
  - Location of and ability to offer consistent engineers and charges.
- Operators should be familiar with, and always follow the manufacturer's guidance for, the individual components of the system, including the boiler/gasifier itself, the flue system, heat metering, fuel-handling equipment, turbine generator and gas engine units, safety procedures and lubrication of key components.
- Gasifiers and syngas engines require additional maintenance and a stricter operational regime due to the specific biomass quality requirements, and the need to treat and condition the syngas prior to combustion.

All CHP systems require effective and reliable monitoring and maintenance to provide the required levels of reliability and efficiency. Monitoring and maintenance of CHP packaged systems will include the boiler/gasifier and the prime mover as a single system. Treatment and conditioning processes of main equipment's will also need to be maintained. In addition, site maintenance requirements should also be taken into account.

The complexity and frequency of maintenance varies for different plant items, and this influences the options for selecting the best source of maintenance and repair expertise. Like any equipment, proper planned maintenance and monitoring of a biomass CHP system is vital in ensuring that:

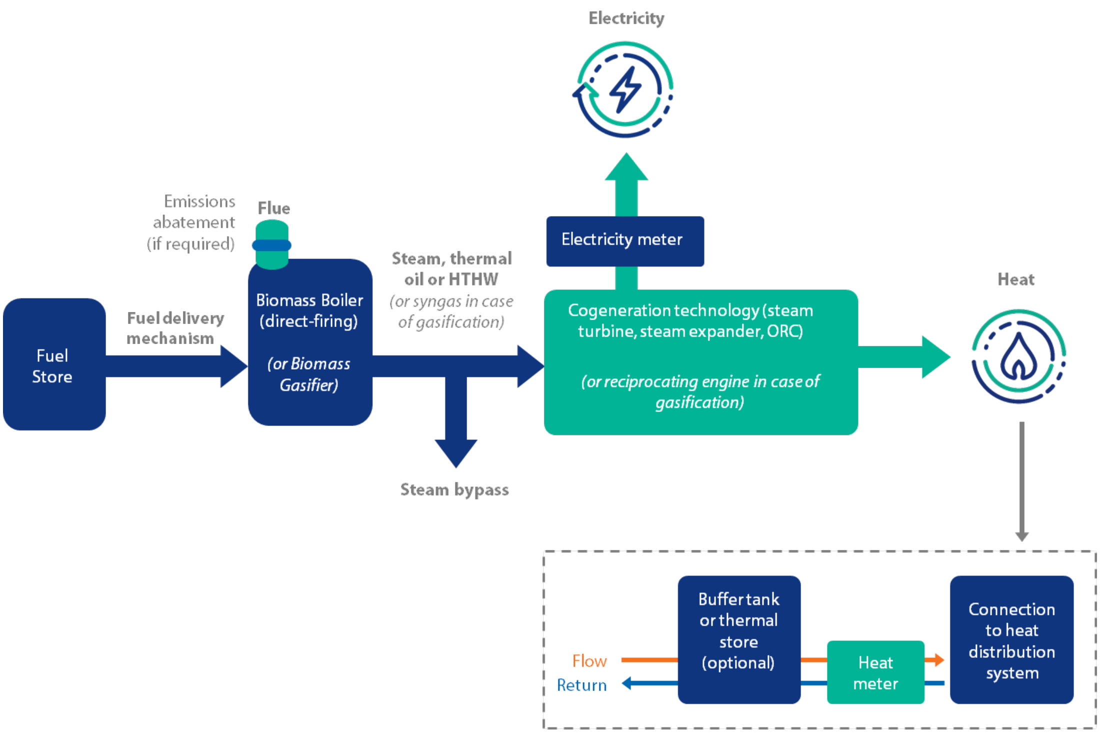
- The safe operation of the system is maintained.
- The system continues to function as designed and commissioned.
- Outages (breakdowns) are minimised.
- The service lifetime of plant is maximised.

This section provides guidance on how to ensure optimum operation. The organisation undertaking the day-to-day operation of the CHP system is referred to in this section as the 'operator'. This could be the site owner/occupier or a services company to whom responsibility for the boiler and generation technology operation has been contracted out. The services company may be able to provide sufficiently specialist staff itself or may sub-contract this to others.

3.1 CHP system operation

Biomass CHP systems usually consists of a boiler or gasifier, prime mover (turbine or reciprocating engine) and heat recovery and utilisation equipment. In addition, they include fuel storage and fuel handling equipment. The electricity generated by the CHP system would also require safe connection to the site demand or exported to the grid. This would require further equipment like the transformers, electrical switch gears, meters and a maintenance schedule. *Figure 3.1* shows a typical arrangement for a biomass CHP system.

Figure 3.1: Typical biomass CHP system components



Effective operation of a CHP system requires the continuous monitoring of site energy demands, and the tariffs and costs associated with meeting those demands. Monitoring should be used as a means of continuously evaluating the most economic use of the plant, taking into account its performance and efficiency, its maintenance costs, and the costs of external energy sources such as electricity and biomass fuel.

It is equally important to budget for the future maintenance costs that are involved with operating the plant. This is particularly important where the costs of plant operation and maintenance are managed by separate budget holders. At the same time, plant operation must not be constrained by inadequate maintenance budgets that prevent the optimum energy performance of the plant from being achieved.

Plant control techniques need to be flexible enough to ensure optimum performance of the whole system. There are varying levels of automation that can be used to achieve the required level of control. Particular attention should be given to control strategy, staff training, shutdown planning, and health and safety.

3.2 Contracting for operation and maintenance – options

It is common for the CHP system owner to operate the system but contract out servicing and repairs to the company that installed the equipment. Some of the ongoing manual input can be taken on by site staff, which may be less costly, but will require a certain level of training in how the system operates. Alternatively, it can be conducted by a contractor, which is higher cost. *Table 1* details the options for operation and maintenance.

Table 1: Operation and maintenance options

Option	Suitability	Advantages	Disadvantages
Original installer operates and maintains the system.	This is suitable for sites with little or no knowledge of biomass CHP systems and available staff. This is a relatively common solution.	• Requires minimal interaction with the biomass CHP system from the site. • Should ensure a high-performing system due to a strong knowledge of the technology.	• Is likely to be the highest cost solution. • Offers a low level of control to the client, which may cause delays in identifying and rectifying issues due to remote nature of contractor.
In-house operation of system with original installer maintenance.	This is suitable for sites with a member of staff, such as a facilities manager, who can be trained to operate the biomass CHP system and provide basic checks and maintenance. This is a common solution.	• Lower costs than having everything done by the installer. • May enable more rapid identification of issues and rectification of minor issues. • Offers greater control of system.	• Requires a level of knowledge and training of member(s) of staff. • May result in issues not being spotted or incorrectly rectified.
The above options, with another third party rather than original installer.	This solution is usually undertaken when the original installer is no longer available or is too costly. As such, it is less common.	• Offers flexibility to choose the contractor. • May result in lower costs and/or better service.	• Care needs to be taken not to void any warranties. • Knowledge level of the system may not be as good as original installer. • May not be capable of the same levels of remote monitoring as the original installer.
In-house operation and maintenance of system.	This is suitable for a site that has strong CHP system and biomass capabilities. This is less common and is still usually supported by external contractors in the cases of severe breakdowns.	• Likely to be lowest cost solution. • Offers complete control over operation and maintenance process.	• This may void a system's warranties unless written dispensation is received. • Requires staff with CHP system and biomass capabilities if good performance is to be maintained.

The following should be considered when selecting a contractor:

- Credentials – including experience, certification, training and accreditation.
- Is it possible to have the same contractor for the biomass conversion equipment and CHP system – this would minimise outages.
- Remote monitoring capabilities – such as remote access to CHP system, electricity and heat meters, and building management system (BMS).
- The level of telephone support offered. Does the contractor have the facility to talk on-site staff through checks and how to resolve minor issues, which will avoid having to pay for call-outs?
- Can the contractor offer an on-call service with a specified maximum response time for attendance at site?
- Location and number of engineers. This will affect how rapidly contractor's staff can attend the site.
- The ability to provide the same engineer for maintenance works. Using the same engineer enables them to build-up knowledge of the system, and more readily identify issues and their solutions.
- Charges and charging structure. This will usually be made up of fixed costs for planned maintenance (and operation if applicable), plus costs of repair parts (i.e. non-consumables) and call-out rates for unplanned maintenance.

3.3 Biomass boiler system maintenance

For custom-built, combustion-based systems, the maintenance and operation of the boiler may be done separately from the CHP unit. This section provides some guidance on the operation and maintenance of the boiler as the biomass conversion process. For small packaged systems, the gasifier and the prime mover (i.e. syngas engine) are parts of the same unit and will be maintained and operated as a single system.

Boiler operators should be familiar with and always follow the manufacturer's guidance for the individual components of the system, including the boiler itself, the flue system, heat metering and fuel-handling equipment. The following generalised information should be considered in the context of that guidance.

3.3.1 The boiler and flue

Biomass system maintenance can be divided into:

- Ash bin emptying and basic checks – undertaken by the operator.
- Regular cleaning and checks – normally undertaken by the operator.
- Services – normally undertaken by the boiler supplier or other specialist.
- Dealing with breakdowns and undertaking repairs – normally undertaken by the boiler supplier or other specialist.

Intervals between maintenance tasks and servicing depend on boiler usage, size and type. It is typical for services to be carried out every 2,000 full-load equivalent (FLE) operating hours[3] or annually, whichever occurs first. Boiler cleaning and regular checks might be monthly or more frequent for heavily used boilers. An ash bin within the boiler house (either integral to the boiler or standalone) will require regular manual emptying (see Section 3.3.2).

The control systems of many modern boilers will provide an alert if cleaning is required or there is some other issue that requires immediate attention.

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3 The full-load equivalent operating hours for a particular period is the actual heat generated in that period divided by the heat that would have been generated if the boiler had operated continuously at its full rated output.

Table 2: Typical maintenance tasks for a biomass boiler

Task	Typical frequency	Typically undertaken by
Basic checks: • Walk-around inspection looking for anything unusual. • Heating system pressure. • Leaks. • Heat meter operation. • System operation.	Daily/weekly	Operator
Empty ash bin(s)	Weekly/monthly as required	Operator
Check safety devices: • Safety and relief valves. • Fire protection/prevention in fuel transport mechanisms. Flue: • Check integrity of flue components. • Clean flue path to stack. • Clean stack condensate drain. Clean combustion chamber: • Clean grate. • Clean combustion air openings. • Clean ignition tubes. • Check refractory linings for damage. Clean the heat exchanger: • Clean the heat exchanger tubes and channels. • Clean the lambda probe. • Check heat exchanger tubes for damage. • Check operation of heat exchanger cleaner (where fitted). • Check integrity of cover seals. Clean flue-gas recirculation piping (where fitted).	Monthly	Operator/specialist contractor
Clean induced-draught fan. Clean temperature sensors. Check operation of primary and secondary combustion air valves. Check and lubricate mechanical drives. Check functioning of deashing systems. Clean and check ignition. Check fitting and sealing of boiler doors.	Service annually or every 2,000 hours full-load equivalent	Specialist contractor

Task	Typical frequency	Typically undertaken by
Calibrate lambda probe.	Service annually or every 2,000 hours full-load equivalent	Specialist contractor
Check and adjust specified mechanical clearances.		
Reset maintenance interval counter (if fitted).		
Test boiler and heating system post-service.		
Any other specific maintenance detailed by the manufacturer.		

Table 2 provides an indication of the typical maintenance tasks for a biomass boiler, but the **guidance and recommendations provided by the boiler manufacturer and its authorised agents should be followed and take precedence**. Before tasks are undertaken by personnel other than those of the boiler manufacturer or its authorised agents, operators should ensure that, as well as the personnel in question having the necessary training and competencies, this will not invalidate any warranties. Furthermore, all boiler maintenance tasks present potential hazards and require strict adherence to established health and safety procedures. Further details are provided in Section 5 of this guide.

3.3.2 Ash disposal

The quantity of ash produced depends on boiler usage and the fuel ash content (see for a worked example).

Example estimate of ash production

A 200kWth boiler operates as part of a biomass CHP system for 1,750 full load equivalent hours annually. It is assumed the boiler has an efficiency of 85% and uses wood pellets with a net calorific value of 4,700kWh/tonne and an ash content of 1.0%. The bulk density of the ash will be around 920kg/litre.

In one year, the boiler will:

- Produce 350,000kWh of useful heat (200 x 1,750);
- Use 87.6 tonnes of pellets (350,000 ÷ 0.85 ÷ 4,700); and
- Generate around 876kg of ash.

Assuming the boiler has two integral ash bins each with a capacity of 50 litres, they will need to be emptied around once a month or more frequently.

There are two types of boiler ash: bottom ash and fly ash. Bottom ash makes up around 98% of the ash from a biomass boiler and arises at the grate. Fly ash is fine ash that is entrained in the combustion gas flows and is collected via a fly-ash drop-out chamber within the boiler and/or as part of separate flue-gas cleaning, such as a cyclone grit arrestor. Fly ash will contain toxic particulates from volatised metals and metal salts. Therefore, it should be treated as a hazardous waste and disposed of appropriately. Bottom ash from contaminated fuel, such as treated waste wood and poorly combusted bottom ash, should also be treated as hazardous wastes.

The default disposal route is to landfill, and ongoing arrangements will need to be made with a licensed waste company for disposal. With appropriate authorisations, it may be possible to find alternative disposal routes such as to land. This may be easier for bottom ash from clean biomass, which generally poses lower risks than fly ash.

Relevant waste categorisations for ash from the Environmental Protection Agency's (EPA) Waste Categorisation, 2015

10 01	Wastes from power stations and other combustion plants (except 19)	
10 01 01	Bottom ash, slag and boiler dust (excluding oil boiler dust)	Non-hazardous
10 01 03	Fly ash from peat and untreated wood	Non-hazardous
19 01	Wastes from incineration or pyrolysis of waste	
19 01 11	Bottom ash and slag containing hazardous substances	Hazardous
19 01 12	Bottom ash and slag other than those mentioned in 19 01 11	Non-hazardous
19 01 13	Fly ash containing hazardous substances	Hazardous
19 01 14	Fly ash other than those mentioned in 19 01 13	Non-hazardous

3.3.3 Fuel store and fuel handling equipment

The principal maintenance burden for fuel stores arises from the mechanical fuel extraction systems that extend to the boiler. Depending on the fuel type, these can include augers (fixed or sweeping), sweeping arms or walking floors. Maintenance requirements are likely to include:

- Clearing blockages;
- Lubricating drive chains and bearings;
- Alignment checks and mechanical adjustments; and
- Mechanical, hydraulic and electrical repairs.

Clearing blockages would normally be carried out by the operator. Other maintenance requirements might be undertaken by the operator, depending on the skills and experience available on site or by specialist contractors.

From time to time, it may also be necessary to clean out fuel stores and ensure that they remain ventilated.

All of these tasks pose significant hazards for the personnel concerned and require strict adherence to established health and safety procedures. Further details are provided in Section 6 of this guide.

3.4 Biomass gasifier system maintenance

Gasifiers, as mentioned above, require cleaner biomass fuel compared with that required for boilers and have stricter operational parameters. Gasifiers require routine checks of fuel hopper, the gas filters, the gasifier housing drum and syngas treatment units.

The details provided in Section 3.3 are also applicable for gasifiers. However, gasification systems will require more routine systems checks than boiler systems due to the need for clean syngas prior to entering the syngas engine. Cleaning processes involving the removal of particulate matter and hydrogen sulfide (H2S) are part of the gasification-based CHP units and these need to be routinely checked to ensure optimum performance.

3.5 Prime mover and electricity generation equipment maintenance

As discussed in the accompanying CHP Technology Guide, the relevant prime mover technologies in biomass CHP systems are steam turbines, steam expanders and Organic Rankine Cycle (ORC) (for combustion-based systems) and gas engines (for gasification-based systems). In the following sections, the key operational and maintenance requirements are discussed.

3.5.1 Operational considerations for steam turbines

A steam turbine extracts thermal energy from pressurised steam produced by biomass boilers and uses it to do mechanical work on a rotating output shaft. The rotary motion of the shaft, which is coupled to a generator, produces electricity. Operation of a steam turbine from start-up to shutdown requires significant care. In addition, generators driven by steam turbines that operate in parallel with other generators or with incoming power from the electricity grid require that the following conditions be satisfied:

1. Both machines must have the same frequency and wave form.
2. Their terminal voltages must be equal.
3. Their sequence of maximum potential values must be the same.

3.5.2 Steam turbine operating problems

The most common problems with steam turbines are:

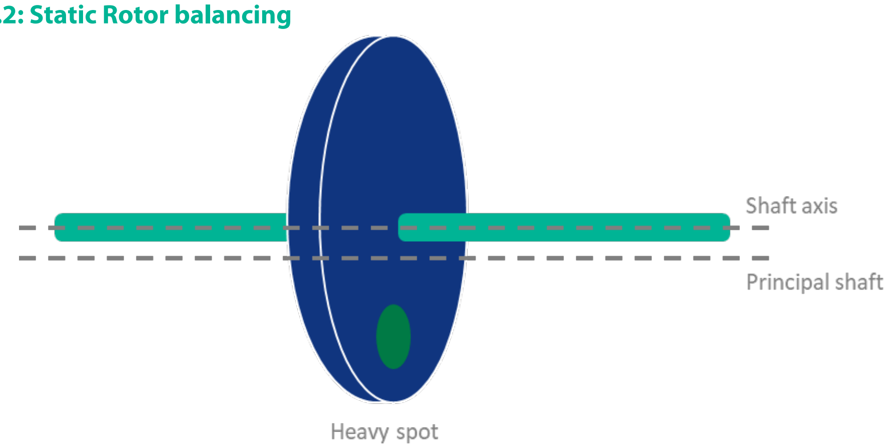
- Vibration – noise and damage to system alignment;
- Cycle governor – over speeding;
- Sticking valve;
- Temperature bow;
- Erosion of blades;
- Loss of power; and
- Bearing problems.

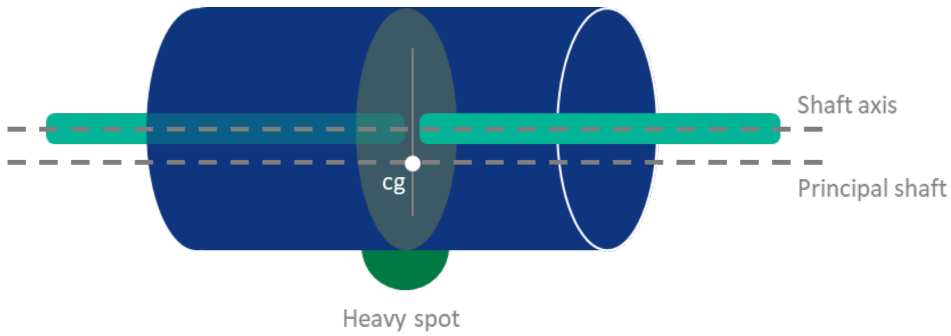
Some of the key control measures to minimise steam turbine operational problems are discussed below.

3.5.2.1 Mechanical performance

Mechanical performance is generally checked at the factory prior to shipment by conducting a running test and again when the turbine is installed on the site. After the blades are assembled, the rotor is balanced statically and dynamically. Static balance means that the weight is evenly disposed around the axis of the shaft. Dynamic balance means that the moments of the out-of-balance weights along the axis about either bearing add up to zero. This is checked by spinning the rotor on resilient bearings, detecting the vibration, and adding or subtracting weights until the vibration is negligible. Modern balancing machines enable this to be carried out with a high degree of accuracy (see *Figure 3.2*).

Figure 3.2: Static Rotor balancing





Rotor balancing is a vital aspect of the maintenance routine for a steam turbine (or its generator). Low-speed balancing is often performed on-site or in a facility that lacks access to a high-speed balance cell. Relying on the results of low-speed balancing can mean that maintenance engineers miss issues that surface only when the machine is run under full-speed conditions. Therefore, as the rotor must be in dynamic balance, at-speed balancing is the most effective way of achieving this.

The couplings between turbine, gearbox and generator need to absorb the changing positions of the shafts between alignment and operational condition, which are caused by the different thermal expansion of the machines and dislocation of the shafts in the bearings. Therefore, the shafts are not connected by a rigid coupling but by a toothed one. The two couplings are of the curved-tooth type made of steel with hardened teeth. The high-speed coupling between turbine and gearbox is lubricated by oil injection. The low-speed coupling between gearbox and generator is lubricated with grease. Both couplings are usually dynamically balanced.

The following could help provide smooth and vibration free operation:

- The bearings must be in line and the seal clearance must be correct. This alignment must be maintained when cold and hot, and during the transition from cold to hot.
- Disturbance of alignment may originate by unequal heat expansion of supports and from pipe expansion. High forces on the turbine have also caused many vibration problems.
- Couplings that do not flex also cause problems. This may result in torque lock or in unloading of bearings. A coupling bolt is a mechanical means of holding two halves of a flanged shaft together to properly transfer the torque while maintaining shaft alignment. Misalignment in steam turbines causes vibration, puts unnecessary load on bearings and curtails operation at full power. Flexible couplings minimise this problem.
- Presence of gear in the line should be checked carefully for bearing load, alignment and resonant frequencies that may be multiples of gear ratio. Also bearing oil supply must be adequate.

Vibration is one of the signs that something is wrong. Therefore, turbines are equipped with instruments that continuously monitor vibration. CHP system operators need to be aware of this issue and make sure that maintenance contractors check for it.

3.5.2.2 Turbine speed control

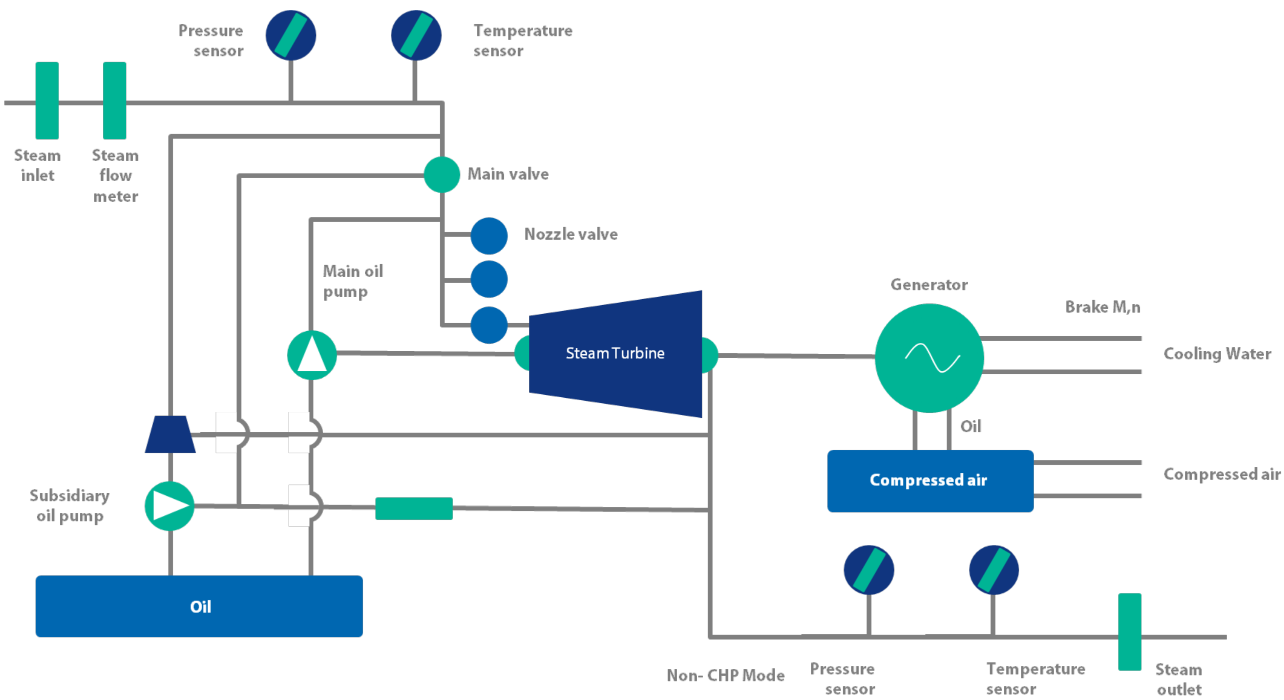
Steam turbines are expensive pieces of equipment that are manufactured with precision and require smooth operation for a long operational life. There are several factors that affects a turbine’s wear and tear, and its overall performance. For example, the variation in load during operation can have a significant impact on a turbine’s performance. Controlling and monitoring turbine speed during operation is vital for the performance of the system. Governors are devices used to control speed and modern steam turbines have an electronic governor that uses sensors to monitor the speed by examining the rotor teeth. Controlling a turbine’s speed by using a governor is essential as turbines need to run up slowly to prevent damage to the generation unit. Turbines used for electric power generation are most often directly coupled to their generators and have to run at a constant speed typically 3000rpm.

The first valve that the steam encounters as it travels from the steam generation system to the steam turbine is the main stop valve (main trip or shutdown valve) which is either fully opened or fully closed. This valve often does not control the steam flow other than to completely stop it. Control or throttling valves in different arrangements and configurations are also used to control the steam inlet. Combined trip and throttle valves are also common. In many steam turbine systems, at least two independent trip valves should be provided for proper redundancy. These valves are immediately ahead of the steam turbine and are designed to withstand the full temperature and pressure of the steam. They will operate if a loss of mechanical load should occur. Uncontrolled acceleration of the turbine rotor can lead to an over-speed trip, which causes the nozzle valves that control the flow of steam to the turbine to close. This failure would allow the turbine to accelerate until it breaks.

It is essential that turbines are driven by dry steam as any water present in the steam gets blasted onto the blades and erosion could occur. This would lead to a dynamic imbalance in the rotor and could lead to its breakdown. Presence of water in the steam entering the blades also destroys the thrust bearing for the turbine shaft. Therefore, boiler controls are designed to ensure high-quality steam is delivered and sufficient condensate drains are installed in the steam piping leading to the turbine.

Because of the high pressures used in steam turbines, casings are quite thick. Consequently, steam turbines exhibit large thermal inertia. They should be warmed up and cooled down slowly to minimise the differential expansion between the rotating blades and the stationary components. Large steam turbines may require between five and nine hours to warm up, but smaller units have faster start-up times.

Figure 3.3: Auxiliary systems of steam turbine [4]

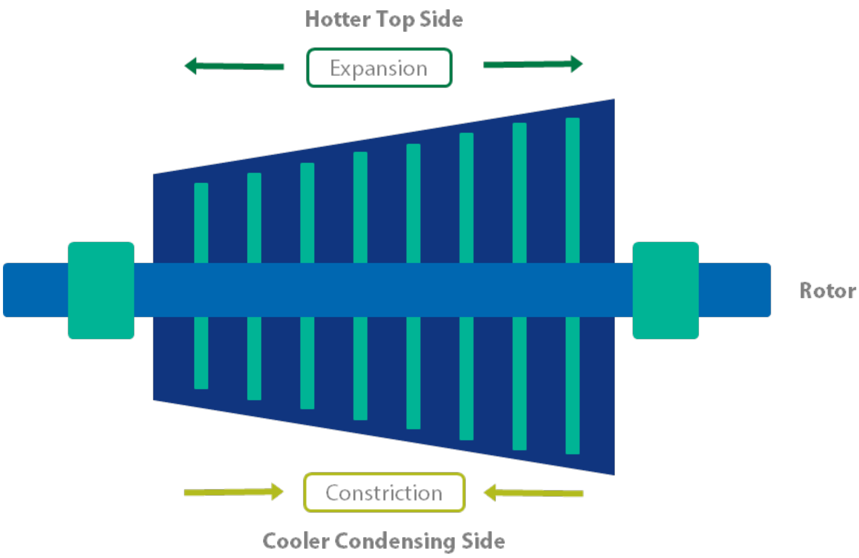


4 ftp://ftp.energia.bme.hu/pub/Steam_and_gas_turbines/25_SteamTurbineAuxMaint.pdf

3.5.2.3 Temperature bow

When a turbine is being shut down, the rotor stops turning and starts to cool. The lower half, particularly on the condensing unit, will cool faster than the top half. In a short period of time, there could be a temperature difference of between 30°C to 90°C (approximately) between the top and the bottom. Due to this temperature difference, the casing and the shaft bow up in the vertical plane. If the throttle is opened and the bowed shaft starts turning within the bowed casing, heavy thumping is heard and this would wipe out the packing in a few revolutions. Leaky valves and damaged sleeves are other causes of temperature bow.

Figure 3.4: Temperature bow



3.5.2.4 Turbine blade erosion and corrosion

When turbines are not running, leaky valves can allow steam to enter the turbine. This condenses inside the turbine and salts present in the water settle on the inside surfaces and cause corrosion (pitting). In the turbine that is running, erosion-corrosion occurs to the units that are operating on saturated steam and inadequate boiler water treatment.

Figure 3.5: Repair of corroded large steam turbine

3.5.2.5 Loss of power

Dissolved salts in steam could also lead to the turbine losing power. These salts stay in the solution while the steam is superheated and after the steam expansion has completed through several stages and the steam has become saturated, the salts condense out with the moisture. These deposits build on the blades and nozzle. Thus, boiler water treatment is necessary for steam turbine CHP systems.

3.5.2.6 Bearing problems

For bearings to run smoothly, they require an adequate film of oil. If dirt is in the oil or the flow of oil is restricted, then the bearings could be damaged. Thus, filtration should be adequate and retain particles that may exceed the thickness of the oil film.

3.5.2 Steam turbine control

An automatic control system for a typical steam turbine:

- Ensures it runs within set limits.
- Controls start-up and shutdown via a stepped sequence.
- Controls the individual components according to the operating parameters – including the turbine controller, interfaces to the generator controller and synchronisation.

Typical monitoring procedures are discussed below:

- Pressure and temperature gauges installed on a steam turbine can be used to identify developing issues. Thermometers on the oil inlet and discharge lines from a bearing will indicate a rise in temperature caused by a bearing that is dirty or out of adjustment, or an insufficient flow of oil. The normal temperature of a steam turbine bearing should not exceed 65°C.
- Comparing the reading on a pressure gauge, situated on the shaft seal, with previous readings will indicate whether the clearances have changed or if wear is taking place.
- An increase in steam pressure at the first stage or at other stages in the turbine, compared with previous readings at the same load and with the same vacuum, is a reasonably good indication that something is wrong with the blades or nozzles in the turbine.
- A gradual increase in pressure is frequently caused by deposits forming on the buckets, blades and nozzles in the turbine, or it may be due to corrosion or erosion of these parts. A sudden increase in pressure is indicative of damage to blades by a foreign body that has passed through the turbine or of blade failure.
- Virtually all circulating water contains solids and dirt. These settle out in the condenser tubes and inhibit the transfer of heat from the steam to the cooling water, resulting in higher steam temperature and lower vacuum at the turbine exhaust. Checking temperature readings helps to determine:
    - The frequency of the cleaning and its associated cost;
    - The loss due to outage of the turbine during the cleaning period; and
    - The saving to be effected by an increase in vacuum.
- A simple, but adequate, method for determining the amount of fouling can be established by:
    - Recording the temperature of the circulating water at the inlet and the outlet of the boiler.
    - Recording the condensate temperature and the temperature corresponding to the vacuum at the time the temperature is taken.
    - Calculating the difference between the temperatures of the two sets of readings and plotting them against months of the year.

3.5.3 Turbine inspection and maintenance

Inspections should always be carried out by specialists from the manufacturer. Using a specialist ensures that the work is carried out correctly and the manufacturer would give a full warranty on work carried out by its personnel.

Table 3: Typical turbine and generator unit inspection

Unit	Procedures and necessary check
Turbine	• Open the bearing pedestals. • Check and record the gland packing clearances. • Remove the journal[5] (i.e. plain) and thrust bearing and conduct a visual check of the contact pattern for wear and cracks. • Mount the journal and thrust bearing. • Check the seating of the bearings in the bearing block. • Check and record the journal and thrust bearing clearances. • Close the bearing pedestals. • Check and record the clearances between distance bushes and fastening. • Check the screws at the bearing pedestals and the casing claws. • Visual check of the turbine/gearbox coupling; testing of the axial mobility. • Check the alignment of turbine/gearbox and gearbox/generator. • Plausibility check of operation data and measured data (temperatures, speeds, vibrations and shaft position).
Control valve	• Remove the control valve plate. • Visual check of the valve beams, valve spindles, diffusers and valves. • Check the levers, straps, bushings and bolts for running-in traces.
Emergency shut down valve (ESDV)	• Visual check of the valve and its seating. • Visual check of the steam strainer; if there are signs of cracks, test by applying a dye-penetration procedure.
Protective equipment	• Check the emergency lubricating oil unit. • Simulate the switching-in of auxiliary oil pump and emergency lubricating oil pump via pressure switches; readjust the switching points if necessary; check the battery capacity of the emergency lubricating oil pump. • Simulate lubricating oil pump switchover caused by failure of low voltage supply.
Rotor turning device	• Check the correct alignment of rotor turning device and gearbox. • Change the lubricating oil of gear.
Generator	• Check generator protection parameters given in operators' manual. • Check voltage regulator.

5 **Bearing** consisting of a shaft or journal which rotates freely in a supporting metal sleeve or shell.

Table 4: Typical maintenance tasks for a steam turbine and generator set (not an exhaustive list)

Unit	Typical task	Frequency	Typically undertaken by
Turbine and generator set • Observe operating performance. • Check for noises and running smoothness, fixtures leakages and general disorders.			
Monitoring devices (pressure and temperature)	• Acquire measuring data of monitoring devices and check them for plausibility. • Check/clarify abnormal changes.	Daily	Operator
Shaft position measuring device Bearing temperature measuring devices Vibration measuring devices	• Plausibility check with recorded operating data.	Quarterly	Operator
Bearing pedestal front/rear	• Check the fastening screws manually and correct if necessary.	Annually	Operator
Steam turbine live steam control valve unit	• Check valve for mobility.	For standstill more than one month, before every start-up	Operator
	• Check valve for leaks.	During operation: permanent monitoring of control commands' execution throughout the whole load range	
	• Check valve for leaks.	Annually, when starting or stopping	
	• Check the hydraulic cylinder and connected hoses or lines for leakage, noises, and operational and control performance.	Daily	

Unit	Typical task	Frequency	Typically undertaken by
Steam turbine, live steam emergency shut off valve	• Check valve for mobility	For standstill more than one month, before every start-up	Operator
	• Check valve for leaks	Annually, when starting or stopping	
	• Check the hydraulic cylinder and connected hoses or lines for leakage, noises, and operational and control performance.	Daily	
	• Check washer column.	Annually	
Safety valve	• Visual inspection.	Daily	Operator
	• Check function by checking system pressure.	Monthly	
Shut-off valves of impulse lines	• Check for leaks and unusual performance.	Monthly	Operator
Gearbox/rotor turning device (RTD)			
Bevel Gear	• Observe operating performance. • Check for noises and running smoothness, fixtures, leakages and general disorders.	Daily	Operator
	• Check the toothing and contact pattern (visual inspection via inspection hole or endoscopy).	Check manufacturer's guidelines	Manufacturer
RTD and motor for bevel gears	• Check oil level of RTD gearbox. • Check for leaks and seal if necessary.	Monthly	Operator
	• Check ball bearing, change if necessary. • Replace the shaft sealing ring, clean cooling air passages.	Given run hours (or two-three years) based on manufacturer's guidelines	Operator

Unit	Typical task	Frequency	Typically undertaken by
Generator			
Generator set	• Observe operating performance. • Check for noises and running smoothness, fixations, leakages and general disorders. • Acquire measuring data of monitoring devices and check them for plausibility.	Daily	Operator
	• Check proper turning of the lubricating oil ring.	Monthly	Operator
Generator cooler	• Check for leakage/condensate. • Acquire measuring data of monitoring devices and check them for plausibility.	Daily	Operator
	• Retighten the fastening screws of the hood.	Annually	Operator
Grounding brush	• Visually check for wear and correct function. – Check, if brush is movable. – Check if brush has contact to shaft. – Check if contacts are connected correctly.	Prior to each start-up in the first year Minimum once each week later Monthly, if there is only little wear	Operator
	• Change of grounding brush.	As soon as the brush is worn out	Operator
Lubricating oil schedule			
Lubricating oil system	• Check operational performance. • Acquire measuring data of monitoring devices and check them for plausibility. • Check for leaks and seal. • Check oil for water content/frothing.	Daily	Operator

Unit	Typical task	Frequency	Typically undertaken by
	• Check oil for usability (oil analysis) refer to lubrication plan.	Refer to manufacturer's lubrication plan given in O&M manual	
Lubricating oil tank	• Visual inspection for leakage, check oil level.	Daily	Operator
Lube oil cooler	• Visual inspection for leakage and other problems.	Quarterly	Operator
Lube oil filter	• Check the clogging indication.	Daily	Operator
Control oil system	• Check operational performance. • Acquire measuring data of monitoring devices and check them for plausibility.	Daily	Operator
Control oil pumps	• Visual inspection of the pumps, check of shaft seal.	After first 500 run hours	Operator
	• Change drive motor's ball bearing.	Refer to manufacturer's O&M manual	Operator
Control oil filter	• Check the clogging indication.	Daily	Operator
Drainage system			
Condensate traps Pneumatic drain valves Manual drain valves Drainage flash tank	• Check for leaks and unusual performance.	Daily	Operator
	• Grease valves.	Half yearly	Operator
Condensate pumps	• Visual inspection of the pumps, check of shaft seal.	After first 500 run hours	Operator
Battery for emergency oil pump • Check capacity of battery annually.			

3.5.4 CHP system shutdown planning and management

Any CHP system including the prime mover and electrical generator will require planned shutdowns for maintenance. The preparation and scheduling of these outages is essential. The costs of shutdown include not only the labour and materials for carrying out the planned work, but also the additional costs of meeting the site's heat and power requirements from other sources. These costs must be taken into consideration when deciding on the timing and duration of a shutdown.

For example, it is not generally advisable to carry out planned maintenance on a biomass CHP system when electricity costs are high, for instance during midweek daytime periods in winter, and during periods when the site heat demand is high. Furthermore, it may be cost-effective to minimise the duration of the shutdown by having work continue outside 'normal' working hours; the extra cost of labour is usually more than offset by the reduced costs and duration of alternative heat and power supplies.

3.5.5 Operational considerations for Organic Rankine Cycles

Organic Rankine Cycle (ORC) systems use heat generated from in a biomass boiler to vaporise an organic working fluid (such as Freon or an organic solvent). The organic vapour rotates the turbine, which is coupled to the generator to produce electricity. The exhausted vapour flows through heat recovery and condensing stages before being pumped back to the evaporator to repeat the closed cycle. The details provided above for steam turbines are also applicable to ORCs. The ORC requires specialised and regular maintenance, which is typically provided by the technology provider.

Typically, ORC systems work more efficiently at lower temperatures and pressures, and at the smaller scales more suited to biomass fuel. They are well suited to operation with thermal oil systems. For an ORC to operate as CHP, the operator needs to ensure that the production of electricity and heat occurs simultaneously (i.e. heat is recovered from the ORC system after electricity is produced, i.e. from the condenser or economiser and not before from the evaporator). This is the case for all prime movers, but especially difficult to establish for an ORC as the unit is provided as a containerised 'black box'. Therefore, it is essential to inspect an ORC to ensure that heat is recovered from the economiser/condenser and not the evaporator in an ORC. *Figure 3.6* shows an arrangement where the ORC operates in a CHP mode and *Figure 3.7* shows where it operates in a non-CHP mode.

Figure 3.6: Illustration of an Organic Rankine Cycle system operating in a full CHP mode

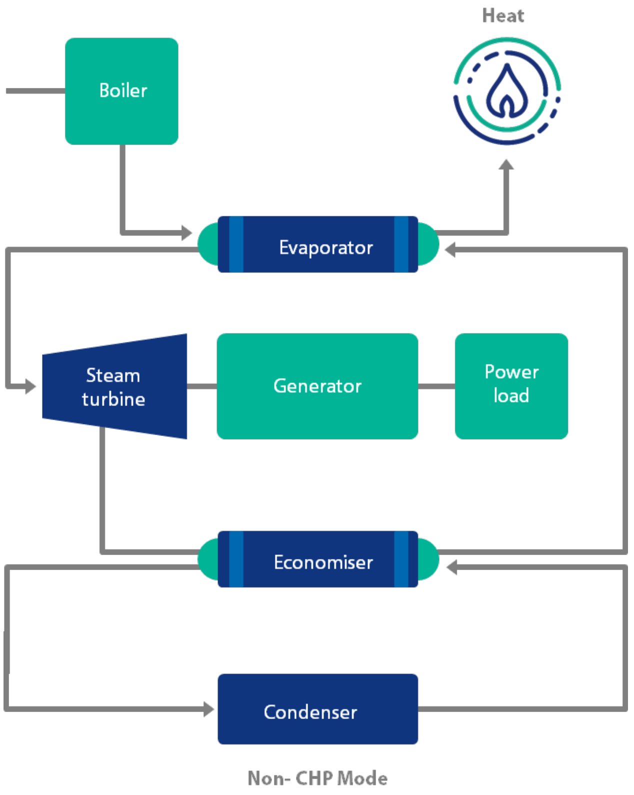
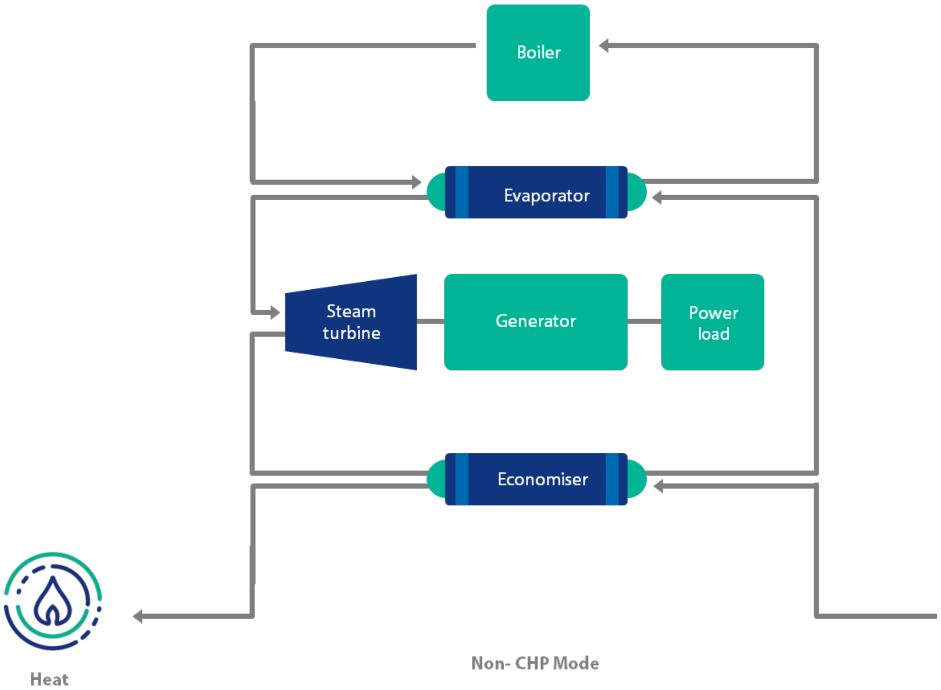


Figure 3.7: Illustration of an Organic Rankine Cycle (ORC) system operating in a non-CHP mode



4. Control and monitoring systems

Control and monitoring system

- Electricity metering.
- Heat metering – hot water and steam measurement.
- Metering calibration should be performed as per manufacturer guidelines.
- See Appendix 1 for a worked example showing how metered data is used for evaluating performance.
- See Appendix 2 for list of monitoring parameters for a steam turbine system.

4.1 Electricity and heat metering

4.1.1 Electricity metering

To measure electricity use, clearly labelled commercial/industrial three-phase electricity meters of billing quality should be used. Watt-hour meters, current transformers and voltage transformers are most commonly used. The manufacturer's specification sheet should confirm accuracy, class and other parameters. A modern electricity meter (see *Figure 4.1*) is a robust device that requires little maintenance. The primary requirement of an electricity meter is to register the energy generated (or consumed) with an acceptable degree of accuracy. Any significant error in the registered energy can represent a loss to the electricity generator or supplier, or the consumer being over billed).

Figure 4.1: Electricity meter

The metering requirements are specific for each connection and depend on the type, size and nature of the installation. These requirements should be specified in the connection agreement. Further information on this subject can be found in ESB Networks, Conditions Governing Connection to the Distribution System[6] (for embedded generators connecting at LV, MV and 38 kV) (and The Meter Code[7] .

[6] https://www.esbnetworks.ie/docs/default-source/publications/conditions-governing-connection-to-the-distribution-system
[7] https://www.cru.ie/wp-content/uploads/2007/07/cer07085.pdf

4.1.2 Heat metering

In a combined heat and power (CHP) system, several meters could be required to measure hot water and steam, and to ensure the performance of each component and its losses are measured. Maintenance of the installed heat metering system (flowmeter, temperature and pressure sensors, and integrator) should be based on the manufacturer's manual. Meter calibration should be undertaken periodically as advised by the manufacturer. Some key requirements are discussed below.

4.1.2.1 Day-to-day checks

Heat meters, if installed correctly, should require very little maintenance. However, regular checks are necessary to ensure that meters are functioning correctly and the components have not been inadvertently damaged. These checks can be undertaken at the same time as manual meter readings are taken, but should be at least weekly. Where meter readings are taken remotely, visual checks of meters should still be undertaken, but may be less frequent.

The temperature and flow sensor leads and electrical connections can be particularly vulnerable to accidental physical damage, though this should be mitigated by good installation practice. Even if not damaged, temperature sensors can become dislodged or loose in their pockets, which may cause reading errors. Integrators and their electrical connections also become damaged through carelessness.

Most heat meter integrators will display error codes if any input parameters from the flow or temperature sensors go out of range or if a communications failure is detected (where a data communications module is fitted). A failure of the integrator itself is usually self-evident.

Heat meters on biomass systems are often installed in dusty environments (particularly where wood pellets are used). Therefore, it is important that the integrator and areas around electrical connections are kept clean. Operators should be aware of the International Protection (IP) class of the integrator, which varies between manufacturers and models.

Checks of boiler efficiency by comparing heat output to fuel input (see Section 3.4) that show deviations from normal values could be an indication of a heat meter not reading correctly, rather than a boiler issue.

4.1.2.2 Heat meter power sources

Heat meters consists of an integrator which requires electrical power. Depending on the integrator model and the options available, the power can be provided by a lithium ion battery (or batteries), the mains or a lower voltage supply (e.g. 12V or 24V direct current).

If the integrator is battery powered, the user should be aware of the lifetime of the battery as specified by the manufacturer. This can range from 5 years to 15 years, depending on the type of battery installed and whether additional integrator modules, such as for data communications, have been specified. The user should plan for battery replacement, but also be aware that batteries can suddenly and unexpectedly fail.

4.1.2.3 Calibration

Heat meters should be supplied with calibration certificates ideally valid for a set period of time. However, manufacturers do not always state recalibration intervals or expected meter lifetimes, even on their calibration certificates, and there is no requirement in the Measuring Instruments Directive (2004/22/EC) (MID)[8] or EN1434 to do so[9] In the absence of guidance from the manufacturer, a period of no longer than five years between recalibrations is considered good practice.

Any incentive scheme may specify intervals for meter recalibration or sample checks of accuracy. Similarly, contracts for heat sales or district heating where consumers are billed based on metered heat use may have specifications for recalibration or accuracy checks.

4.1.3 Steam meters

Where heat is delivered as steam, a steam meter will be required. A steam meter consists of a steam flowmeter and pressure and temperature transmitters. In some cases, there will also be an integrator that gives the reading in energy units (kWh or MWh). The enthalpy of the steam (kWh/kg of steam) is calculated from the pressure and temperature readings and multiplied by the steam flow rate to give an energy reading.

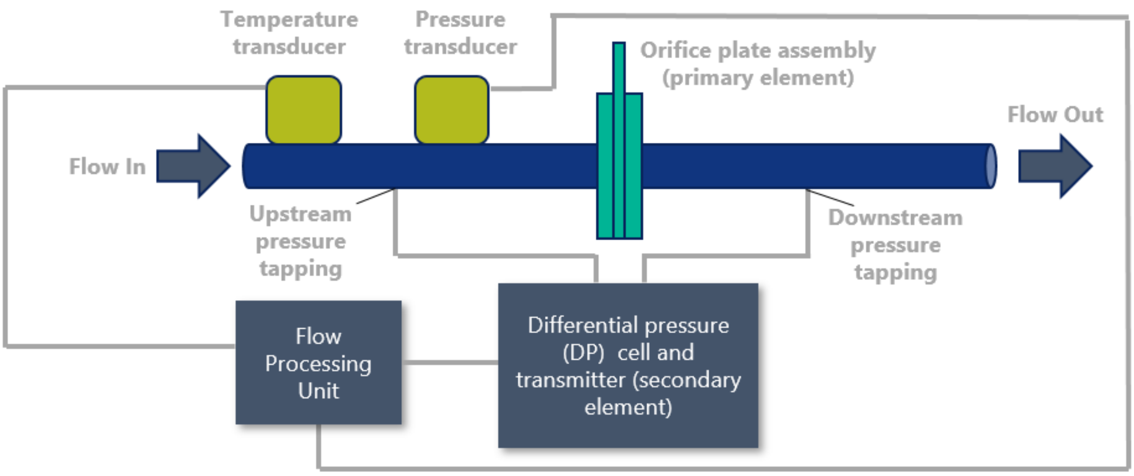
The steam flowmeter consists of two main parts:

1. The 'primary' device or pipeline unit, such as an orifice plate, located in the steam flow.
2. The 'secondary' device, such as a differential pressure (DP) cell, that translates any signals into a usable form.

Figure 4.2: Steam meter

8 Directive 2014/32/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of measuring instruments (recast). Applicable from 20 April 2016.
9 Heat meter accuracy testing, November 2016, Building Research Establishment for UK Department for Business, Energy & Industrial Strategy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/576680/Heat_Meter_Accuracy_Testing_Final_Report_16_Jun_incAnxG_for_publication.pdf

Figure 4.3: Steam meter and its parts



Larger sites use a supervisory control and data acquisition (SCADA) system where flow rate, temperature and pressure readings are transmitted as pulses and a programming software used to calculate energy in steam.

4.2 Biomass boiler control

The operation of all controls and monitoring systems associated with the biomass boiler and wider heating system should be checked on a regular basis, particularly if there are changes to the demands from heat loads. Such checks and any remedial action have two main purposes:

1. To ensure that the boiler and associated systems continue to operate as intended.
2. To identify any modifications to settings needed in response to changes on site or that can be made to improve the efficiency of operation.

The checks that should be made are too specific to heating systems and boilers to be described in detail in this guide. However, they are likely to include:

- The boiler control system (as provided by the boiler manufacturer), including:
  - Boiler flow and return temperature settings and confirmation they are being achieved.
  - Thermal store target temperatures and settings for demanding heat from the boiler (may be integral to the boiler control system).
  - Status and error indicators for the boiler itself, the buffer/thermal store, and primary pumps and control valves.
- Heating system controls (may be a building management system (BMS)) including:
  - Time settings for space heating and hot water services, including for different zones.
  - Optimum start for space heating (integrated with boiler/thermal storage settings).
  - Target temperatures (heated spaces and hot water services).
  - External temperature compensation.
  - Correct operation of secondary circuit pumps and control valves.

4.3 CHP system monitoring

CHP system operation requires the effective use of an overall control strategy to ensure that key objectives are achieved. This strategy must include the means of achieving:

- Plant condition monitoring – to ensure optimum reliability and performance.
- Efficiency of energy conversion and recovery.
- Minimised costs and maximised savings.

Power generation differs from the operation of boilers, and requires different skills and techniques, particularly in relation to the control and monitoring associated with operating electrical generators in parallel with the local electricity system. A CHP system also incorporates heat transfer systems that must be correctly controlled to ensure the safe and long-term operation of the equipment, and to recover heat for beneficial use. Furthermore, a CHP system may incorporate auxiliary equipment such as supplementary firing and gas compression.

The four main types of control system are considered:

- Individual plant control systems;
- Monitoring and advisory systems;
- Total control through distributed system; and
- Manual control of individual plant.

4.3.1 Individual plant control systems

The capabilities of individual plant control systems to be integrated within overall plant monitoring schemes should be a key factor in plant and system selection.

Industrial CHP systems consist of a number of core plant items – turbines, engines, boilers, compressors, etc. Each will be installed with its own control panels and systems to provide basic control functions such as start-up, shutdown and modulation. These systems also provide alarms and automatic shutdown as part of system protection, and it is common for certain key condition parameters to be fed from one plant control panel to another. Each control system needs to have a range of inputs and outputs to function as part of an integrated control and monitoring system.

Operating features normally incorporated in the control systems of individual plant items may include:

- Start-up and shutdown procedures;
- Normal operating parameters, with alarms and automatic shutdown facilities;
- Protection of individual motors and components;
- Input and output of condition signals;
- Modulation in response to control inputs;
- Synchronisation with the local electricity supply system; and
- Monitoring of vibration.

Some plant control systems can also store data of plant conditions. This provides important information for maintenance scheduling and failure diagnosis.

4.3.2 Monitoring and advisory systems

Some CHP systems use a centralised monitoring and advisory system that provides a continuous flow of information to the plant operator. The system may also be configured to provide advice and warnings to the plant operator, but without making automatic changes to plant operation. Such a system is based on the extensive monitoring of a wide range of plant operating conditions: some of these may be integral to individual plant control systems, while others may be site-specific additions to improve overall system operation.

Monitoring and advisory systems are often preferred where plant operating decisions have to take account of factors that cannot be defined for computer-based control. The use of this type of control and monitoring regime requires constant attendance, or the immediate availability of a plant operator or supervisor to make decisions and to initiate the appropriate control actions.

A plant monitoring system will collect data for a wide range of plant parameters. It can also store and process data to provide information for evaluation and plant diagnostic purposes. Typical parameters include:

- Heat and power outputs;
- Fuel consumptions;
- Water consumption;
- Ambient air conditions;
- Exhaust and cooling system conditions;
- Exhaust gas constituents;
- Electricity import and export metering; and
- Predictions of site energy load patterns.

To effective use of the monitoring and data collection facilities, an on-line computer system would contain additional management information, together with the necessary programming, to enable the system to provide advice to the operator or to make and implement plant operating decisions. The management input to such a system would include:

- Fuel tariffs;
- Water costs;
- Electricity purchase and export tariffs;
- Plant maintenance costs;
- Utility sales revenues;
- Costs of alternative supply provisions;
- Fixed costs associated with start-up or shutdown; and
- Environmental constraints on operations.

The combined use of monitoring and advisory functions enables reliable and cost-effective plant operation to be achieved by manual operation. This would include decisions on optimum plant operation and on plant priority and sequencing. It may also include total shutdown at times when alternative energy supplies are more cost-effective.

4.3.3 Total control through distributed systems

Some CHP systems use distributed control systems, with semi-autonomous, computer-based control of the individual plant control panels; and the higher-level supervision of plant operating procedures in an overall plant control protocol. Systems of this type will incorporate a wide range of automatic responses to defined events, such as component or plant failures, changes in heat and power system conditions, and variations in site load. In other words, they will make and carry out automatic control decisions regarding plant operation.

As with the plant monitoring and advisory systems, this system is based on extensive monitoring of a wide range of plant operating conditions, some of which may be integral within individual plant control systems, while others are site-specific additions.

A distributed control system ensures effective monitoring and operation, and includes remote control where appropriate. Interventions by site staff tend to be infrequent and staffing levels can be low with only shift supervision required. This type of system tends to be used in plants that have relatively uncomplicated control requirements, such as those that operate continuously without changes in load or output.

4.3.4 Manual control of individual plant

The other option is where a CHP system has no overall control or monitoring system but is operated and controlled manually according to the information provided by each plant control panel. This is sometimes the preferred option where it is compatible with other site operation and control methods, and where the installation of centralised monitoring or control is not cost-effective.

4.4 Performance evaluation

It is essential that the heat and electricity outputs are metered and logged to help determine whether the installed biomass heating and CHP systems are performing correctly – and because it is likely to be required for any incentive scheme. If metering data is reviewed regularly, this may also provide a potential method for early detection of problems with a heating and generating systems (which may not necessarily be due to the biomass CHP system, but could be another part of the system). This is in addition to monitoring other operational parameters such as combustion efficiency, electrical efficiency, grate temperature, steam pressure and emission levels. Metering and monitoring are discussed further in the accompanying Technology Guide.

The heat and electricity meter readings and fuel consumption values should be logged over time to build up a performance profile for the boiler and generation unit. This can be done by taking manual readings, using the heat meter memory or using remote logging incorporated into the remote monitoring.

Half-hourly or daily consumption rates are preferable, but not always practicable. Heat meter readings and fuel consumption data can then be analysed via a spreadsheet or more advance software. Steam input to the turbine unit should also be monitored by a steam meter. The performance profile created can then be checked against the following to evaluate the system's performance:

- The expected performance in the system specification or manufacturer's manual.
- The performance against a previous period (e.g. the same month in the previous year).
- The correlation of the profile against any demand factor profiles, such as increased output or shutdown periods. If the correlation is poor, this may suggest more heat is being supplied than is needed or the heat demand is not being adequately met. This can be investigated in more depth by looking at the site's building management system.
- The output of any fossil-fuel boilers, and whether the balance between fossil and biomass heat is as expected.
- Steam input to the turbine and its power generation is performing as expected.

Other operational parameters (e.g. combustion efficiency, overall power efficiency, grate temperature, pressure and, if possible, emissions levels) should be monitored against those stated in the system specification and manufacturers' manuals. If these go out of their specified ranges, it may indicate that the system is not operating correctly and should be investigated as soon as possible.

4.5 Emission limits and monitoring

4.5.1 Emission limits for boiler combustion

Statutory emission limit values (ELVs) for biomass combustion plants in Ireland apply or will apply as follows:

- Directive (EU) 2015/2193 on the on the limitation of emissions of certain pollutants into the air from medium combustion plants, known as the Medium Combustion Plant Directive (MCPD)[10], applies to plants with a rated thermal input of 1MW or more, but less than 50MW, excluding those covered by Directive 2010/75/EU on industrial emissions, known as the Industrial Emissions Directive (IED) (i.e. biomass boilers burning contaminated waste wood and plants of 50MW or more). There is also an exemption for on-farm combustion plants that exclusively use unprocessed poultry manure where the total rated thermal input is less than or equal to 5MW.

Table 5 summarises the MCPD ELVs for solid biomass in milligrams per normal cubic metre (mg/Nm^3) of flue gas[11].

Table 5: Summary of MCPD ELVs for solid biomass

Applicability	Rated thermal input (MW)	Emission limit values (mg/Nm^3)		
		NOx*	Dust/PM**	SO_2***
Existing plants from 1 January 2030	1 to ≤5 Δ	650	50	200† 300‡
Existing plants from 1 January 2025	5 to ≤20		30	
	20 to ≤50		50	
New plants from 20 December 2018	1 to ≤	500	50	200†
	5 to ≤20	300	30	
	20 to ≤50		20	

Δ On-farm combustion plants that exclusively use unprocessed poultry manure are exempt.
† Does not apply to plants firing exclusively woody biomass
‡ If firing straw

*Oxides of nitrogen
** Particulate matter
*** Sulfur dioxide
≤ Less than or equal to

- From 1 January 2020, new solid fuel boilers up to 500kWth (thermal output) that are placed on the market and put into service will be required to comply with Directive 2009/125/EC establishing a framework for the setting of ecodesign requirements for energy-related products as implemented by Commission Regulation (EU) 2015/1189, but it does not apply to non-woody biomass boilers. The requirements include the following ELVs.

Table 6: Ecodesign ELV requirements for solid fuel boilers (thermal outputs up to 500kWth)

Applicability	Rated heat output (kWth)	Emission limit values (mg/Nm^3)			
		CO*	NOx	Dust/PM	OGCs**
Manually stoked	≤500	700	200	60	30
Automatically stoked		500		40	20

*Carbon monoxide
**Organic gaseous compounds

10 Implemented in Ireland via the European Union (Medium Combustion Plants) Regulations 2017 http://www.irishstatutebook.ie/eli/2017/si/595/made/en/print
11 Defined at 273.15K and 101.3kPa after correction for water vapour content and at 6% oxygen content.

Since ecodesign requirements are product standards, there are no related obligations on users to monitor actual performance in use.

- The standard EN 303-5:2012 Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500kW, sets ELVs for appliances up to 500kW rated heat output, but adherence by manufacturers is voluntary. The standard defines three classes – 3, 4 and 5 (5 is the best). The ELVs for this standard are the same as those stated in Directive 2009/125/EC.
- Prospective operators should consult the requirements of any incentive scheme to which they are intending to apply for specific ELVs required by the scheme.
- With regard to local air quality, Irish legislation is evolving. Developments can be monitored via the Department of Communications, Climate Action and Environment's website[12] .

4.5.2 Emission limits for gasification

Gasification-based biomass CHP systems are viewed as a clean technology in comparison to combustion systems. The syngas required for these systems needs to be treated, and particulate matter and metallic components removed prior to combustion in an engine. As a result, these components do not enter the atmosphere following combustion of syngas. However, the treatment adds to capital and operating costs.

The main components of syngas entering the gas engine are carbon monoxide (CO), hydrogen (H) and nitrogen (N) with smaller amounts of carbon dioxide (CO_2) and methane (CH_4). The combustion of syngas involves H and small amounts of CH_4. The main components of the flue gas from syngas engines are CO2, due to the relatively high temperature of syngas combustion (in comparison to natural-gas combustion), and nitrogen oxides (NO and NO_2), which form in the flue gas. Volatile organic compounds (VOCs) and hydrocarbons are, on the other hand, fully decomposed as a result of high temperatures. Levels of these components should meet Irish legislation as discussed above.

4.6 Record-keeping

The following records should be kept for a biomass CHP system:

- Performance records as detailed in the performance evaluation section.
- Maintenance records, including details of what was checked and what was done.
- An issue and resolution log. This should cover ongoing and historical issues, and related actions and resolutions. This makes it easier to rectify repeat issues and keep on top of current ones.
- The record-keeping requirements relating to any financial support schemes should be verified.
- Documents from construction for reference (e.g. the construction contract, operating and maintenance manual, installation photos, safety file, system design specification and drawings, commissioning certificates, and meter calibration certificates).
- The maintenance contract for reference.
- Copies of warranties. Also create a schedule of the warranties so it is clear when they expire. Some warranties are based on whichever occurs first – a given time period or a number of operating hours. The expected time taken to reach the operating hours should be verified and monitored if it is expected to be less than the warranty time period. Schedule a service before the end of the warranty to ensure any repairs and replacements can be identified and rectified under warranty. Replaced parts may have their own warranties and a record of these should be kept in case the part requires a second replacement within that warranty period.

[12] https://www.dccae.gov.ie/en-ie/environment/topics/air-quality/national-clean-air-strategy/Pages/default.aspx

5. Heat sales

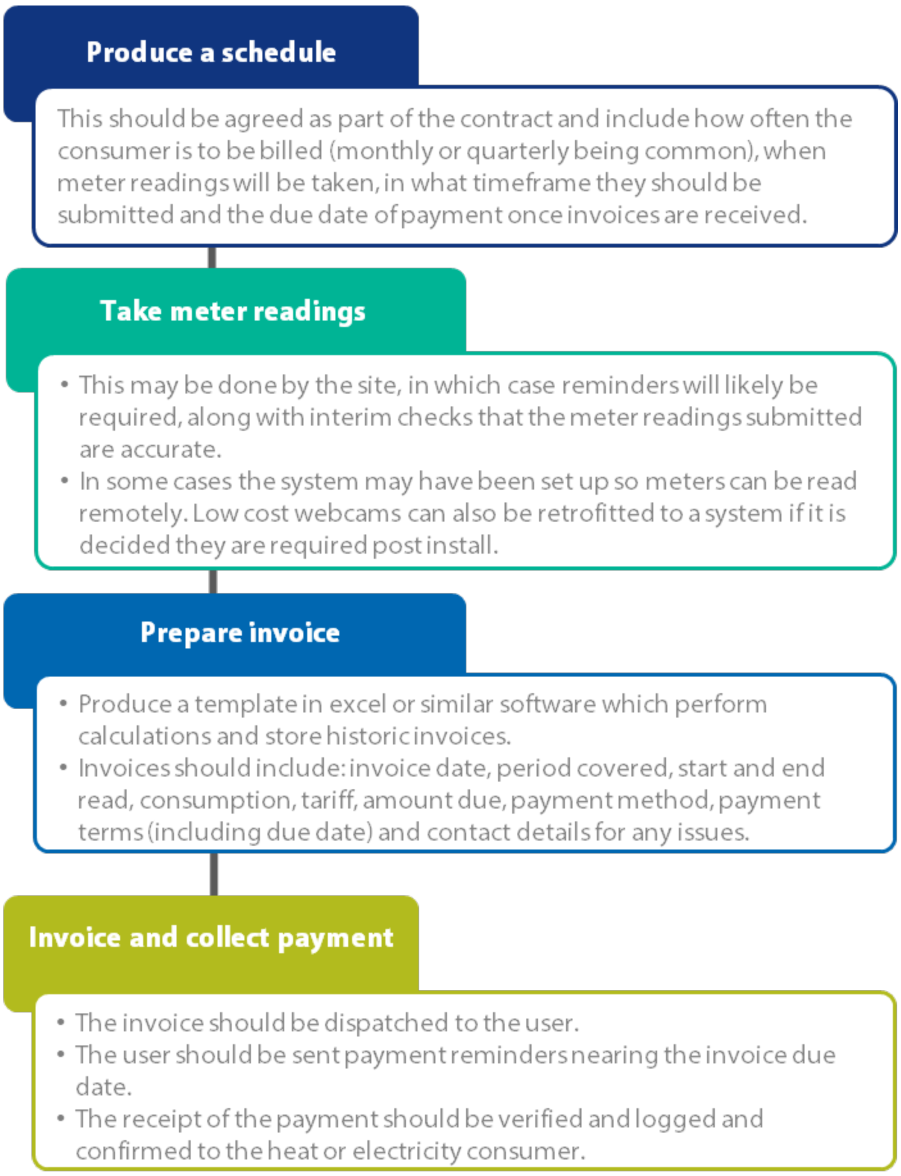
A heat sales system will be required for projects where the biomass combined heat and power (CHP) system will be supplying heat to sites not owned by the biomass CHP system owner. This guide focuses on the ongoing requirements of a heat sales system. How to identify customers and develop a sales system is discussed in the accompanying Implementation Guide.

In terms of electricity, the developer / operator is advised to contact the CRU regarding requirements for electricity supplier licensing. See the Implementation Guide for further details.

5.1 Metering and billing

The sales system will require the user's consumption to be metered and then the user billed for it. The process for this is shown in *Figure 5.1*.

Figure 5.1: Process for establishing a heat sales system



5.2 Contract reviews

The sales contract should be reviewed annually, the main purpose being to assess the tariff that has been set. The price in the tariff should have been indexed against an appropriate parameter such as fossil-fuel costs, retail price of heat or costs of biomass fuel. As such, the current price of fossil fuels and biomass should be reviewed, and the impact of these on the heat sale tariff assessed. e.g., if biomass costs increased of reduced, the tariff may need adjusting accordingly.

The amount heat generated and consumed should be reviewed at this point to assess if it is as expected and to enable any differences to be identified for discussion. The contract review can also be used as an opportunity to identify any issues or improvements and discuss any potential changes in demand.

6. Health and safety

Health and safety

- This guide aims to alert readers to the hazards and risks that need to be managed when dealing with biomass conversion technologies and combined heat and power (CHP) prime movers. It does not provide a comprehensive treatment of the subject, and additional advice and guidance should be sought.
- Fuel delivery and handling hazards include vehicle movements, mobile and fixed plant movements, below-ground fuel storage and increased dust levels from pneumatic delivery.
- Fuel storage hazards include carbon monoxide (CO) build-up in fuel stores, oxygen depletion, dust-laden atmospheres, mould growth on the fuel and fuel storage fire.
- Boiler and gasifier hazards include sudden shutdown (e.g. due to loss of power), build-up of uncombusted gas mixtures in the unit and/or its flue, CO entering the boiler house from the boiler and/or flue system, exposure to soot and ash (particularly during cleaning operations), entry into the confined space of larger boilers for cleaning and other maintenance, sudden ash-bin ignition and flue system tar fire.
- Syngas from gasification systems has a very high CO concentration in comparison to boiler flue, which poses a significant asphyxiation hazard. In addition, a major component of the syngas is hydrogen which is highly flammable.
- Owners should always comply with equipment manufacturers' health and safety guidance for biomass conversion systems and CHP prime movers.

Biomass conversion systems give rise to a range of potential hazards that do not arise with systems operated on natural gas, liquefied petroleum gas (LPG) or oil, or arise to a lesser degree. There is less knowledge and experience of biomass systems among heating system designers, installers and operators. Design and installation standards are also less developed for biomass systems.

This section considers operational health and safety issues associated with biomass fuel delivery and handling, fuel storage, the biomass conversion process and the prime mover. The information provided is applicable to biomass boilers and gasifiers.

Important health and safety note

This guide does not provide a comprehensive explanation of the hazards and risks associated with operating a biomass combined heat and power system

Readers are strongly advised to consult the Combustion Engineering Association's (CEA) publication 'Health and safety in biomass systems'. [1]While the CEA document references specific UK legislation, equivalent provisions in Ireland can be found via the Health and Safety Authority's (HSA) website.[1]

Further advice can also be sought directly from the HSA – t: 1890 289 389 (LoCall) or e: **wcu@hsa.ie.**

6.1 Fuel delivery and handling

Biomass fuel is, in most cases, delivered to a site by lorry. For bulk wood chip, the load will typically be discharged by tipping into a hopper, onto a conveyor or simply onto a hardstanding that may or may not be covered. In the latter case, the fuel will tend to be moved in batches to the local fuel store by telescopic handler or similar. For small volumes, pellets can be purchased in bags, which will normally be on a pallet and unloaded using a forklift truck. Fuels such as logs, straw, and bulk bags of pellets and chips may be unloaded by a forklift truck, tractor, telescopic handler or similar vehicle, or the lorry's own crane. This movement of heavy vehicles, particularly when reversing, poses a hazard to pedestrians and vehicle users.

Although bulk wood pellets can be delivered in a similar way, it is more common for them to be pneumatically blown into a silo or store. The increase in dust levels caused by this can result in respiratory health problems and poses a heightened risk of dust explosion in confined areas.

Fuel handling includes the extraction of fuel from stores for delivery to the boiler or gasifier. Wood pellet and wood chip stores are usually equipped with augers, agitators, walking floors and/or conveyors. These pose a hazard, particularly as they are normally submerged in the fuel and not visible to personnel.

Measures to mitigate these risks include staff training, strict procedures, use of a banksman, safety equipment and exclusion zones.

6.2 Fuel storage

Other than well-ventilated, open storage facilities, biomass fuel stores are likely to be considered as 'confined spaces' under the Safety, Health and Welfare at Work (Confined Spaces) Regulations 2001 and the HSA's associated Code of Practice for Working in Confined Spaces.[13]

The storage of biomass fuel gives rise to various hazards, including fire, explosion, asphyxiation/poisoning and respiratory irritation.

Measures to mitigate these risks include staff training, strict procedures, avoidance of lone working, safety equipment, cleaning and ventilation.

6.3 Biomass conversion process

Hazards associated with the boiler or gasifier arise from the wet (heating medium) side, the fire (combustion) side and the flue/chimney system.

Table 7 summarises the main hazards, associated risks and mitigation measures, but these should not be taken as being comprehensive or even suitable for site circumstances. Operators should undertake their own full risk assessments, and establish site-specific health and safety plans and procedures.

Table 7: Summary of the main hazards and associated risks of biomass CHP systems

Hazard	Risks	Comments	Example mitigation
Sudden system (boiler/gasifier) shutdown (e.g. due to loss of power).	Excessive wet-side temperature or pressure leading to explosion, or ruptures leading to escape of boiling water/steam (in case of boiler) or syngas (in case of gasification systems) causing physical injuries and/or plant damage.	Biomass systems cannot be extinguished quickly due to the remaining fire-bed and thermal inertia. System design and operating procedures must allow for the safe management and control of sudden shutdown scenarios.	Good system design. Well-trained staff. Clear operating procedures/method statement.

13 www.hsa.ie/eng/Publications_and_Forms/Publications/Codes_of_Practice/COP_Confined_Space.pdf

Hazard	Risks	Comments	Example mitigation
Build-up of uncombusted gas mixtures within the system and/or its flue.	Explosion within the boiler or gasifier or flue and consequential injuries, and loss and damage to property.	Uncontrolled combustion or gasification can arise from uncontrolled draught, excessive fuel charging, delayed ignition or uncontrolled air to the combustion/gasification space.	Well-trained staff. Clear operating procedures/method statement.
Carbon monoxide (CO) escape into the boiler house from boiler and/or flue system, or from syngas leaving the gasifier.	Asphyxiation/poisoning.		Place CO alarms in the boiler house and adjacent rooms, particularly if the flue passes through the building.
Exposure to soot and ash from combustion or gasification, particularly during cleaning operations.	Health effects due to toxic/carcinogenic content of soot and ash in small particulate form.	Health risks arise particularly from polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs) and heavy metals.	Staff training. Appropriate personal protective equipment (PPE) including full overalls, rated dust masks and eye protection.
Entry into the confined space of larger boilers for cleaning and other maintenance.	Health impacts and/or injury from excessive temperature, presence of mineral fibre insulation, exposure to soot and ash (see above), refractory collapse and ignitors/burners.		Establish method statement for entry and cleaning. Boiler must be extinguished for sufficient time (over 24 hours) to produce a safe working temperature.
Sudden ash-bin ignition.	Physical injury.	Bottom ash can still contain significant volatile content. Ignition can be caused by the sudden inrush of fresh air from opening sealed ash containers.	Staff training to avoid sudden opening of sealed ash containers.
Flue system tar fire.	Injuries and fatalities. Loss and damage to property.	A build-up of tar in the flue ductwork and stack can occur from poor-quality fuel and prolonged low fire running.	Flue cleaning and avoiding the conditions for tar production.

It should be noted that while combustion systems need to address health and safety issues related to steam escaping from the systems, gasification systems require additional health and safety measures to prevent syngas escaping from the gasifier and the syngas engine.

6.4 Prime mover

The installation of a biomass combined heat and power (CHP) system may require the adoption of new safety systems and procedures, particularly regarding the operation and maintenance of the prime mover.

The steam turbine and the generator are designed in accordance with the latest state of the art and according to the established safety requirements. However, their operation could bring risk to the operator and other assets. The major risks of injury to personnel that operate a turbo set are determined by the operating parameters of the steam, and the lubricating and control oil that is used; and by the considerable kinetic forces resulting from the high rotational speed of the turbine. At high pressure and high temperature, a steam leakage may cause serious burns or grievous bodily harm possibly resulting in a fatality.

Steam turbine plant components that are being inspected, maintained or repaired must be de-energised if that is stipulated in manufacturer's health and safety requirements or by a site's own requirements. The fundamental safety instructions that should be adhered while operating a steam turbine generator set are;

- Check that de-energised sections are voltage-free earth and short-circuit them; then insulate them from neighbouring sections that are energised.
- The electrical equipment of the steam turbine and of the generator must be regularly inspected and any deficiencies eliminated immediately.
- The manufacturer must give explicit approval for any welding, cutting or grinding work to be carried out on the steam turbine and on the generator.
- Before welding, cutting or grinding, clean dust off the surroundings of the steam turbine and generator, and make sure there is sufficient ventilation.
- All pipelines, hoses and screwed connections must be regularly checked for leakage and any visible external damage.
- Before repair work is started, depressurise any sections of the system that are to be opened and pressure lines according to the component description.
- Wear the stipulated personal hearing protectors.
- When handling oils, greases and other chemical substances, the safety regulations pertaining to the product must be observed.
- Care must be taken when handling hot operating and auxiliary materials.
- Any malfunction that could negatively affect safety must be rectified immediately.

When syngas (for gasification CHP systems) is used within an enclosed area, a review of ventilation facilities will need to be carried out and it may be appropriate to install gas detectors appropriate, possibly connected to an automatic gas shut-off valve.

Changes to the plant must be accompanied by an assessment of any risks and hazards that may arise as a result. It is important to keep proper records of plant safety tests, together with maintenance and equipment schedules.

7. References and other sources of information

A substantial amount of guidance on biomass systems has been published over recent years. Not all of this guidance will remain correct or accurate. Factors that are likely to vary and should always be cross referenced against other sources are:

- Technology: develops and improves over time.
- Costs: these may be out of date, or specific to a certain technology or location.
- Fuel availability: this may be specific to a certain location.
- Financial support schemes: these are subject to change over time.
- Legislation: this is subject to change over time.

7.1 General

Sustainable Energy Authority of Ireland (SEAI)
www.seai.ie

SEAI, Combined Heat and Power in Ireland, 2016 Update
https://www.seai.ie/resources/publications/Combined%20Heat%20and%20Power%20in%20Ireland%20Update%202016

Chartered Institution of Building Services Engineers (CIBSE), 2016, AM12 Combined Heat and Power for Buildings (CHP)
https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I7nsAAC

Carbon Trust, 2012, Biomass heating: A practical guide for potential users
https://www.carbontrust.com/media/31667/ctg012_biomass_heating.pdf
It should be noted that the costs and Renewable Heat Incentive (RHI) are mainly UK-specific.

Invest Northern Ireland, 2014, Biomass: A best practice guide for businesses in Northern Ireland
http://www.elementconsultants.co.uk/wp-content/uploads/2018/02/biomass-a-best-practice-guide-for-businesses-in-northern-ireland1.pdf

7.2 Energy efficiency

SEAI EXEED (Excellence in Energy Efficiency Design)https://www.seai.ie/energy-in-business/training-and-standards/exeed-certified-program/

7.3 Fuel

SEAI Conversion Factors
https://www.seai.ie/resources/seai-statistics/conversion-factors/

Wood Fuel Quality Assurance (WFQA) scheme for Ireland
http://wfqa.org/

En*plus*® certification scheme for wood pellet quality
https://enplus-pellets.eu/en-in/

Enterprise Ireland (2015) Animal By-products legislation: an explanatory guide
https://www.leanbusinessireland.ie/wp-content/uploads/2017/05/2015-Animal-By-Products-OCTOBER.pdf

7.4 Sustainability legislation

The proposed revised EU Renewable Energy Directive, which will come into effect in 2021, extending the scope of the existing EU sustainability criteria for bioenergy to cover biomass and biogas used for heating, cooling and electricity generation.
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016PC0767R%2801%29

7.5 High efficiency CHP

European Union, Energy Efficiency Directive, 2012/27/EU
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0027&from=EN

European Union, Commission Delegated Regulation, 2015/2402
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R2402&from=EN
Further details on harmonised efficiency reference values for separate production of electricity and heat

Commission for Energy Regulation: Certification Process for High Efficiency CHP Decision Paper, CER/12/125
https://www.cru.ie/wp-content/uploads/2012/07/cer12125.pdf

7.6 Health and safety

Combustion Engineering Association (CEA), 2011, Health and safety in biomass systems, design and operation guide
www.cea.org.uk/files/4313/7502/0795/Biomass_HS_final_071211.pdf

Health and Safety Authority, 2013, Safety, Health and Welfare at Work (Construction) Regulations 2013
http://www.hsa.ie/eng/Legislation/Regulations_and_Orders/Construction_Regulations_2013/.

Details of the duty holders and responsibilities are included on this website.
http://www.hsa.ie/eng/Your_Industry/Construction/Construction_Duty_Holders/

7.7 Procurement and contracts

Carbon Trust, 2012, Biomass installation contracting guide, practical procurement advice
https://www.carbontrust.com/media/88611/ctg073-biomass-contracting-guide.pdf

Carbon Trust, 2012, Template contracts for supply of biomass fuel, supply of heat energy, operation and maintenance agreement and services agreement https://www.carbontrust.com/resources/guides/renewable-energy-technologies/biomass-heating-tools-and-guidance/

Energy network (produced by North Karelia University of Applied Sciences), 2003, Heat sales contract
http://elearn.ncp.fi/materiaali/kainulainens/nwh/heat_energy_entrepreneurship/business_models/material/Contract%20for%20supplying%20district%20heat.pdf

SEAI, Energy Contracting
https://www.seai.ie/energy-in-business/energy-contracting/

US Department of Energy, A Guide to Performance Contracting with ESCOs
https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20939.pdf

City of Madisonville, Kentucky, Municipal Government, Sample Energy Services Contract
https://madisonvilleky.us/images/PDF.General/Sample_Electric_Service_contract.pdf

SEAI, Connecting Renewable and CHP Electricity Generators to the Electricity Network
https://www.seai.ie/resources/publications/Guide-to-Connecting-Renewable-and-CHP-Electricity-Generators-to-the-Electricity-Network.pdf

ESB Network, Connecting a Renewable Embedded Generator
https://www.esbnetworks.ie/new-connections/generator-connections/connect-a-renewable-embedded-generator
ESB Network, Conditions Governing Connection to the Distribution System – sets out requirements for Customer equipment at the interface between the Distribution System and the Customer's installation.
https://www.esbnetworks.ie/docs/default-source/publications/conditions-governing-connection-to-the-distribution-system

ESB Networks, Standard Connection Agreement for Embedded Generating Plant is available here:
https://rmdsie.files.wordpress.com/2014/03/standard-connection-agreement.pdf

8. Glossary

Ash content	Percentage of a biomass fuel's mass, on a dry basis, that will be produced as ash upon complete combustion of the fuel.
Auxiliary firing	The combustion of a fuel to supply a site heat demand when the generator is not running.
Auger	An archimedean (a rod with a helical projection) screw used to transfer material that is in a particle form.
Bioenergy	Renewable energy from living (or recently living) plants and animals (e.g. wood chippings, crops and manure).
Biomass	Any organic matter that can be burned for energy. Typically derived from solid wood into wood chips and pellets. Also, from short rotation coppice, miscanthus, sawdust and straw.
Boiler efficiency	The thermal transfer of energy contained in a fuel to the fluid in the boiler.
Building energy management system (BEMS)	A computer-based system for remote monitoring and control of building services used for interactive energy management.
Calorific value (CV) – net	The net calorific value of a fuel is the total energy released during combustion excluding that needed to evaporate any water arising as a combustion product and the moisture content of the fuel. Also known as the lower heating value (LHV) of the fuel.
Calorific value (CV) - gross	The gross calorific value of a fuel is the total energy released during combustion including that needed to evaporate any water arising as a combustion product and the moisture content of the fuel. Also known as the Higher Heating Value (HHV) of the fuel.
Capital costs	Initial set-up costs of plant or a project, after which there will only be recurring operational or running costs.
Carbon monoxide (CO)	A toxic product of the incomplete combustion of a fuel. Biomass fired boilers operating in slumber produce high levels of CO. Therefore, airtight exhaust flues and proper dispersion are essential.
Carbon dioxide (CO_2)	A normal product of combustion – the result of complete combustion of CO.
Client	The ultimate person or organisation procuring the biomass plant.
Cogeneration	The simultaneous production of heat and electrical power from a single fuel source for useful purposes. See also 'Combined heat and power (CHP)'.
Cogeneration scheme	All the equipment and operating systems for the total system defined by a boundary. It will include one or more boilers, prime movers driving electrical generation or mechanical equipment and a means of recovering heat for useful purposes.
Combined cooling heat and power (CCHP)	Combination of cogeneration with absorption chilling to give the simultaneous production of heat, power and cooling. See also trigeneration.
Combined heat and power (CHP)	The simultaneous production of heat and electrical power from a single fuel source for useful purposes. See also cogeneration.
Commissioning	The process of verifying that new heating plant meets the performance specifications as per design and called for in the installation contract.
Consultant	Professional person or organisation appointed to provide assistance of an advisory nature under a predetermined contract.

Contractor	Person or organisation appointed for the task of executing the scope of works.
Energy services company (ESCo)	Services company that sells heat (and/or other forms of energy) to the customer instead of a CHP and/or fuel. May install, own and maintain the CHP, or may sub-contract some or all of that.
Energy service contract	The contract underpinning the relationship between an ESCo and a client.
Expander	A device that transforms pressure in a working fluid (such as steam) into mechanical energy.
Frequency	The number of times per second that alternating current changes direction. Expressed as hertz (Hz). Public electricity supply in Ireland is 50Hz.
Flue	The passageway between combustion device and terminal of a chimney that acts as a duct to exhaust combustion gases to a position and height where they will not cause annoyance or health hazard.
Flue gas recirculation (FGR)	FGR is the feeding of a proportion of the cooled flue gases back to the combustion chamber to reduce the temperature of combustion at the grate with the aim of reducing the production of nitrous oxides. Sometimes referred to as exhaust gas recirculation (EGR).
Frequency	The number of times per second that alternating current changes direction, expressed as hertz (Hz). The public electricity supply frequency in Ireland is 50Hz.
Generator	A machine whose shaft is driven by an engine or turbine and converts mechanical energy into electricity. See also alternator.
Grate	Metal construction that supports a solid fuel during combustion. It allows the ash to pass through or over to collection. Various designs available with moving components to mix and move the fuel.
Ground works	Work done to prepare sub-surfaces for the start of construction work. May include ground investigations, site clearance and landscaping. Does not include demolition work.
Header	A pipe connecting two or more boilers in parallel and to other parts of the boiler house. Flow header connects outputs from the boilers, return header connects boiler returns. In a cogeneration system, the headers can also be on the heat demand side of the scheme.
Heat demand	The demand of heat of a site at any one time, typically expressed in kWth or MWth.
Heat exchanger	A device that transfers heat between two fluid systems (e.g. water flows from boiler system and heating pipework). Many different configurations available but plate-heat exchangers most commonly found.
Heat Supply Agreements (HSA)	The contract underpinning the relationship between a supplier and a customer for the sale of heat.
Heat meter	Device that measures the rate of heat transferred by a system by monitoring the flow rate of water and temperature difference between flow and return pipes.
Heat to power ratio	The amounts of heat energy and electricity produced by a cogeneration scheme, expressed as a ratio.
High temperature hot water (HTHW)	Pressurised hot water at 120°C and above.
In-house	Work or activities conducted by employees within an organisation.

Installer	Organisation or person contracted for the installation of equipment. May also be the supplier.
Lambda (λ)	Denote the ratio between the actual amount of combustion air (oxygen) and the minimum theoretical (stoichiometric) amount of combustion air (oxygen) required for complete combustion of the fuel.
Lambda sensor	A sensor that measures the oxygen content in the boiler flue gas so that adjustments can be made to combustion air supplies and fuel feedrate to maintain efficient combustion.
Liability	A person or organisation's legal responsibility to pay debts or fulfil obligations.
Load factor	The average intensity of usage of energy generating or consuming plant expressed as a percentage of its capacity.
Low loss header	A particular design of header arrangement that allows boilers to be controlled at their own flowrate compared to the flowrate of load systems.
Low temperature hot water (LTHW)	Hot water at up to 95°C.
Maximum demand	Maximum power, measured in kW or kVA, supplied to a customer, equal to twice the largest number of kWh consumed during any half hour in a billing period (usually a month).
Medium temperature hot water (MTHW)	Pressurised hot water at 95°C to 120°C.
Moisture content (MC)	Percentage, by weight, of biomass fuel that contains water. For example, wood pellets typically have an MC of less than 10. Wood chips and logs are likely to have a more variable MC of between 20% and 60%.
Network	The distribution system that links energy production to energy usage. Can describe electricity and heat supply.
Operating costs	Costs of maintaining the ongoing operation of a process or facility. Does not include any capital outlays or costs incurred in the design or commissioning phases of a project.
Oxides of nitrogen (NOx)	Produced from the combustion of biomass at high temperatures. Exposure to a significant amount of the gases can be detrimental to human health and the environment.
Oxides of sulfur (SOx)	Produced by the combustion of sulfur in a fuel. Presence in flue gases can cause corrosion on heat exchange surfaces if temperatures are not properly controlled.
Parasitic load	Electricity used within the cogeneration scheme, which reduces the amount available for use or export.
Particulate	Particles of solid matter, usually of a very small size, derived from the fuel either directly or as a result of incomplete combustion.
Peak load	The maximum heat demand a site experiences across a year, typically expressed in kWe or MWe. Used to size heating systems.
Performance guarantees	An agreement between a client and contractor to deliver a facility that meets objectives. Common measures included in performance guarantees are; • Availability – what might be reasonably expected of, or achieved from, the plant allowing for scheduled and unscheduled downtime. • Reliability – gives a measure of the unscheduled downtime of a plant. • Utilisation – takes into account when the plant was actually operating compared to planned hours.

Power factor	The quantification of the time lag between the voltage wave and the current wave expressed as the cosine of the angle between active (kW) and reactive (kVA) power.
Power purchase agreements (PPAs)	Contract underpinning the relationship between a supplier and a customer for the sale of electricity. The PPA defines all commercial terms for the sale of electricity such as payment terms, dates of commercial operation and termination.
Programmable logic control (PLC)	A programmable device for the control of a system according to predetermined logic.
SEAI	Sustainable Energy Authority of Ireland.
Short rotation coppice	Dense growth of small trees or bushes regularly trimmed back for re-growth. Willow or poplar grown as an agricultural crop on a short (2 to 5 years) rotation cutting cycle and at a planting density of 10 to 20 cuttings per hectare.
Slumber mode	Operating mode of a biomass system when it is reduced to a low output to reduce thermal cycling of components. Typically done overnight when there is no demand for heat.
Solar thermal	Device designed to receive solar radiation and convert it into thermal energy for a useful output, typically to heat water for space heating or domestic hot water.
Soot	Black powdery substance produced by the incomplete burning of organic matter.
Supplier	Organisation or person contracted for the delivery of goods or assets.
Synchronism	The condition where generator frequency, voltage levels and phase angle match those of the network.
Technical specification	A document that outlays the design of a system such that a contractor can provide a quotation for its installation.
Thermal store	A reservoir of heat energy provided from the boiler to enable the heating system to meet the majority of energy demands. Enables the boiler to be of a smaller size and improves its operating efficiency by allowing running for longer continuous periods. May also perform the role of a buffer vessel.
Transformer	A device with primary and secondary windings to convert the voltage of alternating current electricity from one value to another (step-up or step-down).
Trigeneration	Combination of cogeneration with absorption chilling to give the simultaneous production of heat, power and cooling. See also Combined cooling, heat and power (CCHP).
Turndown ratio	The turndown ratio of a boiler is a measure of its ability to operate at heat outputs less than the full rated output. It is the ratio of the maximum heat output to the minimum level of heat output at which the boiler will operate efficiently or controllably. For example, a boiler with 2:1 turndown ratio will be able to operate down to 50% of its full rated output.
Warranty	Agreement provided by an organisation such as a contractor or manufacturer that it will remedy, without additional charge, deficiencies in their service or goods that have arisen within a stated period after their installation.

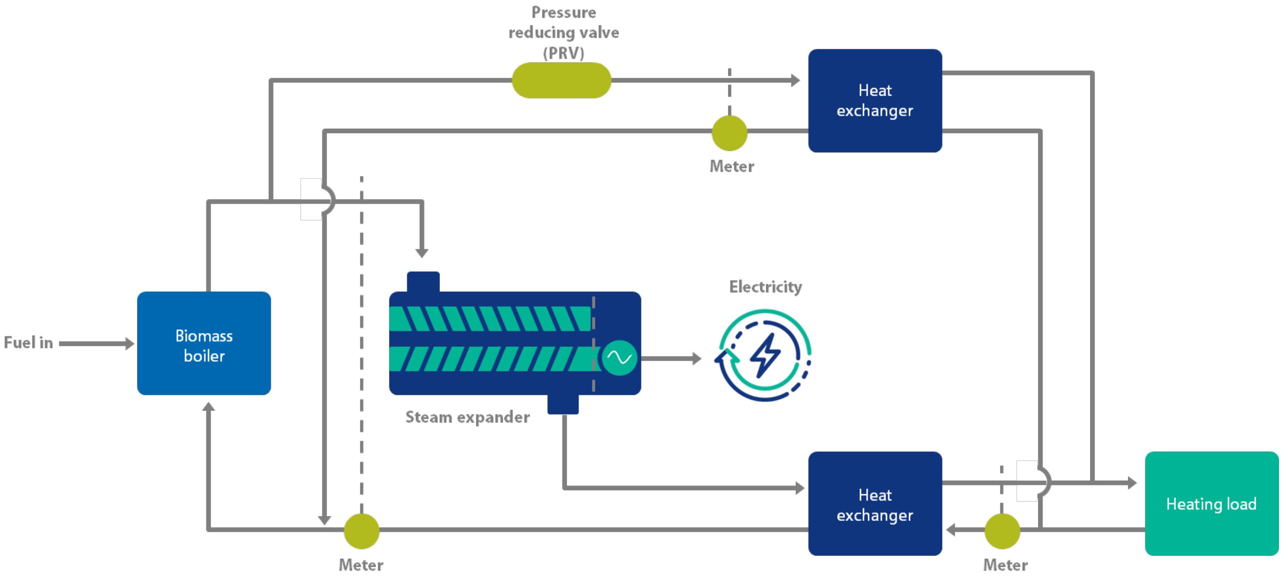
Appendix 1. Recording and monitoring of a CHP system

Worked example

This worked example shows a typical record sheet for a biomass combined heat and power (CHP) installation. In the illustration below, it has been assumed that the CHP system consists of a steam expander (capacity = 110kWe) which generates electricity and heat. The biomass boiler (capacity = 1MWth) generates steam, which is used in the steam expander.

The boiler is fired using virgin wood chip. On arrival, the wood chip weight, volume and moisture content are recorded. The steam expander receives heat from the biomass boiler, which has a maximum output of 110kWe of electricity at the generator terminals. All of the heat generated by the scheme is used on site, there is no heat rejection facility. There is a steam by-pass connection to allow heat generated by the boiler to be used during steam expander maintenance or shutdown.

Note: The readings used in the example below do not represent any facility and are given only to show various calculations.



Recording fuel input (M1)

Year	Wood chip delivered (tonnes)	Opening stock (tonnes)	Closing stock (tonnes)	Fuel input (tonnes)	Gross CV of fuel (MJ/kg)	Energy input to boiler (MWh)
2018	**A**	**B**	**C**	**FI* = A+B-C**		**EI** =** $\frac{FI \times E \times 1000}{3600}$
Jan	280	-	100	180	16.2	810
Feb	260	100	50	310	16.8	1,447
Mar	290	50	0	340	17.0	1,606
Apr	230	0	75	155	16.9	728
May	300	75	50	325	17.0	1,535
Jun	170	50	20	200	18.5	1,028
Jul	250	20	100	170	18.0	850
Aug	255	100	50	305	17.0	1,440
Sep	245	50	75	220	17.5	1,069
Oct	260	75	20	315	17.2	1,505
Nov	265	20	20	265	17.0	1,251
Dec	300	20	30	290	16.5	1,329
				3,075		14,598

*FI = Fuel input (tonnes)

**EI = Energy input (MWh)

Recording power output (M5)

Year	Start reading (MWh)	End reading (MWh)	Power output (MWh)
2018	**F**	**G**	**P = G-F**
Jan	12,345	12,405	60
Feb	12,405	12,455	50
Mar	12,455	12,530	75
Apr	12,530	12,580	50
May	12,580	12,650	70
Jun	12,650	12,695	45
Jul	12,695	12,730	35
Aug	12,730	12,775	45
Sep	12,775	12,860	85
Oct	12,860	12,915	55
Nov	12,915	12,955	35
Dec	12,955	13,000	35
			640

Recording heat output

Year	Start reading (MWh)	End reading (MWh)	Heat to CHP – HM2 (MWh)	Start reading (MWh)	End reading (MWh)	Bypass heat – HM3 (MWh)	Start reading (MWh)	End reading (MWh)	CHP heat output – HM4 (MWh)
2018	H_s	H_e	$H = H_e - H_s$	I_s	I_e	$I = I_e - I_s$	J_s	J_e	$J = J_e - J_s$
Jan	159,310	159,935	625	253,100	253,106	6	777,100	777,650	550
Feb	159,935	160,828	893	253,106	253,108	2	777,650	778,480	830
Mar	160,828	161,872	1,044	253,108	253,111	3	778,480	779,430	950
Apr	161,872	162,435	563	253,111	253,113	2	779,430	779,930	500
May	162,435	163,473	1,038	253,113	253,147	34	779,930	780,880	950
Jun	163,473	164,179	706	253,147	253,199	52	780,880	781,530	650
Jul	164,179	164,843	664	253,199	253,239	40	781,530	782,150	620
Aug	164,843	165,749	906	253,239	253,273	34	782,150	783,000	850
Sep	165,749	166,605	856	253,273	253,275	2	783,000	783,750	750
Oct	166,605	167,424	819	253,275	253,307	32	783,750	784,500	750
Nov	167,424	168,218	794	253,307	253,308	1	784,500	785,250	750
Dec	168,218	169,112	894	253,308	253,309	1	785,250	786,100	850
			9,802			209			9,000

Summary table

Year	Energy Input to Boiler (MWh)	Power Output	Power Efficiency %	Heat to CHP (MWh)	Bypass Heat (MWh)	Boiler Eff	CHP Heat Output (MWh	CHP Heat Efficiency	CHP Overall Efficiency
2018	**EI**	**P**	**ηPOWER** $= P/_{EI}$	**H**	**I**	**ηHEAT**$_{Boiler}$ $= (H+I)/_{EI}$	**J**	**ηHEAT**$_{CHP}$ $= J/_{EI}$	**ηPOWER + ηHEAT**$_{CHP}$
Jan	810	60	**7.4%**	625	6	78%	550	**68%**	**75%**
Feb	1,447	50	**3.5%**	893	2	62%	830	**57%**	**61%**
Mar	1,606	75	**4.7%**	1,044	3	65%	950	**59%**	**64%**
Apr	728	50	**6.9%**	563	2	78%	500	**69%**	**76%**
May	1,535	70	**4.6%**	1,038	34	70%	950	**62%**	**66%**
Jun	1,028	45	**4.4%**	706	52	74%	650	**63%**	**68%**
Jul	850	35	**4.1%**	664	40	83%	620	**73%**	**77%**
Aug	1,440	45	**3.1%**	906	34	65%	850	**59%**	**62%**
Sep	1,069	85	**8.0%**	856	2	80%	750	**70%**	**78%**
Oct	1,505	55	**3.7%**	819	32	57%	750	**50%**	**53%**
Nov	1,251	35	**2.8%**	794	1	64%	750	**60%**	**63%**
Dec	1,329	35	**2.6%**	894	1	67%	850	**64%**	**67%**
		640		9,802	209		9,000		

Appendix 2. Monitoring parameters

Parameter	Unit	Parameter	Unit
Pressure live steam	bara	Temperature generator bearing front side	°C
Temperature live steam	°C	Temperature generator bearing rear side	°C
Pressure extraction steam	bara	Temperature generator winding L1	°C
Temperature extraction steam	°C	Temperature generator winding L2	°C
Pressure exhaust steam bara	°C	Temperature generator winding L3	°C
Temperature extraction steam	°C	Temperature generator cool air	°C
Pressure exhaust steam bara	bara	Temperature generator warm air	°C
Temperature exhaust steam	°C	Voltage generator L1	V
Pressure control oil	bara	Voltage generator L2	V
Pressure lube oil	bara	Voltage generator L3	V
Temperature lube oil	°C	Current generator L1	A
Temperature journal bearing turbine front side	°C	Current generator L2	A
Temperature journal bearing turbine rear side	°C	Current generator L3	A
Temperature axial bearing turbine loaded side	°C	cos φ generator	
Temperature axial bearing turbine unloaded side	°C	Active power generator	kW
Relative vibration turbine front side	mm/s	Current excitation generator	A
Relative vibration turbine rear side	mm/s	Voltage excitation generator	V
Relative vibration gear box	mm/s	Turbine speed	min-1
Relative vibration generator front side	mm/s		
Relative vibration generator rear side	mm/s		
Axial position of turbine rotor	mm		

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