# Biomass CHP

## Technology 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.

SEAI is funded by the Government of Ireland through the Department of Communications, Climate Action and Environment.



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# 1. Introduction

Ireland has a long-term vision for a low-carbon energy system aimed at reducing greenhouse gas emissions from the energy sector 80%-90% (compared to 1990 levels) by 2050. Achieving this target requires a radical transformation of Ireland's energy system: reducing energy demand and moving away from fossil fuels to zero or low-carbon fuels and power 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 as possible. In addition, other potential impacts from biomass use, such as emissions of pollutants, need to be minimised and biomass installations must be operated safely.

Combined heat and power (CHP) is the simultaneous generation of useful heat and electricity. CHP systems that use biomass as a fuel (for example, wood pellets, energy crops and chicken litter) differ significantly from those that use natural gas or biogas. To ensure a well-functioning, safe and efficient biomass CHP system, these differences need to be properly addressed in planning, design and operation.

The guidance presented in this Technology Guide and the accompanying Implementation Guide, and Operation and Maintenance Guide is intended as a comprehensive starting point for readers to gain a better understanding of biomass CHP technology, its implementation and ongoing management. It should also be read in conjunction with the accompanying set of guides on biomass boilers.

## 1.1 The Energy Efficiency Obligation Scheme

Ireland chose to implement the Energy Efficiency Obligation Scheme from 1 January 2014. This was pursuant to the 2012 Energy Efficiency Directive, Article 7. The directive imposes a legal obligation on Member States to achieve new savings each year, from 1 January 2014 to 31 December 2020, of 1.5% of the annual energy sales to final customers of all energy distributors and all retail energy sales companies by volume, averaged over the most recent three-year period prior to 1 January 2013.

The target is cumulative, which means that it is based on incremental annual savings that deliver a total volume of savings at the end of the obligation period in 2020. Guidance on how to claim savings from CHP projects in accordance with the requirements of the Energy Efficiency Obligation Scheme is outside the scope of these guides on biomass CHP, but other guidance documents are available.[1]

The 2018 revision of the Energy Efficiency Directive will see the implementation of a new Article 7 requirement which will run from the January 1st 2021 and run through to December 31st 2030. The design of the Article 7 implementation has not yet been finalised.

## 1.2 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 Ministerial Terms and Conditions, the Grant Scheme Operating Rules and Guidelines and the Tariff Scheme Operating Rules and Guidelines, where relevant, set out the basis on which the Support Scheme for Renewable Heat will operate.

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1 https://www.seai.ie/resources/publications/Combined-Heat-and-Power-Calculator-Guidance-Document-V5.pdf

## 1.3 Purpose of this guide

This Technology Guide is principally intended for engineers, consultants and installers – particularly those with limited experience of non-domestic biomass CHP systems. It will also be of interest to others who wish to know more about such systems when engaging with the supply industry (for example, facilities/engineering managers, environmental managers and technical maintenance staff). It has two main aims:

1. To provide the reader with a sound technical appreciation of biomass CHP systems, good practice and essential technical issues.
2. To direct the reader to sources of more detailed information on aspects of the technology. This guide and its two companions do not 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.

## 1.4 Scope

This guide concentrates on solid biomass CHP systems for non-domestic premises in the installed power capacity range of 20kWe to 2MWe. However, much of the guidance will also apply to smaller and larger scale systems. The guide covers combustion-based and gasification-based biomass CHP technologies 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 (for example, in industrial processes). Direct-air heating systems are not covered in this set of biomass CHP guides. Certain systems are designed to provide cooling as well as heat and power. These are known as combined cooling, heat and power systems – sometimes referred to as trigeneration. However, such systems are more common for larger scale biomass CHP systems. While trigeneration is mentioned in these guides, it is not discussed in detail.

Regarding fuels, the guides focus 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 (for example, short rotation coppiced 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 an anaerobic digestion plant.

# 2. Biomass CHP

## 2.1 Introduction

Combined heat and power (CHP) technologies simultaneously produce electricity and heat in a single, highly efficient process. In comparison with the separate production of heat and power, it is more efficient because it makes use of heat that would otherwise be wasted in the power generation process. As an example, in comparison to a heat-only biomass boiler and a biomass power station, a biomass CHP system with an electrical efficiency of 25% and a heat efficiency (based on useful heat demand) of 50% can provide primary energy savings of 10% – as defined in the Energy Efficiency Directive, 2012/27/EU2) . CHP systems can achieve overall (electrical and heat) efficiencies of up to 80% and a biomass-fuelled CHP system where the biomass has been sourced sustainably can reduce carbon emissions by almost 100% compared with conventional fossil-fuel-fired heat and power generation.

The heat recovered from a biomass CHP system can be supplied to a site with a similar heat demand, reducing dependency on heat-only technologies such as fossil-fuelled or biomass boilers. If demand exists, it may be possible to generate revenue for the site owner by selling heat to a neighbouring site. The power generated can be consumed on site, offsetting electricity costs or, if connection is possible, exported to the grid.

CHP systems are most suitable for applications where electricity and heat demand exist for extended periods. For many organisations, CHP offers the single most significant opportunity to reduce energy costs and improve environmental performance. Biomass CHP has several advantages when compared with the separate production of heat and power:

- Reduced dependency on fossil fuels.
- Saves almost 100% of carbon emissions when compared with conventional fossil-fuelled boilers and power stations.
- Environmental benefits can be further enhanced by using fuel produced from waste materials.
- Biomass CHP achieves higher overall efficiencies than separate production of biomass heat and power.
- Reduced exposure to climate change legislation and opportunity to receive income from incentive schemes.

## 2.2 Technology characteristics

Biomass CHP has been available for many years and has become a well-established technology. Biomass CHP systems consist of a biomass conversion technology and a prime mover.

Biomass conversion technologies transform biomass into energy that will, in turn, be used in a prime mover (see below) to generate electricity and heat. The three main categories of biomass conversion technologies are combustion, gasification and anaerobic digestion to produce biogas that is subsequently combusted. This guide and the accompanying Technology, and Operation and Maintenance Guides on biomass CHP focus on combustion and gasification systems.

**Prime mover technologies** turn the energy from the biomass conversion technologies into mechanical motion to drive a generator that produces electrical power. In the case of combustion biomass conversion technologies, heat energy (in the form of steam or hot organic working fluid) is used to drive one of the following prime movers:

- Steam turbine;
- Screw-type steam expander; or
- Organic Rankine Cycle.

2 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0027&from=EN

Gasification biomass technologies produce a fuel that is then combusted in the prime mover, which is most commonly a reciprocating engine, though larger systems with gas turbines exist.

Commercially available biomass CHP systems can be packaged or custom-made. In a packaged system, the biomass conversion and prime mover units are manufactured and delivered as a single integrated unit (typical for small gasification CHP units). In custom-built biomass CHP systems, the energy conversion unit and the prime mover are designed separately and can be delivered to site and installed separately.

Combustion and gasification-based biomass CHP systems are available as small packaged systems. Biomass gasification systems involve the production of a syngas (mainly comprising hydrogen and carbon monoxide) from the biomass fuel and its subsequent combustion in a reciprocating engine to produce heat and electricity. Biomass gasification CHP systems have become more common in recent years and are now commercially available, but at a smaller scale than combustion systems – sizes typically range from 0.02MWe to 0.15MWe. Some schemes have installed multiple gasifier/engine trains to increase overall capacities into the 1MWe range.

Biomass combustion CHP systems are more common than gasification systems and can be differentiated depending on the type of prime mover used for heat and power generation. Steam turbines are the most common prime mover used with biomass boilers as part of a CHP system and typically have generation capacities greater than 0.5MWe. In recent years, Organic Rankine Cycles and screw expanders have become very common on a smaller scale. Organic Rankine Cycle systems typically have sizes in the range 0.05MWe to 2MWe and can use high temperature hot water, hot clean exhaust gas or thermal oil for power generation. Screw-type expanders can be up to 0.75MWe and use steam in the prime mover for power generation. See *Table 1* for further details.

**Table 1: Commercially available biomass CHP technologies**

| **Biomass conversion technology** | **Combustion (direct-firing)** | | | **Gasification** | **Anaerobic digestion** |
|---|---|---|---|---|---|
| **Energy carrier** | Steam | Steam, high temperature hot water, thermal oil | Steam | Syngas | Biogas |
| **Prime mover for power generation technology** | Steam turbine | Organic Rankine Cycle | Screw-type steam expander | Reciprocating syngas engines | Reciprocating biogas engines |
| **Typical range of capacity** | Over 0.5MWe | 0.05MWe-2MWe | 0.05MWe-0.75MWe | 0.02MWe-0.15MWe | 0.1 MWe-1MWe |

**Figure 2.1: Typical biomass CHP system components**

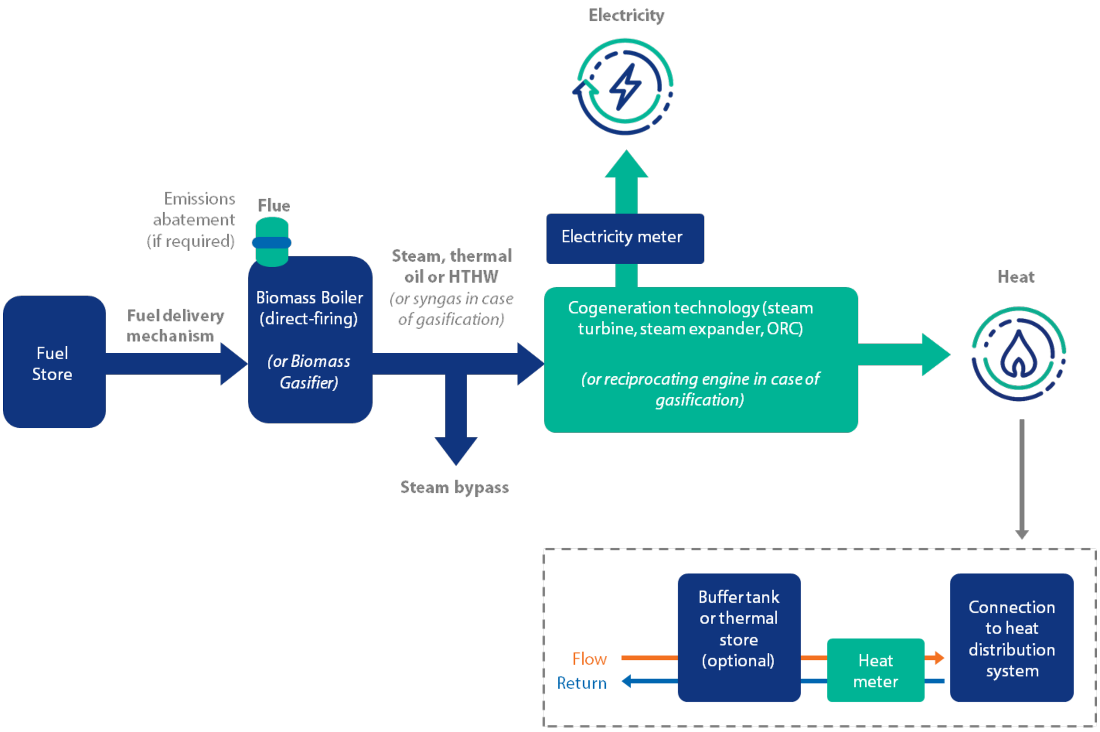



*Figure 2.1* shows a simplified biomass CHP system (combustion or gasification based). Biomass fuel is delivered from the fuel store to the boiler (or gasifier) where it is converted to steam, high temperature hot water (in the case of combustion boilers) or syngas at very high temperatures (in the case of gasification).

In the case of Organic Rankine Cycle, heat from the biomass boiler is passed via steam, thermal oil or high temperature hot water through a heat exchanger to another working fluid for use in generating electricity, with heat extraction facilities. In the case of steam turbines and steam expanders, steam can be used directly in the prime mover. For gasification systems, the resulting gas is treated and conditioned before it is admitted to a gas engine for heat and power generation. Detailed discussion of prime movers for heat and power generation, and energy conversion technologies (combustion versus gasification) is found in Sections 4 and 5.

A biomass CHP system is more complex than a fossil fuel-based CHP system. In a natural gas-fired CHP, for example, the gas can be combusted directly in a reciprocating engine or a gas turbine. No boilers or gasifiers are required, which simplifies the design and operation significantly and reduces capital and operating costs. In the case of gasification biomass CHP systems, the syngas needs to be treated before it is combusted in a reciprocating engine.

Biomass CHP requires a large space for the fuel delivery, storage and supply area, and for the boiler or gasifier – and buffer tank if required. Biomass systems have greater maintenance requirements than fossil-fuel systems. Ash disposal also has to be taken into consideration. A biomass boiler system needs to be designed differently and consideration must be given to the characteristics of the boiler, including a slower response time and a smaller turndown ratio.[3] These issues, and potential solutions, are described in Section 4.

3 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.

# 3. Biomass fuels

It is possible to use a range of biomass fuels in boilers, but each has characteristics that will affect the choice of boiler type, and the design and requirements for other parts of the system such as fuel handling and storage.

Unsuitable fuels can result in one or more of the following:

- Damage to the boiler;
- Health and safety issues;
- Inefficient operation of the boiler;
- Excessive emissions;
- Blockages in the fuel-feed system;
- Condensation of tar in the flue; and
- Disruption to the generation/supply of heat.

As discussed in the accompanying Implementation Guide, the choice of fuel will be determined by availability, reliability of supply and price, and site characteristics such as the scale of heat loads to be supplied; space available for fuel deliveries, storage and handling; the level of automation required; and any local air-quality restrictions.

## 3.1 Types of biomass fuel

**Figure 3.1: Wood logs stacked for drying**

The most commonly used biomass fuel is wood, supplied as logs, chips (or shredded wood) or pellets. The characteristics of each form of wood influences which type of boiler installation it is most appropriate for.

- **Wood logs** (*Figure 3.1*) may be more easily available in rural areas**.** They are most commonly used in smaller scale systems as they generally require manual loading into the boiler.

- **Wood pellets** (*Figure 3.2*) are available from various suppliers and normally meet a particular standard specification. This means they should have consistent combustion and handling qualities. They have a higher energy density than wood chips, so require less space for storage. Although pellets tend to be used in smaller boiler installations (up to around 200kW), there are no hard-and-fast rules and larger boilers suitable for pellets are available.

**Figure 3.2: Wood pellets**

- **Wood chips** (*Figure 3.3*) are typically cheaper than wood pellets on a euro per kWh basis, though they require more storage space. Wood chips are typically used for larger systems, though boilers suitable for wood chips down to around 15kW rated output are available.

**Figure 3.3: 'Clean' wood chips**

Wood chips may originate from:

- 'Clean' wood (that is, virgin wood, or untreated wood arising as a by-product of processes such as in sawmills and furniture production processes);
- Waste wood (that is, wood that has already been used for a purpose).

If using waste wood chips, there is the potential for environmental pollution[4] from:

- Treatments/coatings such as paints, laminates, varnishes and preservatives;
- Resins and glues; and
- Extraneous materials such as metals, grit, plastics, glass, paper and textiles.

Contaminants of particular concern include heavy metals and halogenated organic compounds. The presence of copper, chromium or arsenic means the waste must be treated as hazardous.

Waste wood is subject to regulatory control unless the holder demonstrates, to the satisfaction of the relevant competent authority (Environmental Protection Agency (EPA) or local authority), that the material meets by-product or end-of-waste status criteria. A boiler burning wood deemed to be waste wood will need to comply with the requirements of the Industrial Emissions Directive (Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control)). However, this requirement can be waived if an exemption is granted by the EPA on the basis that the waste wood is demonstrated to be free of halogenated organic compounds or heavy metals.

4 EPA Position Paper 'The Regulation and Management of Waste Wood'. www.epa.ie/pubs/advice/waste/waste/regulationandmanagementofwastewood.html

**Determining if wood is waste wood or a by-product (Extract from 'The Regulation and Management of Waste Wood', EPA, Sept 2013)[1]**

Regulation 27 of the Waste Directive Regulations (S.I. 126 of 2011) provides that a substance or object, resulting from a production process, the primary aim of which is not the production of that item, may be regarded as not being waste, but as being a by-product if the following conditions are met:

- Further use of the substance or object is certain.
- The wood can be used directly without any further processing, other than normal industrial practice.
- The wood is produced as an integral part of a production process.
- Further use of the wood is lawful (i.e. the wood fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts).

Operators must notify the EPA when they decide that a material is to be regarded as a by-product. Where no notice is given to the EPA, the material is presumed in law to be a waste until the contrary is proved.

The EPA considers that the following typically meet Regulation 27 requirements, provided that they are not discarded; not mixed with non-virgin woods; are untreated; and are free of extraneous materials such as metals:

- Residual branches, bark, chip and dust arising from tree felling and tree surgery.
- Virgin wood from sawmilling and the manufacture of timber products.

### 3.1.2 Other fuels

Other biomass that can be used as a fuel includes:

- **Straw**. This is typically burnt as bales in specially designed boilers. It has a relatively high silica content and often contains high concentrations of chlorides which, by reducing the ash fusion temperature, promote slag formation. Slag can bind to the grate and cause blockages of and damage to ash-handling equipment. Straw boilers are designed to manage these problems.

- **Poultry litter or other animal bedding.** Poultry litter consists of chicken manure and bedding (typically wood chip/shavings). Under EU regulations, on-farm combustion of poultry litter can be undertaken up to a total rated thermal input of 5MW. The combustion of poultry litter or other animal by-products must conform to the regulations listed in EC 1069/2009.. These regulations are transposed into Irish Law as Statutory Instrument (S.I.) No. 187/2014 – European Union (Animal By-Products) Regulations 2014 (ABPR).[5] Enterprise Ireland has produced an explanatory guide to this legislation[6] and further information is available from the Department of Agriculture, Food and the Marine.[7]

The combustion of poultry litter is usually, though not exclusively, carried out in fluidised-bed combustion boilers, which can provide more effective combustion, particularly for lower quality and variable moisture content fuels (see Section 3.2.2).

5 http://www.irishstatutebook.ie/eli/2014/si/187/made/en/print
6 Enterprise Ireland (2015) Animal By-products legislation: an explanatory guide, see: https://www.leanbusinessireland.ie/wp-content/uploads/2017/05/2015-Animal-By-Products-OCTOBER.pdf
7 For contact details and relevant forms see: https://www.agriculture.gov.ie/agri-foodindustry/animalbyproducts/applicationformsconditionsforabpprocessingoperations/applicationformsforabpprocessingoperations/

**Legislation relevant to the on-farm combustion of poultry litter**
The requirements for on-farm combustion of poultry litter are set out in Regulation EC 1069/2009 laying down health rules as regards animal by-products and derived products not intended for human consumption. This has been transposed into Irish law through S.I. No 187/2014.

There are two relevant amendments:
- Commission Regulation (EU) 142/2011 implementing Regulation (EC) No 1069/2009 of the European Parliament and of the Council laying down health rules as regards animal by-products and derived products not intended for human consumption and implementing Council Directive 97/78/EC as regards certain samples and items exempt from veterinary checks at the border under that Directive. .
- EU Regulation 592/2014 amending Regulation (EU) No 142/2011 as regards the use of animal by-products and derived products as a fuel in combustion plants.

- **Energy crops**. These are crops grown specifically for use as a biomass fuel. They include woody energy crops (for example, short rotation coppice, such as willow and poplar) that are typically harvested on a three-year cycle and grassy energy crops such as miscanthus, which is harvested annually. The woody energy crops would normally be chipped or pelletised prior to use.

Miscanthus can be baled and burnt in boilers, but can also be chipped or pelletised. Its use, other than at power station scale, is limited, but some wood-chip boilers can use miscanthus chip and some straw boilers can use baled miscanthus. Because miscanthus has a low ash-fusion temperature, it is prone to slag formation when combusted. Therefore, the temperature of combustion needs to be carefully controlled and the addition of slaked lime to the fuel to raise the ash-fusion point is sometimes recommended by boiler suppliers.

## 3.2 Fuel characterisation and quality standards

The varying physical characteristics of biomass fuels determine the combustion process and the applications for which they are most suited. Their important characteristics are summarised in *Table 2*, and should be specified on any fuel supply contract.

National and international standards organisations have developed standards for biomass fuels that cover specifications for the physical and chemical characteristics that are important in combustion, handling and storage; and for procedures for the analysis of these characteristics and combustion emissions.

These standards help avoid inefficiencies in the boiler, excessive emissions, blockages in the fuel-feed system or condensation in the flue. Fuel suppliers can then process fuels to a common specification, analysts can follow standard procedures and boiler/combustion equipment suppliers can design their equipment accordingly. Boiler manufacturers invariably provide specifications stipulating the fuel standards that are applicable to the equipment they supply.

In Europe, the European Committee for Standardization (CEN), under Technical Committee CEN/TC 335,[8] has developed a suite of standards relating to different aspects of biomass fuels. These have been adopted internationally by the International Organization for Standardization (ISO).

8 https://standards.cen.eu/dyn/www/f?p=204:7:0::::FSP_ORG_ID:19930&cs=17158638AB0C35D5E52A369017E54A1D6

**Table 2: Summary of key physical characteristics of biomass fuels**

| Parameter | |
|---|---|
| **Calorific value** | The calorific value of a fuel indicates the energy content that is released when the fuel is completely combusted. Calorific value can be expressed on either a 'gross' or 'net' basis[9] (sometimes referred to as the higher and lower heating values). Biomass fuel calorific values are normally expressed in net terms as MJ/kg or kWh/tonne. The moisture content of a biomass material has a significant impact on its calorific value. The higher the moisture content, the lower the calorific value of the fuel. Calorific value may be expressed on an as-received basis (i.e. reflecting the moisture content of the fuel when it is delivered to the end user) or expressed on a dry-weight basis, allowing comparisons to be made between fuels. It is important to understand the basis on which any calorific value is quoted: net versus gross and at what moisture content. |
| **Moisture content** | The moisture content of a biomass fuel is expressed as a percentage of the fuel's weight; the higher the moisture content, the lower the calorific value. In general, wood pellets will have a moisture content of less than 10%. Wood chip and logs can be purchased at a wide range of moisture content depending on various factors, but principally on how seasoned the wood is or the degree of drying that has been undertaken. Specifications for biomass fuels should always include an acceptable range for moisture content. |
| **Bulk density** | Bulk density is a measure of the mass of the fuel divided by its volume and is important for transporting and storing the fuel. The volume will include space between the particles (e.g. logs, chips or pellets). The higher the bulk density, the more fuel exists in a specific volume. Fuel with a high moisture content has a higher bulk density and lower energy density than the same volume of fuel with a lower moisture content. |
| **Energy density** | Energy density is a measure of the energy contained within a unit of fuel and is derived from the bulk density and calorific value. Energy density is expressed in energy available in a specific volume of fuel (e.g. $MJ/m^3$) and is derived from multiplying the calorific value of a fuel by the bulk density. Understanding the energy density of a fuel is important as it impacts on fuel consumption rates, size of fuel storage, frequency of deliveries and total annual fuel quantities. |
| **Particle size** | Boiler manufacturers specify acceptable fuel particle sizes for their equipment (usually by referencing a specification and class) to ensure optimum combustion. Feed systems will be designed accordingly, and using fuel with particles oversized or undersized (fines) can lead to blockages. For automatic systems, it is particularly important that the fuel flows well, without bridging (in the case of chips) or disintegration, which can result in the accumulation of fine particles, especially in the case of pellets. |
| **Ash content** | The ash content is specified as a percentage of the fuel's mass on a dry basis. The quantity of ash produced is dependent on the fuel's ash content, but will also increase should combustion efficiency reduce or the fuel contain extraneous matter. Wood fuels tend to have relatively low ash content, although the inclusion of bark increases this. |

9 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.

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.

The overarching standards for biomass fuels are Solid biofuels – Fuel specifications and classes – Part 1: General requirements (ISO 17225-1:2014). This provides the most useful parameters and is most widely used as a basis for classification and standardisation. The scope of ISO 17225-1:2014 'determines the fuel quality classes and specifications for solid biofuels of raw and processed materials originating from a) forestry and arboriculture; b) agriculture and horticulture; and c) aquaculture.'[10]

Further parts of ISO 17225 deal with specific fuels:
- EN ISO 17225-2:2014 Solid biofuels – Fuel specifications and classes – Part 2: Graded wood pellets (ISO 17225-2:2014).
- EN ISO 17225-3:2014 Solid biofuels – Fuel specifications and classes – Part 3: Graded wood briquettes (ISO 17225-3:2014).
- EN ISO 17225-4:2014 Solid biofuels – Fuel specifications and classes – Part 4: Graded wood chips (ISO 17225-4:2014).

The standards are available to purchase from [www.nsai.ie.](http://www.nsai.ie) They provide definitions for key fuel parameters, including:
- Moisture content;
- Dimensions: to ensure it meets the requirements of the boiler and its fuel-handling system;
- Ash content;
- Chlorine content;
- Bulk density; and
- The origin of the material: the source and content of the fuel.

Various standards set out methods for testing to demonstrate that a specification is being met. A useful source of information on existing standards is Woodenergy.ie.[11]

As well as formal standards, there are certification schemes for wood fuels such as the Wood Fuel Quality Assurance scheme for Ireland[12] and En*plus*®,[13] a European certification scheme for wood pellets that verifies that pellets meet ISO or CEN standards and other requirements such as sustainability. Wood chip is not always sold under a specific standard. Therefore, it is important that the site operator ensures that the fuel characteristics are clearly specified at the design stage and that fuel purchased meets those requirements. Purchasing fuel certified under schemes such as the Wood Fuel Quality Assurance or EN*plus*® should help achieve this.

## 3.3 Fuel delivery, storage and handling

### 3.3.1 Fuel delivery

The practicalities of fuel delivery require consideration of:
- The proposed fuel type (wood chip, pellet, logs, bales, etc.);
- Vehicle access and other physical constraints at the site; and
- Vehicle types and delivery methods available from potential suppliers.

Examples of fuel delivery methods are summarised in *Table 3* along with their typical applications, advantages and disadvantages.

10 https://standards.cen.eu/dyn/www/f?p=204:110:0::::FSP_PROJECT:39131&cs=1D71D6D8661FDD010555C381013211288
11 http://www.woodenergy.ie/
12 http://wfqa.org/
13 https://enplus-pellets.eu/en-in/

**Table 3: Summary of fuel delivery methods**

| Delivery method | Typical applications | Advantages/disadvantages |
|---|---|---|
| Tanker with pneumatic flexible hose | Usually pellet, but can be used for chip | Can deliver high volumes, but requires specialist vehicles and hose connection points at the fuel store. Hoses can extend and may benefit sites with restricted access. Discharge rates should not exceed 12 tonnes/hour per 100mm delivery pipe to avoid pellet damage during delivery. Depending on the store, slower discharge may prove necessary in practice. Pneumatic systems can be noisy and tend to give rise to dust. |
| Bulk bags | Pellet, chip or logs | Suitable for smaller consumption volumes and flexibility in fuel types. Can be more expensive due to smaller loads. Further handling usually needed post-delivery. |
| Tipper trailer | Pellet, chip or logs | Widely available, quick to unload. Requires good vehicular access and clearance to tip the trailer. Normally requires a large storage area. Storage may need to be underground or with a ramp to allow trailer discharge. |
| Walking floor trailer | Chip | Suitable for large volumes, but good access and clearance required for delivery and vehicle turning. |

### 3.3.2 Fuel discharge to store

As indicated in *Table 3*, pellets are most commonly blown from lorry to store via a pneumatic hose connected to a fill pipe with a standard industry connector. Deliveries can take some time as the rate of discharge should be limited to avoid mechanical damage to the pellets.

Wood chips are most often delivered by lorry with a tipper or walking floor trailer, either directly into an underground store via a metal grill or into a surface-level bunker.

### 3.3.3 Fuel storage

Biomass fuel storage design should be site specific. It will be influenced by the fuel and delivery method chosen, available space at the site and any other physical constraints, and the location of the boiler in relation to the fuel store. Fuel stores can be above or below ground, integrated with existing or purpose-built buildings, or comprise a containerised system. While some fuels may be kept outside, such as logs and bales, there should be some shelter to keep them dry. Wood chip can be stored in open-fronted bays providing there is a roof, with the optimal solution being enclosed with adequate ventilation. Wood pellets must be kept in enclosed containers or hoppers. Types of fuel store include:

- Bunkers – purpose built or converted from existing buildings or stores;
- Bag silos – supported by frames; and
- Hoppers and silos.

### 3.3.4 Fuel monitoring

Many biomass boiler installations use visual checks to show the amount of fuel remaining in the store to monitor fuel consumption. For enclosed stores, one or more sight glasses or windows are usually fitted to avoid the need to open the store. Ultrasonic or laser fuel-level sensing systems can provide a remote-monitoring function and be connected to a building management system. This can alert the operator or fuel supplier when the fuel level has reached the reorder point.

### 3.3.5 Fuel handling

The method of conveying the biomass fuel to the boiler will depend on the fuel and storage type. Typically, bales and logs are batch fed, which is manually intensive and only suitable for smaller systems or where there is sufficient labour on hand. Wood chip is commonly fed via an auger system. This uses an agitator arm within the fuel store and a screw feed to move the fuel from the store to the boiler grate. Walking floor systems and scraper chain conveyors are used on larger systems. Usually, wood pellets are pneumatically conveyed from the pellet store, with larger systems being gravity fed from an overhead hopper or silo.

### 3.3.6 Health and safety

A health and safety statement should be produced as various risks are associated with handling and storing biomass fuels. Particular risks arise from sealed pellet storage rooms, bunkers and hoppers where carbon monoxide can build up from the fuel itself. Similar issues can occur with wood chips. The UK Health and Safety Executive suggests taking mitigating actions.[14] It is recommended to install carbon monoxide alarm/s in the fuel store and plant room.

As well as carbon monoxide, pellet stores can produce significant amounts of dry dust, which can produce an explosive atmosphere. Precautions should be incorporated at the design stage and during operation. Further information can be found in the accompanying Operation and Maintenance Guide.

14 www.hse.gov.uk/safetybulletins/co-wood-pellets.htm and http://www.hse.gov.uk/research/rrpdf/rr1077.pdf

# 4. Biomass conversion technologies

The main elements of biomass CHP systems are the biomass conversion technology and the prime mover. The most commonly adopted biomass CHP systems tend to be a hot water or steam generating boiler followed by a power generation technology such as steam turbine or Organic Rankine Cycle (the prime mover).

Heat is used in the prime mover for power generation, and any heat not used can be extracted for further use or rejected. In the last decade, gasification-based CHP has become commercially available. This consists of a gasifier, where the biomass is converted into syngas, which is then combusted in a reciprocating engine for heat and power generation. This section focuses on biomass conversion technologies (combustion and gasification), while Section 5 focuses on prime mover technologies.

## 4.1 Biomass combustion (direct-firing): biomass boilers

A biomass boiler is a key component in a biomass CHP system. Biomass boilers differ from their conventional counterparts and present particular challenges in the design and implementation of biomass boiler systems. These are described below.

**Boiler size**. Biomass boilers are larger than their traditional fossil fuel equivalents e.g. natural gas boiler. Furthermore, greater space is required around biomass boilers to facilitate access for cleaning, and fuel-feed and ash-removal systems.

**Boiler responsiveness**. Biomass boilers are slower to respond to changes in heat demand, although this can be managed by intelligent control, thermal storage and/or the use of top-up conventional boiler capacity. The turndown ratio of biomass boilers is also more restricted than gas- or oil-fired boilers.

**Fuel storage**. Considerable space is needed on site for fuel storage – something that is not required for natural-gas boilers. Boilers fired on oil or liquefied petroleum gas need space for fuel storage, but biomass systems require far more due to the lower energy density of the fuel.

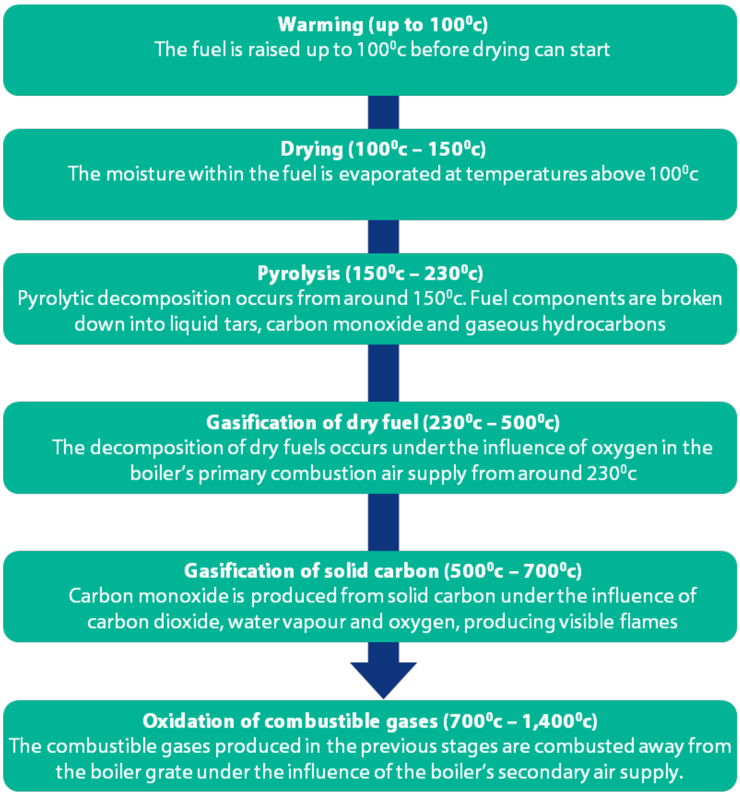
**Fuel delivery**. Vehicle access and associated safety procedures for fuel deliveries need to be suited to the use of large vehicles and/or frequent deliveries.

**Emissions**. The control of emissions from biomass boilers tends to be more challenging than for oil and gas-fired boilers. Fly ash and particulate matter may require additional abatement equipment. Also, oxides of nitrogen (NOx) emissions per unit of heat generated are usually higher than those from conventional boilers. If they are not sufficiently managed by the control of combustion conditions, then additional flue-gas abatement equipment may be required.

The combustion of biomass can be broken down into six stages as shown in *Figure 4.1*.

A more detailed description of the combustion process can be found in the Chartered Institution of Building Services Engineers publication Biomass Heating, AM15: 2014.

**Figure 4.1: The six stages of biomass combustion**




## 4.1.1 Boiler types and characteristics

Various factors determine biomass boiler selection, including:

- Heat generating capacity;
- Fuel type and characteristics;
- Boiler responsiveness and turndown ratio; and
- Requirements for limiting emissions.

There is a wide range of biomass boiler types available to meet an end user's specific requirements. This guide describes the most common types of boiler available. Additional advice can be sought from biomass boiler suppliers or manufacturers.

Biomass boilers can be classified by a combination of the following parameters:

- Capacity;
- Automatic versus manual feed;
- Stoker type;
- Ignition: automatic ignition versus slumber mode;
- Fire tube orientation; and
- Fuel type(s).

### 4.1.1.1 Boiler capacity

The majority of non-domestic biomass boilers are in the heat output range of around 50kWth to 5MWth. Most boilers are designed to produce heat in the form of hot water. Most boilers of capacity greater than around 1.5MWth can generate steam, and boilers that heat thermal oil as the heat transfer medium are available above around 3MWth. Much larger capacity boiler systems (for example up to 100MWth) producing high pressure steam for substantial power generation are also available and well established biomass-fired systems.

Most non-domestic boilers are automatically fed with fuel, though smaller boilers may only have a small integral fuel hopper that requires regular manual replenishment with wood pellets. In addition to log boilers, some larger boilers for certain fuel types, such as straw, may also be manually fed. Automated systems are, by their nature, more complicated and less mechanically robust than manual systems.

### 4.1.2 Special considerations

Various issues must be taken into account when considering the installation of a biomass boiler (as opposed to traditional fossil-fuel boilers). Further information is provided in the accompanying Implementation Guide, and Operation and Maintenance Guide.

#### 4.1.2.1 Delivery of fuel

In most cases biomass will have to be delivered by road as wood logs, chips or pellets, which are relatively diffuse energy carriers. This means delivery is infrequent by very large road vehicles or is more frequent by smaller vehicles. The implications of this on access and the volume of road traffic in the vicinity of the boiler installation have to be considered.

#### 4.1.2.2 Physical size of boiler

A biomass boiler will be much larger than a fossil-fuelled boiler of equivalent capacity. This is due mainly to the inherent combustion characteristics of solid, organic materials, which require a large volume combustion chamber. Biomass boilers also require additional space in the boiler house to allow access for cleaning fire tubes, and feed and ash-extraction systems.

#### 4.1.2.3 Boiler responsiveness and ability to modulate

Biomass boilers are less responsive to changes in heat demand and are limited in their turndown ratio. In conventional gas or oil boilers, ignition is instantaneous and the boiler can also be shut down instantaneously with little residual heat remaining. However, in the case of biomass boilers, when there is no current demand for heat, the fuel that has already been deposited onto the grate will continue to burn and, depending on the type of boiler, it may be necessary to empty the contents of the fuel delivery system onto the grate and combust the fuel.

Also, some biomass boilers have significant thermal mass embodied in their refractory linings. These are incorporated into the boiler structure to radiate heat to dry moist fuels prior to gasification (see Section 4.2) or pyrolysis (the process of thermal decomposition of biomass at high temperatures in the absence of oxygen). This contributes to the sluggishness of response compared with oil and gas-fired boilers and must be accounted for in the design. Judicious boiler sizing and the use of thermal stores are advised (see Section 4.2.2).

#### 4.1.2.4 Waste and cleaning

Owing to the production of ash, biomass boilers need more regular cleaning than gas or oil-fired boilers. Ash is not present in the combustion products of oil or gas as these fuels have no (or very little) mineral content. The mineral content of biomass depends on its source, with fuels containing bark and herbaceous (grassy) biomass producing relatively high levels of ash.

The two types of ash to consider from biomass combustion are bottom ash and fly ash. Bottom ash is formed on the grate and is pushed off the grate into the ash pan by the introduction of new fuel onto the combustion chamber. Fly ash is very fine and is carried on the thermal currents inside the boiler and deposited in the fire tubes, captured by abatement systems in the flue or released to the environment. This means that biomass boilers require boiler tube cleaning, which is not necessary with oil and gas boilers. It is also necessary to collect and dispose of bottom ash properly.

If allowed to melt, ash can form an unwanted clinker on the grate, which could lead to operational issues and more frequent maintenance. The melting point of silica (the main component of ash) is 1,700°C. However, if chlorides are also present in the fuel, this can be reduced to as low as 773°C, which is well within the combustion temperatures developed in the boiler.

Greater detail concerning the types of biomass boilers available is given in the Biomass Technology Guide of the accompanying set of guides. It is recommended that readers refer to those guides in addition to the material in this guide.

## 4.2 Biomass gasification

Gasification is when fuel (such as biomass) is heated in a controlled environment with very little oxygen available; thus, the fuel is not burnt, and a syngas is produced. When referring to the gasification of biomass, the 'syngas' can also be called 'product' gas. In this guide, 'syngas' is used to refer to the gaseous product of gasification. Syngas predominantly consists of hydrogen, carbon monoxide and carbon dioxide. This gas can then be reacted with heat and catalysts through the Fischer-Tropsch process[15] to produce a liquid fuel.

Biomass gasification was first developed in the eighteenth century to produce gas from coal for early street lighting. Since the 1970s, it has been promoted for heat and electricity generation.

Despite ongoing development, biomass gasification still faces technical difficulties, this is particularly the case for biomass gasifiers designed to supply electricity rather than steam for heating or cooling purposes only.

Electricity-generating gasification plants are expensive to build and operate, and are prone to greater problems than conventional biomass combustion plants. In addition, biomass gasification plants for electricity generation through a reciprocating (gas) engine offer minor efficiency gains in comparison to conventional biomass plants (an energy efficiency differential of around 3% or 4%). Most biomass gasification plants that use a steam boiler and turbine for generating electricity are considerably less energy efficient than a comparable combustion plant (typically 5% to 10% less).

In recent years, many small gasifier CHP unit suppliers entered the market worldwide. In Europe, these are mainly located in Germany and Austria. In Europe, the USA and Canada there are over 50 no. manufacturers that offer commercial gasification plants from which 75% percent of the designs were fixed-bed and 20% fluidised-bed systems with the rest being less common types of gasification system (for example, entrained-flow gasifiers). Prime movers have long been commercially proven with natural gas and biogas but they are now also demonstrated with syngas on a small scale. As discussed above, larger gasification systems with CHP engine units are not very common yet and are associated with significant challenges due to the need to clean the syngas as well as issues encountered with syngas combustion, which include high combustion temperatures and backfiring of the engine.

15 The Fischer-Tropsch process involves a series of chemical reactions used to convert carbon monoxide and hydrogen mixtures in syngas (resulting from gasification) into liquid hydrocarbons.

### 4.2.1 Types of gasifier

The two main types of gasifier used as part of biomass CHP systems are fixed-bed gasifiers and fluidised-bed gasifiers (*Figure 4.2*). These are briefly introduced below and compared (with advantages and disadvantages) in *Table 4*.

**Table 4: Comparison of fixed-bed and fluidised-bed gasification**

| | Fixed-bed gasification | Fluidised-bed gasification |
|---|---|---|
| Commercial | • Simple and reliable for certain types of fuel.<br>• Many processes for different applications in operation. | • Can be used with a wide range of fuels.<br>• Commercial designs are available. |
| Design | • Requires combination of several modular single low power reactors and so more space is required than for fluidised bed.<br>• Poor temperature profile and distribution in bed and poor heat exchange.<br>• High ash content fuel is possible.<br>• Internal moving parts, but simple and robust construction. | • Less space required due to great potential of scale-up.<br>• Tolerates wide range of fuel quality.<br>• Less complex technology with no moving parts.<br>• Good temperature distribution in reactor and good heat exchange. |
| Availability | • Few plants working continuously at design conditions for more than 5,000 hours/year. | • Few plants working continuously at design conditions for more than 5,000 hours/year. |
| Quality of main products | • Wide range of tar, phenols and ammonia content in syngas. Syngas contains high levels of tar, phenols and ammonia in case of updraft fixed bed reactors, and so requires clean-up. Syngas from downdraft reactors has lower levels of contaminants.<br>• Wide range of gas temperature (low in case of updraft fixed bed reactors). For downdraft, syngas temperature is usually higher than bed.<br>• Dust content: for updraft reactors, syngas is low in dust while for downdraft reactors, syngas is usually high in dust. | • Amount of tar and phenols in product is very low.<br>• Gas composition is uniform due to steady conditions in bed.<br>• Gas temperature similar to that in the bed.<br>• Syngas is high in dust and particulates.<br>• Inevitable loss of carbon in ash due to non-uniform solid composition. |

| | Fixed-bed gasification | Fluidised-bed gasification |
|---|---|---|
| Operation | • Easier to operate than fluidised bed.<br>• Channelling possible.<br>• Low pressure drop.<br>• Residence time for solids in the reactor can last from hours to days.<br>• Poor heat exchange/potential for hot spots.<br>• Can operate at partial load (as low as 20%).<br>• Fast change of fuels with different calorific values is a limitation in terms of operating fixed bed reactors. | • Good solid/gas contact and mixing.<br>• High pressure drop.<br>• Residence time for solids is much lower than for fixed beds (seconds to minutes).<br>• Better heat exchange/no hot spots.<br>• Can operate at partial load (as low as 50%).<br>• Easily started and stopped.<br>• Fast change of different fuels is easier than for fixed bed reactors. |
| Potential for scale-up | • Limited potential for scale-up due to low maximum size, long periods to heat up. | • No hot spots, better heat exchange. |
| Efficiency | • High carbon conversion efficiency. | • High carbon conversion efficiency. |
| Clean-up | • For updraft, extensive clean-up of syngas is required for use in engines. For downdraft, syngas is relatively clean. | • High carbon conversion efficiency. |

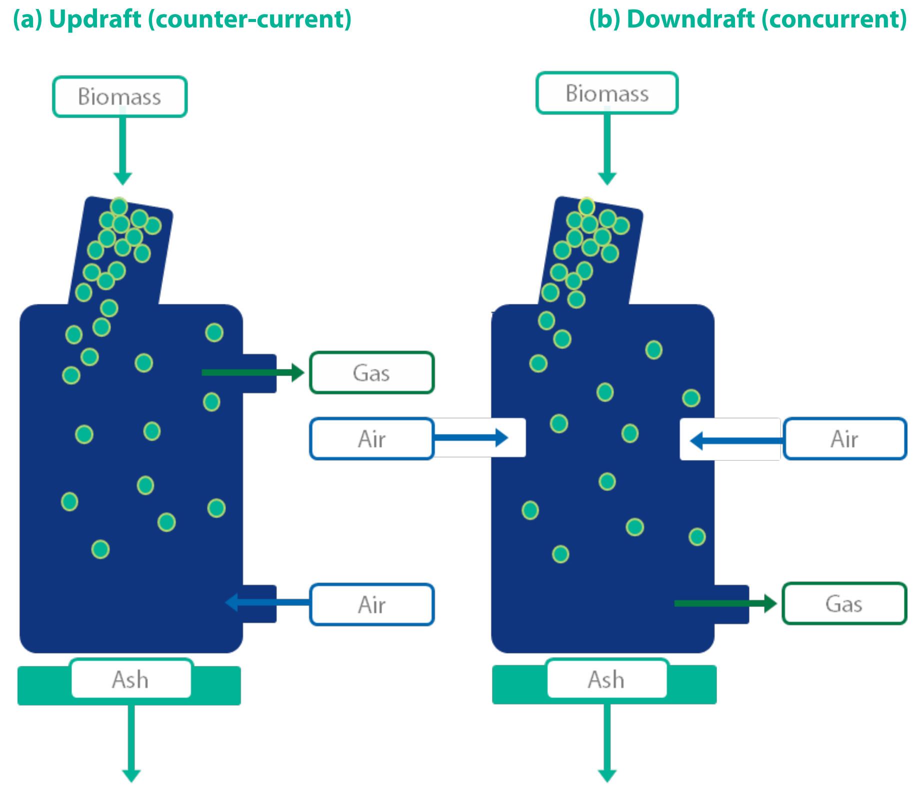
#### 4.2.1.1 Fixed-bed gasifiers

Fixed-bed gasifiers are classified according to whether the air/oxygen is fed at the bottom of the gasifier or at the top (or from the sides). The two main types of fixed-bed gasifier are updraft reactors (counter-current), where air is fed at the bottom, and downdraft reactors (concurrent), where air is fed from the sides.

With updraft fixed-bed reactors, as air flows upwards, the syngas leaving at the top is rich in tar, so has a lower calorific value than other designs and requires significant cleaning before it is used in an engine. Some of the char falls to the bottom of the reactor and burns to provide heat.

With downdraft fixed-bed reactors, the biomass fed at the top and the air/oxygen move in the same direction. Due to the presence of the throat in the middle of the reactor, the biomass burns as it falls down forming a reaction zone. This leads to syngas with a high quality, which then leaves at the bottom of the reactor rather than at the top. As with the updraft reactor, ash is collected at the bottom. A hybrid updraft/downdraft design is also available.

**Figure 4.1: Fixed-bed gasifier designs**




### 4.2.1.2 Fluidised-bed gasifiers

In the reactor of a fluidised-bed gasifier, air at speeds in the range 1-10 m/s is blown in at the bottom into a mass of bed material; biomass is fed in at the side and syngas, formed from the gasification process, escapes at the top of the reactor. There are two types of fluidised-bed gasifiers, bubbling and circulating (*Figure 4.3*). Compared with a fixed-bed reactor, a fluidised-bed reactor has lower tar content in the syngas and reduced requirement for gas cleaning. Both types of reactor can be operated at high pressures. Therefore, they are more suitable for use with gas turbines as there is no need for pressurisation of the syngas after it leaves the gasifier.

The gasification of biomass with downstream reciprocating gas engine conversion of syngas into electricity and heat (*Figure 4.4*) is only one option for gasification plants. The two other most common options are:

- Steam turbine-based energy recovery where the syngas is combusted for steam generation in a boiler.
- Gas turbine-based energy recovery where the syngas is directly combusted in a gas turbine.

A combined cycle gas turbine, which involves electricity generation using a gas turbine and a steam turbine, is another option. At lower capacity scale, reciprocating engine conversion is the most common combination. More information can be found on the CHP Focus website.[16]

16 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/345189/Part_2_CHP_Technology.pdf

**Figure 4.2: Fluidised-bed gasifier schematic**

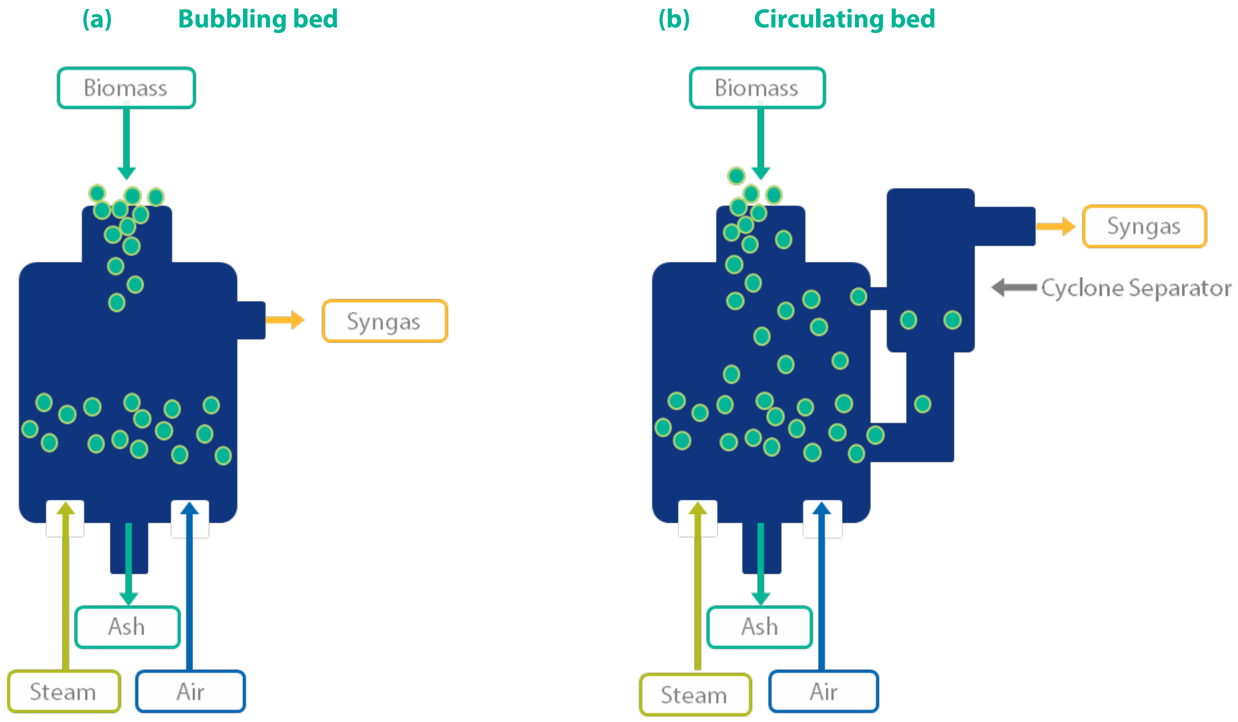
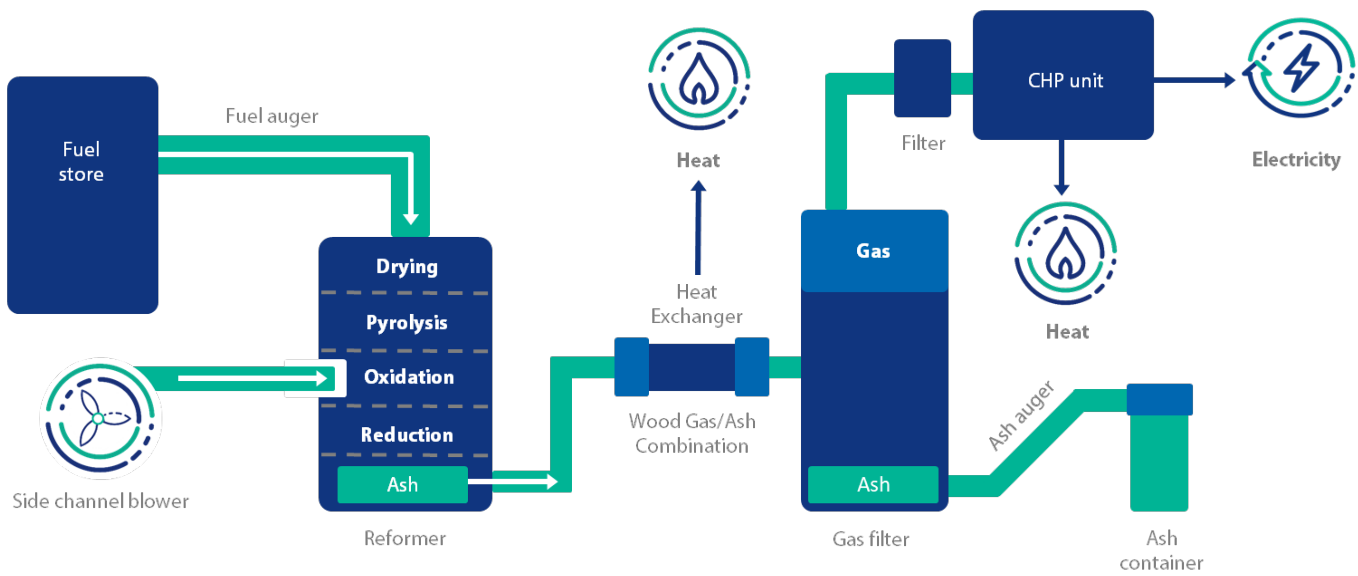



**Figure 4.4: Small gasifier unit principle**



# 5. Prime mover technologies

Selecting an appropriate technology for the power generation stage of a biomass CHP system is based on key factors such as the power demand, the heat demand and the grade of heat. This section considers the main characteristics of the different power generation technologies and how they interface with the primary boiler. Steam and thermal oil systems are costlier than water systems, require specifically designed boilers and give rise to additional safety considerations. Refer to *Table 1* and *Table 5* for the different technologies.

The technologies relevant to biomass CHP discussed in this section are:

- Steam turbines (back-pressure and pass-out/condensing);
- Organic Rankine Cycle;
- Screw-type steam expanders; and
- Reciprocating syngas engine.

The typical characteristics of these technologies are shown in *Table 5*.

**Table 5: Typical characteristics of CHP prime movers**

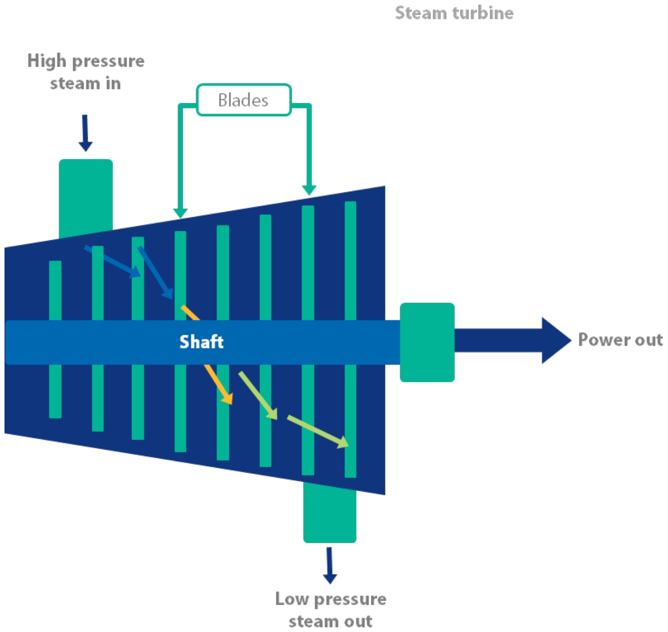
| Prime mover | See section | Electrical output range | Biomass fuels | Typical heat-to-power ratios | Grade of heat output | Electrical efficiencies |
|---|---|---|---|---|---|---|
| Steam turbine (back-pressure) | 5.1 | 0.5MWe upwards | Any, used to produce steam | 3:1-10:1 | Medium | 10%-20% |
| Steam turbine (pass out/condensing) | 5.1 | 2MWe upwards | Any, used to produce steam | 3:1-10:1 | Medium to low | 10%-20% |
| Organic Rankine Cycle | 5.2 | 0.05MWe to 2MWe | Any, used to heat working fluid | 5:1 | Low | 5%-20% |
| Steam screw expanders | 5.3 | 0.05MWe to 0.75MWe | Any, used to produce steam | 10:1 | Low | Low efficiencies (less than 12%) |
| Gas engine | 5.4 | 0.02MWe to 0.15MWe | Syngas/biogas (from gasification/anaerobic digestion) | 1:1-1.7:1 | Low to high | 25%-40% |

## 5.1 Steam turbines

The steam turbine is an important option because it can use the energy derived from any fuel – solid, liquid or gas. The fuel is burned in a boiler, generating high-pressure steam that is then ‘let down’ (expanded) through the turbine, which drives an alternator to generate electricity and provides lower pressure steam or hot water for site use. *Figure 5.1* shows a sketch of a simplified steam turbine operation principle. *Figure 5.2* shows the main components of a steam turbine system.

Steam turbines are one of the most versatile and oldest prime mover technologies still in general use to drive generators or mechanical machinery. Steam turbine CHP is usually the technology of choice for fuels that require the energy content to be released and turned into steam. It also particularly suits sites where the heat requirement is high in relation to the power demand.

**Figure 5.1: Simplified steam turbine operation**



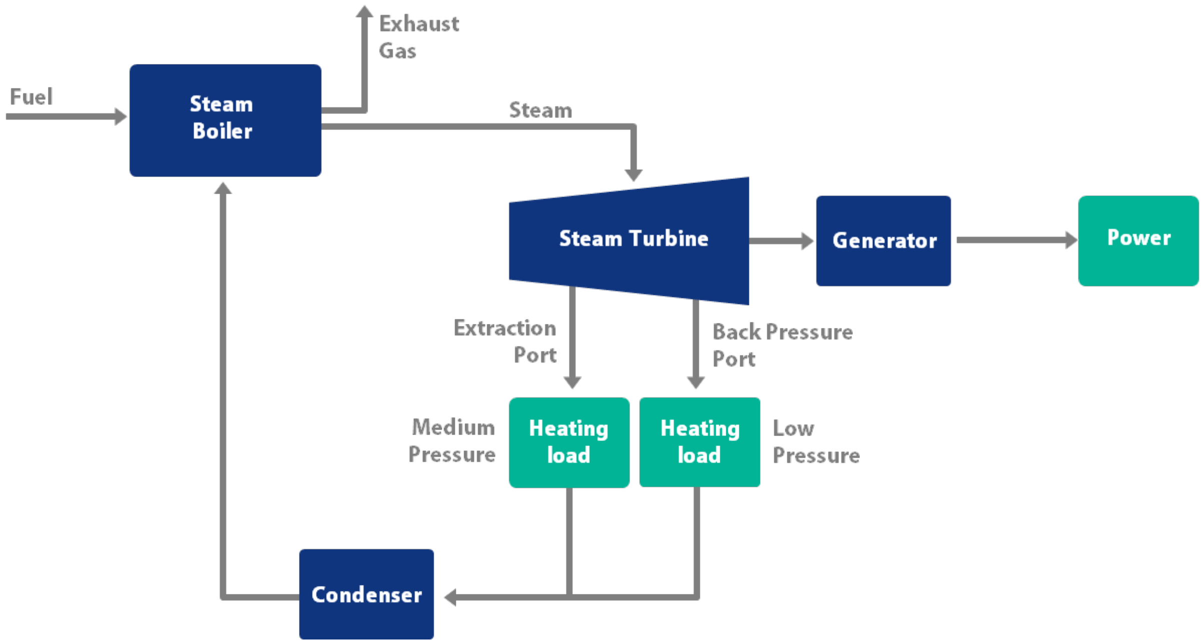

Steam turbines offer a wide range of designs and complexity. Steam turbines for large scale electricity generation may have several pressure casings and elaborate design features, which are designed to maximise the efficiency of a power plant. For industrial or smaller applications, steam turbines generally have a simpler, single-casing design and are less complicated, so more reliable and economical. CHP plant can be adapted to utility and industrial steam turbine designs.

Steam turbine CHP plant is very reliable and typically has a long operational life. When properly operated and maintained, steam turbines can achieve long-term availabilities of up to 99%, often with over a year between scheduled shutdowns. Any restriction on full plant availability is more likely to be the result of a chosen fuel and steam generation technology. Steam turbines are available with power outputs of more than 0.5MWe.

In the steam turbine, one or more sets of blades attached to the turbine rotor and are driven round by steam as it is expanded from high to lower pressure. The rotation of the blades causes a shaft to turn, which is connected (usually via a gearbox) to a generator. The amount of power produced depends on how far the steam pressure can be reduced through the turbine before being extracted to meet other site heat energy needs.

Steam turbine sets are designated by their operating mode(s) (back-pressure, pass-out/back-pressure, condensing and pass-out/condensing). The most common two types of steam turbine are back-pressure steam turbines and extraction (or pass-out/condensing) steam turbines.

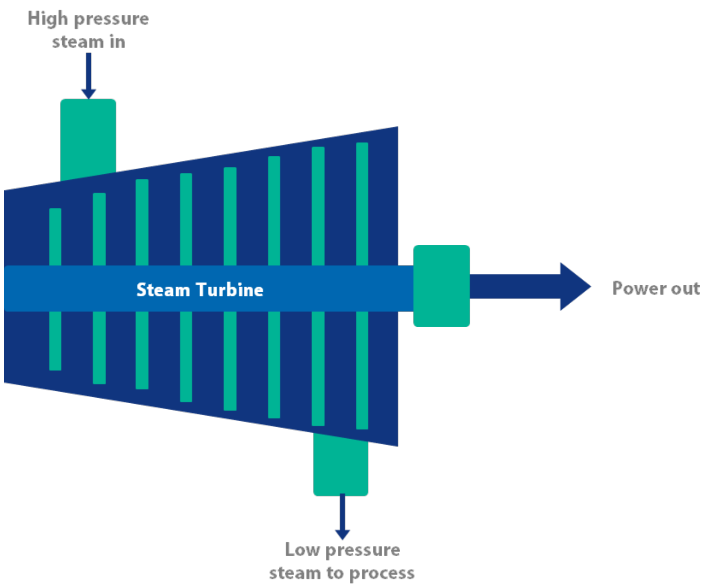
**Figure 5.2: Steam turbine system**




### 5.1.1 Back-pressure turbines

The back-pressure turbine is the simplest arrangement (*Figure 5.3*). All the steam flows through all stages of the turbine and is exhausted at the pressure required by the site.

**Figure 5.3: Back-pressure steam turbine arrangement**

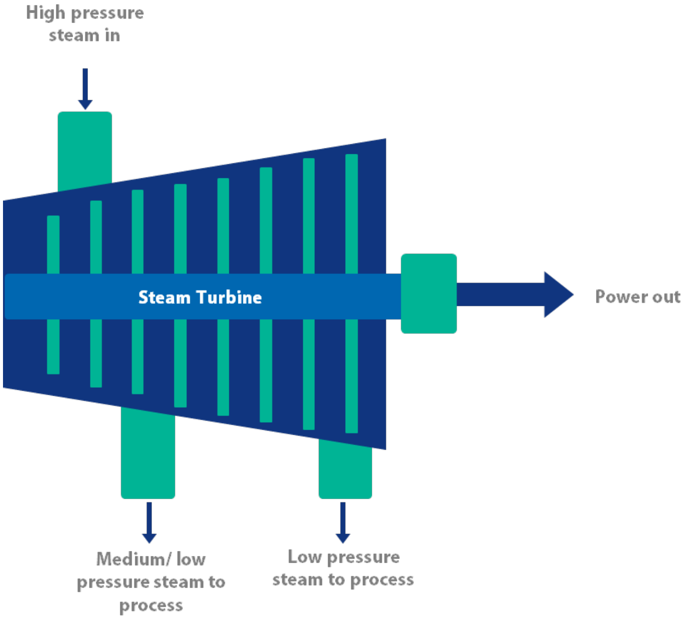



Back-pressure turbines have the advantage of a simpler configuration, relatively lower capital cost, lower cooling water requirements and higher efficiencies than extraction turbines. However, they are more inflexible to changes in a site's heat demand.

### 5.1.2 Extraction turbines

Where more than one grade of heat is required, the higher grade is supplied by extracting 'pass-out' steam at the appropriate pressure from an intermediate stage part-way along the turbine – an extraction turbine has one or more openings in its casing for extraction of the steam (*Figure 5.4*), this allow the steam to be 'portioned' out. The rest of the steam continues to the condensing section which generating further power, and exits the process at the lower pressure or is expanded to vacuum. Power output may be maximised by expanding the steam down to a vacuum using a condenser. This fully condensed steam is at such a low grade of heat that it is often not useful thereafter.

**Figure 5.4: Extraction (pass-out/condensing) steam turbine arrangement**




The steam extraction pressure may or may not be automatically regulated depending on the turbine design. Regulated or controlled extraction allows greater steam flow through the turbine to generate additional electricity during periods of low thermal demand by the CHP system. Steam turbine CHP only produces significant amounts of power when the steam input is at high pressure/temperature and the heat output is relatively low grade. To maximise the power generation, higher steam pressures are frequently selected, increasing the capital costs of the steam boiler and plant running costs. The optimum choice is a compromise between output and costs that reflects plant size and the pass-out/back-pressures required.

Multistage (moderate to high pressure ratio) steam turbines have thermodynamic efficiencies that vary from 65% for very small (under 1MW) units to over 90% for large industrial and electricity generation units. Small, single-stage steam turbines can have efficiencies as low as 40%.

**Figure 5.5: Steam turbine in a bioenergy plant**

## 5.2 Organic Rankine Cycle generators

Biomass CHP systems based on Organic Rankine Cycle (ORC) technology are commonly available across Europe from a small number of manufacturers.

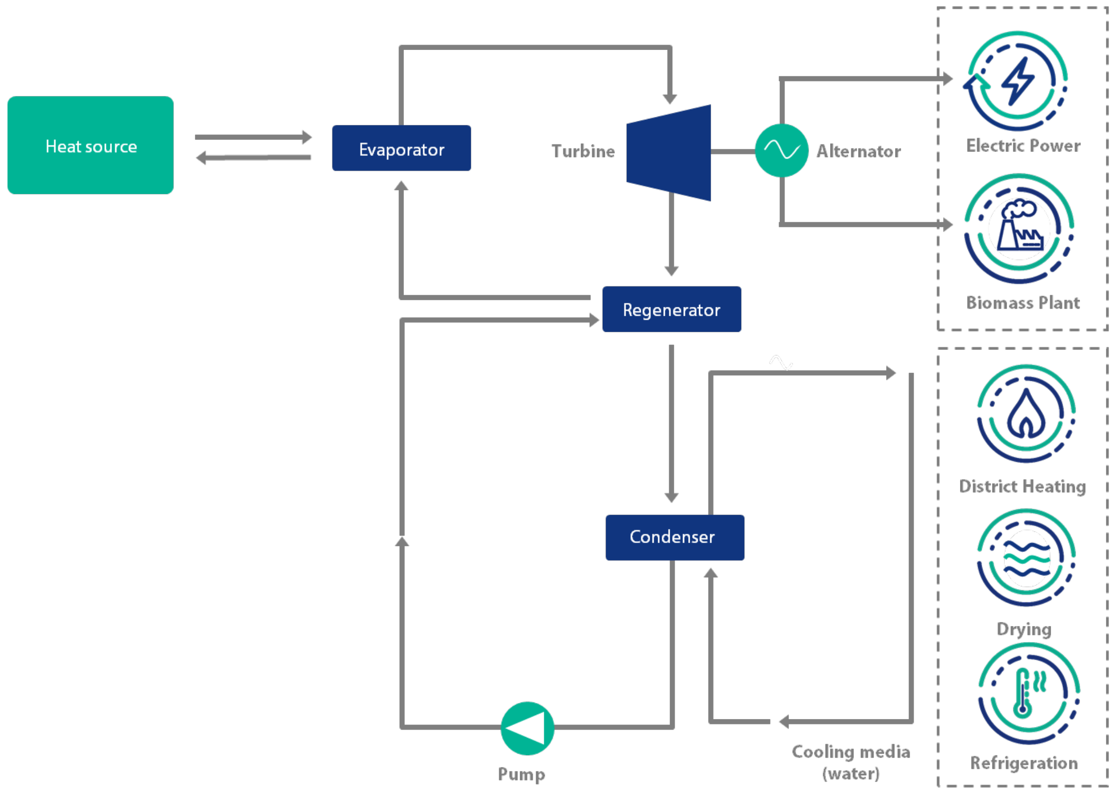
The working principle is similar to the steam cycle described in the previous section. The key difference is the use of an organic working fluid (hydrocarbons such as isopentane, isooctane, toluene or silicon oil) instead of steam. The organic working fluid has favourable thermodynamic properties – a lower boiling point and a higher vapour pressure than water. Therefore, it is able to use low temperature heat sources to produce electricity. The organic fluid is chosen to best fit the heat source according to their differing thermodynamic properties, and so obtain higher efficiencies.

The organic rankine cycle system uses heat generated from a biomass boiler to vaporise the working fluid in an evaporator. In a similar way to steam passing through a steam turbine, the vaporised organic fluid rotates the turbine that is coupled to the generator to produce electricity. The exhausted vapour flows through heat recovery and condenser stages where it is cooled and liquefied before the feed pump brings the organic fluid from the condensation pressure to the maximum pressure and passes it back to the evaporator to repeat the closed cycle.

The organic rankine cycle process can be designed so that hot water feed temperatures between 80°C and 120°C, and a temperature differential between feed and return in a range of 15°C to 50°C are possible. Return temperatures vary between 50°C and 100°C. On this basis, the exact hot water feed temperature required can be perfectly adjusted to the design requirements of the heat or cooling energy customers.

When an organic rankine cycle unit is being installed, the hot water regenerator (see Figure 5.6) should be positioned after the organic rankine cycle process to keep the hot water feed temperature from the organic rankine cycle as low as possible. The lower the hot water feed temperature at the condenser outlet, the higher the electrical efficiency.

**Figure 5.6: Organic Rankine cycle principle**



Organic rankine cycle systems typically work more efficiently at low temperatures and pressures, and at scales more suited to biomass fuel. They are well suited to operating with thermal oil systems. Electrical outputs are typically in the range 0.05MWe to 20MWe. Systems are also claimed to operate efficiently even at partial loads and with high availabilities (greater than 98%). The advantages of organic rankine cycle are listed in *Table 6* below.

**Table 6: Advantages of Organic Rankine Cycle systems**

| Technical advantages | Operational advantages |
|---|---|
| • High cycle efficiency.<br>• Very high turbine efficiency.<br>• Low turbine mechanical stress due to low peripheral speed.<br>• Low rotational speed of the turbine enables the generator to be directly coupled to it and avoids the need for a gearbox in many applications.<br>• No erosion of blades, due to the absence of moisture in the vapour nozzles. | • Simple start-stop procedures.<br>• Automatic and continuous operation.<br>• No operator attendance needed.<br>• Quiet operation.<br>• High availability (typically 98%).<br>• High efficiency at partial load.<br>• Low maintenance cost.<br>• Long life. |

## 5.3 Steam screw expanders

Steam screw expanders are simple derivatives of screw compressor technology and are driven by wet (saturated) steam. While wet steam is usually considered detrimental to the performance of other technologies such as steam turbines, as it may lead to corrosion of the blades, the steam screw expander takes advantage of the wetness in 'lubricating' and sealing the twin-rotor screw. Steam with fluctuating flow rates and gauge pressure of up to 25MPa (25 bar) and can be accommodated.

A high-pressure steam feed from the boiler rotates the steam screw expander, which drives a generator to produce electricity. The low-pressure steam exhausted from the screw expander can then be used as a low-pressure steam supply to a process. There are also examples of installations having small organic rankine cycle units on the low-pressure steam side of the expander to increase electrical generating capacity where the process requires a lower grade of heat, such as in drying applications.

Screw expanders are typically sized between 50kWe and 750kWe, most commonly around the lower end of that range. Screw expanders have a relatively low electrical efficiency, typically less than 10%.

There is a wide range of example installations (farm-based drying applications; large, commercial greenhouse heating; manufacturing processes utilising steam; industrial waste heat recovery; and hospitals where aging steam boilers fired with fossil fuels have been supplemented or even replaced by biomass fired boilers and steam screw expanders).

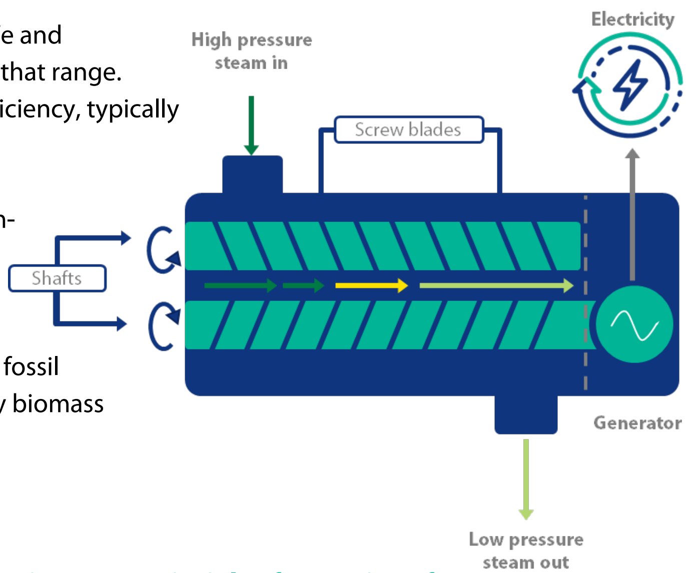



**Figure 5.7: Principle of operation of steam screw expander**

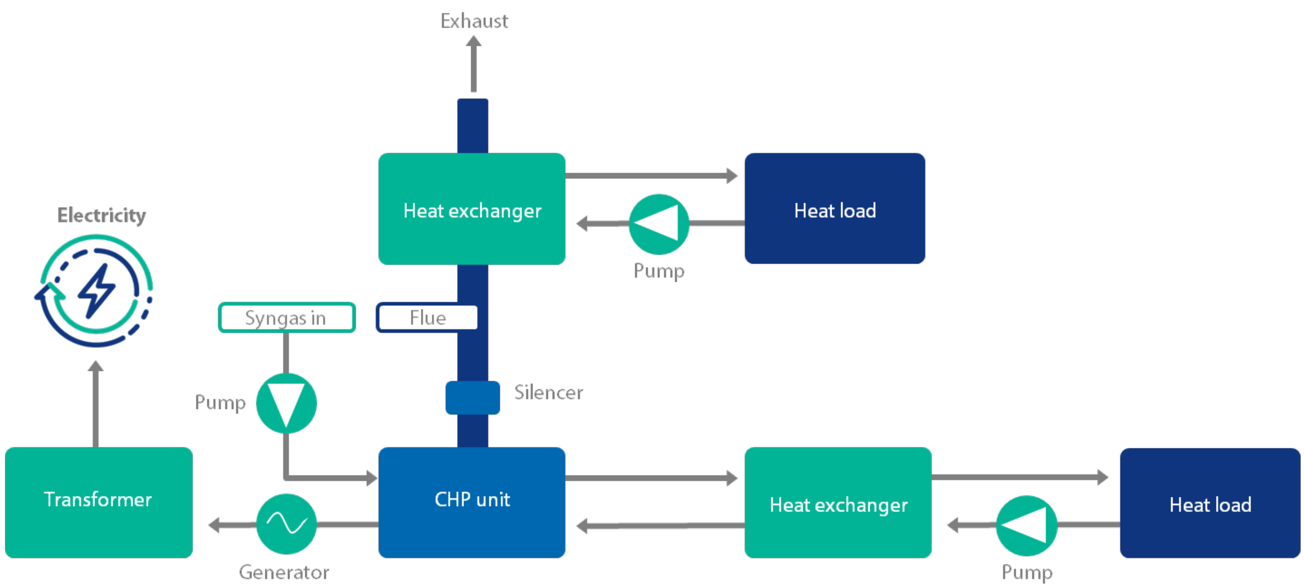
## 5.4 Reciprocating engines

Reciprocating engines are relevant because they are used in combination with biomass gasifiers to generate power and heat. The engines used in CHP systems (see *Figure 5.8*) operate on the same principle as automotive petrol and diesel engines. They are efficient and can achieve long-term availability levels of between 85% and 92%.

Heat produced by the engine can be recovered from two sources:

- The engine exhaust (gases at a temperature of about 400°C);
- The engine and lubricating oil cooling systems (hot water typically at 80°C).

**Figure 5.8: Reciprocating Engine CHP system**




Reciprocating engine efficiencies are higher than those for gas turbines, and there is very little reduction in engine efficiency when operated at part load. The usable heat-to-power ratio is typically between one and two. Several suppliers and manufacturers have been testing reciprocating engine s with different gas components and compositions, and are now able to adapt their reciprocating engines (mainly introduced for natural gas combustion) to burn biogas and syngas. Historically, reciprocating engines were developed and demonstrated with natural gas, and later with biogas. Developing engines to combust syngas was a challenge for many years.

In certain applications, gasifiers are used to convert solid biomass to gases. In these cases, reciprocating engine s can be used. The key challenge with gasification coupled to a gas engine for energy recovery is to create a stable gasification process that produces a consistent gas composition, which minimises the production of heavy tars. Systems tend to not perform well using wood with variable quality and moisture content (typically, fines and moisture above 10% are not desirable).

**Figure 5.9: A typical syngas reciprocating engine**

Most recent developments in packaged biomass gasifier with reciprocating engine CHP technology involve small units with electrical outputs ranging from a few kWe to 180kWe.

## 5.5 Absorption cooling

Absorption cooling allows cooling to be produced from heat rather than electricity. A site with a large and continuous cooling demand, and perhaps a declining demand for heat, may consider replacing a conventional electricity-based cooling system with absorption cooling. When a prime mover provides electricity, heat and cooling via an absorption chiller it is often referred to as trigeneration.

Converting an electrical load into a heat load in this way has several advantages:

- It reduces electrical demand.
- It increases options for heat utilisation.
- It 'irons out' some of the seasonal peaks and troughs in the requirement for heat.
- In some cases, using heat for cooling can turn a marginal CHP case into a viable option.

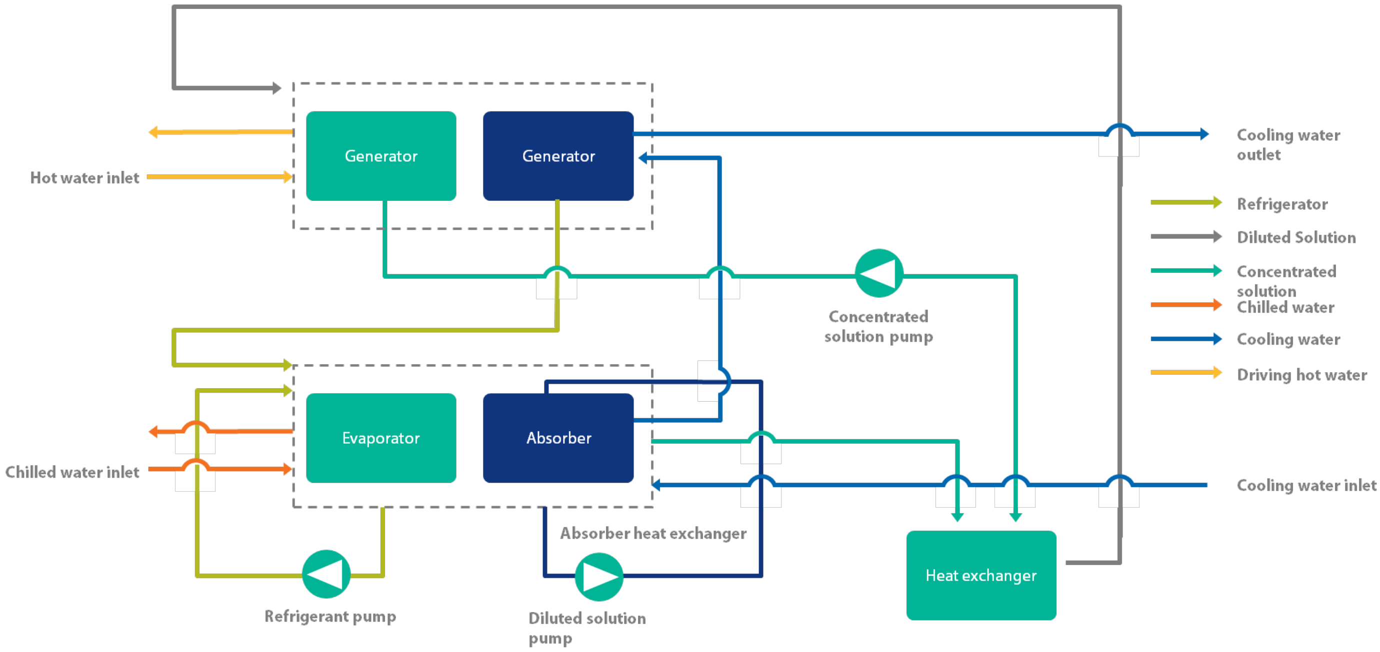
Absorption coolers (or absorption chillers) use an evaporator and condenser in the same way as refrigeration by mechanical vapour compression, but they replace the compressor in the conventional system with a chemical absorber and a generator. A pump provides the necessary change in pressure.

Absorption cooling is based on the strong affinity of certain pairs of chemicals to dissolve in one another. Well proven examples include lithium bromide (in solution) and water, and ammonia and water. Lithium bromide tends to be more common as it is safer and non-toxic.

The process operates as follows (also see *Figure 5.10*):

1. Refrigerant (water) is evaporated by the return leg of a chilled water system in a low-pressure vessel – the evaporator (step 1). This cools the chilled water coils.
2. The lithium bromide solution in the absorber draws refrigerant water vapour from the evaporator and absorbs it, diluting the solution (step 2). The absorption process generates heat, which needs to be removed.
3. The weakened solution is pumped to a higher pressure (step 3.1) and passed from the absorber, via a heat exchanger, to the generator (step 3.2). The heat exchanger improves the system's efficiency.
4. Heat from an appropriate heat source (e.g. waste heat/heat from a CHP unit) is applied in the generator part of the chiller unit (step 4.1), the absorbed water is driven off and passed to the condenser, and the absorbing liquid is returned, again via the heat exchanger, to the absorber (step 4.2).
5. The condensed water is returned to the evaporator (step 5).

**Figure 5.10: Absorption chiller cycle**




As absorption chillers have few moving parts, they are reliable and have low maintenance requirements. As with conventional cooling, absorption cooling requires heat dissipation facilities. Furthermore, the amount of heat rejected from an absorption cooler is greater than the amount rejected from an electrically driven chiller of equivalent capacity, so the heat dissipation unit needs to be larger.

Cooling towers are usually relatively inexpensive to install and are an effective method of heat dissipation, but they require appropriate environmental, visual and planning consideration during design, and regular treatment and maintenance to minimise health risks (for example, legionella).

Alternative options include:

6. Dry air coolers – these are similar to vehicle engine radiators, but are much larger and are usually fitted with electrical fans to force air through the cooler. Because they are less effective at rejecting heat than wet cooling towers, they are larger than the latter for a given duty.
7. Adiabatic coolers – these operate as dry air coolers until ambient temperatures reach a set threshold (e.g. 23°C) at which point water is sprayed over the cooling coils to increase the rate of heat dissipation by introducing evaporative cooling.

The efficiency of an absorption chiller is measured by the coefficient of performance, which is defined as useful thermal energy output (i.e. chiller load) divided by the heat input.

Coefficient of performance = Cooling duty (kW)/Generator heating duty (kW)

Coefficient of performance does not have a unit and does not include the energy consumed by pumps, fans or other ancillary components.

There are two basic types of absorption chiller: single and double effect.

- Single-effect chillers can use low temperature hot water (e.g. 80-100°C) and have coefficient of performance s of around 0.7.

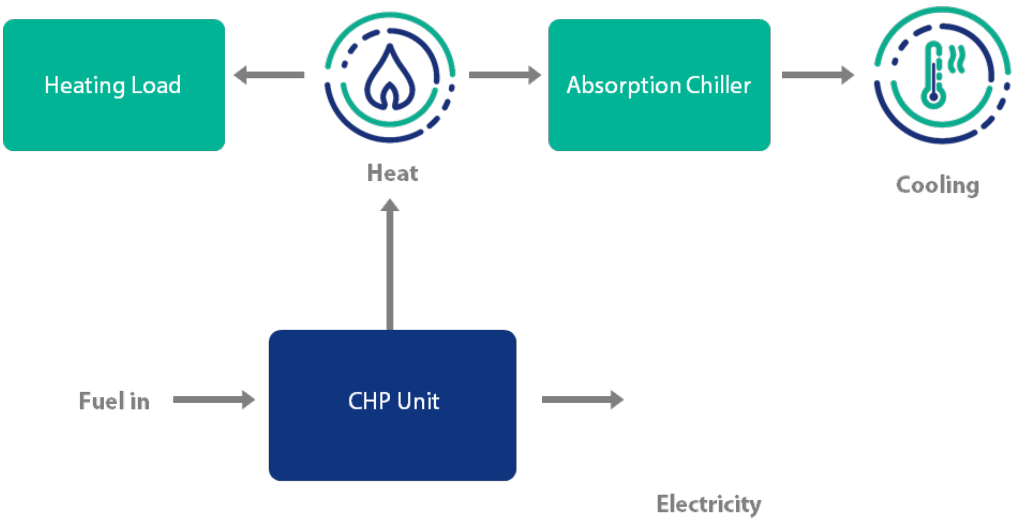
- Double-effect chillers use higher temperature hot water (e.g. 180-210°C), steam or exhaust gases from the CHP system and have a coefficient of performance of around 1.3 (i.e. chilled energy delivered exceeds heat required to drive the system). Units are also available that can use several heat sources. The coefficient of performance of such units are much less than those of vapour compression chillers, so it is important that the carbon content of the heat from the CHP system and the cost of heat production is low. The lower coefficient of performance also mean that about twice as much heat needs to be rejected from the condenser circuit as for vapour compression chillers.

**Figure 5.11: Typical absorption chiller installation**

Because absorption chiller capacity is a function of thermal energy input quantity and quality, and chiller design (single or double effect), it is important to match CHP prime movers with the right absorption chiller. Compared with a single-effect chiller, a double-effect chiller has a higher coefficient of performance so requires a greater generator temperature. Either design can be used where high temperature heat sources are available. While a double-effect chiller can produce greater capacity from a high-temperature heat source, a single-effect chiller is less complex and typically less expensive.

Where absorption chillers are included in a CHP scheme supplying power and heat to specific loads, it is referred to as a combined cooling heat and power system, or trigeneration. See *Figure 5.12*.

**Figure 5.12: Absorption chiller trigeneration system**



# 6. Design and sizing

## 6.1 Selection of technology

One of the main considerations when planning to install a biomass CHP system is its size relative to a site's energy (electricity and heat) demands – from economic and environmental points of view. Typically, biomass CHP systems are primarily designed to satisfy a site's base load heat demand, on the grounds that excess heat cannot be stored or exported easily. Where the latter is not the case, careful attention to the electricity load will be required, and the output may have to be modulated.

Best practice for optimum sizing of a CHP system will involve the construction of a spreadsheet model to determine the annual energy flows of the system so that operating costs and savings can be evaluated. It will need to accurately model the variability of the site's energy demands and sensitivity to fluctuating energy costs. Ideally, heat and power demand data at half-hourly or hourly granularity over the course of a year will have been obtained.

Therefore, prior to the sizing of the CHP system, a detailed assessment of the heat and electricity demands of the site will have been conducted. This data can be gathered by a variety of methods such as:

- Examining existing electricity bills;
- Taking on-site measurements; and
- Modelling in dynamic simulation software.

The consumption profiles of the site are best understood by graphical representation across a time period such as a day or a whole year.

The model should be built to determine and include:

- Whether the CHP system is economically beneficial based on fuel and electricity costs.
- Whether the output of the CHP system is to follow the heat or electricity demand.
- The operation of the thermal store.
- The peak heat demand and whether it can be met by thermal store or if standby boilers are required.
- The electricity import costs and revenue from exported electricity.
- A range of different CHP sizes (and different CHP technologies if needed).

The analysis required for the detailed model is complex and is best carried out by a professional such as a chartered building services engineer or the suitability qualified installer. It is strongly recommended that readers refer to Chartered Institution of Building Services Engineers publication Combined Heat and Power for Buildings, AM12: 2016 for a detailed explanation of CHP sizing.[17]

For more detailed guidance on sizing of a CHP system and assessing energy demands, refer to the accompanying Implementation Guide.

## 6.2 Sizing of absorption cooling

Normally, absorption chillers are sized to supply the base cooling load with vapour compression chillers used for peak periods. This enables maximum use of the CHP/absorption chiller and avoids frequent start/stops. An absorption chiller is normally sized so that its heat requirement does not exceed the heat output of the CHP system. If this was the case, boiler heat would be used for the absorption chiller, which is less efficient than using electric chillers. If there is no other heat demand in the summer cooling period, then the absorption chiller heat requirement will need to match the CHP heat output closely to avoid heat rejection or part-load operation.

17 CIBSE, Combined Heat and Power for Buildings, AM12: 2016': https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I7nsAAC

# 7. Thermal system design

The key differences between biomass and conventional boilers need to be factored into the design and operation of a biomass CHP system. These are highlighted in Section 4 and in the Technology Guide of the accompanying set of guides on biomass boilers.

In addition to the profile of heat demand, the biomass boiler's response time for modulating its heat output and turndown ratio, and how heat is recovered/extracted from the power generation step are key factors in sizing a CHP system, its thermal storage and any top-up fossil-fuel boiler capacity.

In a CHP system, there are essentially two heat circuits:

- Primary circuit – the supply of heat (steam, thermal oil or hot water) from the biomass boiler to the prime mover (power generation technology).
- Secondary circuit – the recovery of heat from the prime mover technology and delivery to the heat consumer.

The primary circuit will be dependent on the choice of power generation technology – whether it is steam to supply a steam turbine or a steam expander, or thermal oil or hot water to an Organic Rankine Cycle. The secondary circuit will depend on the desired heat use – and if it is to be connected to an existing heat supply circuit.

Generally, the time lag between the start-up of a biomass boiler and its flow water being up to temperature is greater than that for conventional boilers. So, heat demand will have to be anticipated or initially provided from a separate source. The biomass boiler will need to be switched on earlier – manually or through controls such as the site's building management system. Alternatively, heat stored within thermal storage can be used to meet the gap between initial demand and when the biomass boiler is able to provide output to the system.

Lower turndown ratios for biomass boilers, compared to those for conventional boilers, means that careful sizing of the system is needed to maintain efficiency. Biomass boilers can be used with conventional boilers and thermal stores to provide flexibility and maximise efficiency, but this depends on the heat demand profile.

## 7.1 System types and heat transfer media

Heat transfer media include water, steam and thermal oil, with the most common being water at a flow temperature of around 85°C. The choice of medium will depend on the grade (temperature) of heat required, with steam and thermal oil used where higher temperatures are required.

Steam and thermal oil systems can cost more than water systems, require specially designed boilers and give rise to additional safety considerations. This guide discusses water systems, though many of the general principles apply to steam or thermal oil systems. *Figure 7.1* and *Figure 7.2* show some simple configurations for a biomass boiler, prime mover and thermal store connected to a heat load.

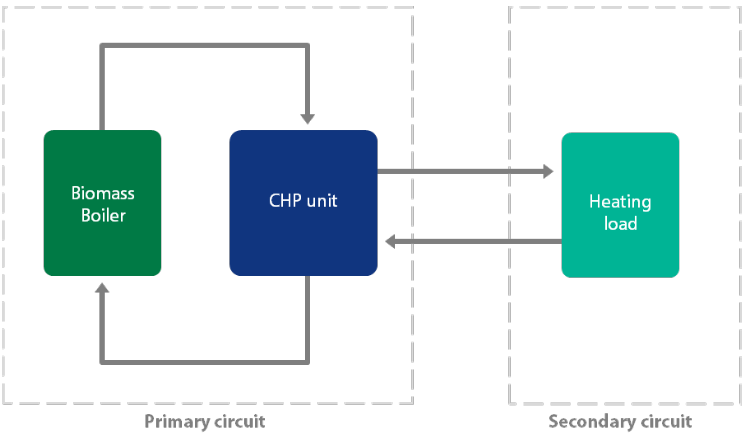
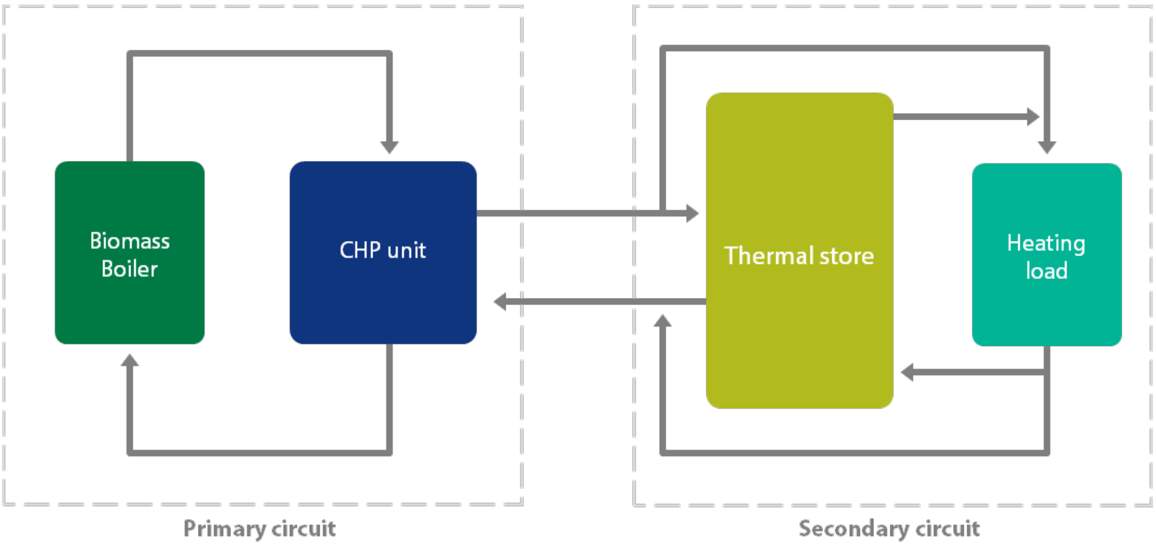



**Figure 7.1: Biomass boiler and prime mover connected to heat load**

**Figure 7.2: Biomass boiler prime mover and thermal store connected to heat load**




## 7.2 Buffer vessels and thermal stores

The terms 'buffer vessel' and 'thermal store' tend to be used interchangeably, but they have different functions. The term accumulator is also sometimes used for thermal store, particularly in respect of log boilers. These elements of the system is used to eliminate or limit the dumping of unused heat, for a system to be deemed efficient dumping of heat should be minimised.

### 7.2.1 Buffer vessels

Most hot water biomass boiler systems use buffer vessels to receive the residual heat from the biomass boiler once the heat demand is no longer present. Biomass boilers tend to have a higher thermal capacity because of more refractory material and much longer response times than fossil-fuelled boilers. The resulting residual heat must usually be removed from the boiler through the heating medium once the heat demand has been removed.

Capturing and the subsequent re-use of the residual heat will improve the system's overall efficiency and prevent the boiler overheating, including the risk of excessive pressure within the boiler's water circuit. Buffer vessels are used for this purpose. The heat stored in buffer vessels can then be used when the boiler is restarted, assuming the downtime is not too long.

As most large biomass boilers require the use of a buffer vessel, the manufacturer of the boiler will specify the minimum buffer vessel sizing requirements. The required capacity of a buffer vessel will depend on various factors including:

- Whether the boiler has automatic ignition;
- The type of grate;
- Whether the feed auger needs to be emptied onto the grate and the fuel burned off prior to shut down;
- The type of fuel; and
- The mass of the ceramic lining within the boiler.

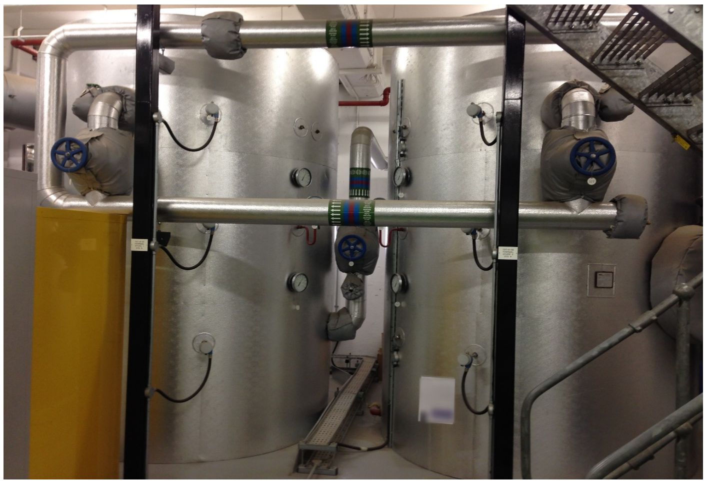
The capacity ratio of buffer vessels can vary from 5 litres/kW to 60 litres/kW of boiler capacity, depending on these factors. Due to their limited purpose, buffer vessels tend to be relatively small compared with thermal stores.

### 7.2.2 Thermal stores

The purpose of thermal stores is to smooth out variable heat demand, allowing a smaller boiler to be used and to run for longer at peak efficiency. This also assists with continuous operation of power generation technologies.

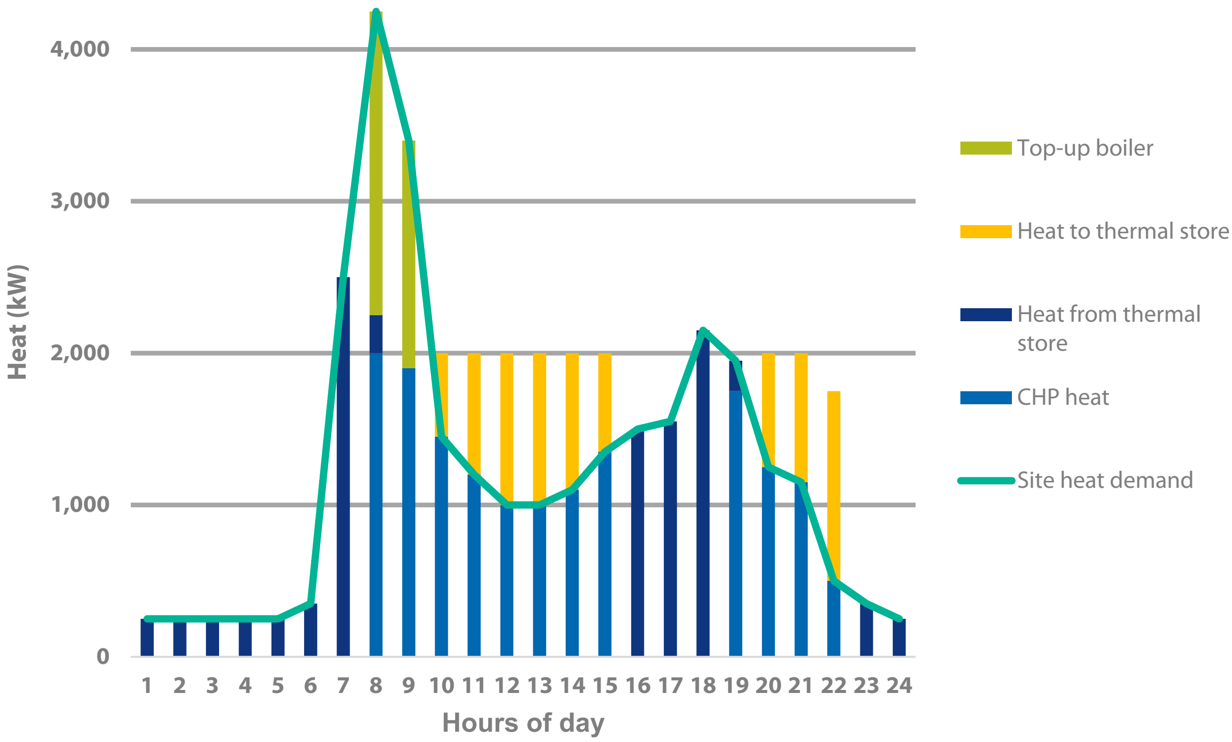
Thermal stores are often configured to act as buffer vessels. Thermal storage depends on the stratification of the heating medium (mainly water) and hence tends to have a large height-to-diameter ratio. Water inlets to thermal stores are designed to minimise turbulence and maintain stratification.

**Figure 7.1: Thermal storage vessels**



The use of thermal storage can alter the operational demands on biomass boilers and any backup conventional boilers, thus changing the design economics of a biomass system. This is achieved because thermal stores enable smaller biomass boilers to operate continuously for longer periods compared with larger boilers that must vary output significantly or even start up and shut down frequently. The result is improved efficiency and utilisation of the biomass boiler. A smaller biomass boiler will also have a lower capital cost.

**Figure 7.2: Loading and drawdown from thermal store in CHP system**




Given the number of variables in terms of heat load, size and number of biomass boilers, size and number of top-up and backup fossil-fuel boilers, and size of any thermal store, a detailed design analysis is needed to determine the optimum system in each case. There are publications and design tools available that will help with this, as detailed in Section 12.

## 7.3 Connection to the heat-distribution system

With a completely new heating system, the biomass CHP and heat load systems can be designed together and more easily matched. However, many biomass boiler systems are fitted to existing heating systems to displace conventional boiler capacity. Fitting to existing systems is more likely to require some form of hydronic separation between the biomass boiler system and load system.

### 7.3.1 Heat exchangers

Heat exchangers provide isolation between the biomass boiler and load systems; plate heat exchangers are most commonly used. Heat exchangers are used for various reasons, including to:

- Separate systems that operate at different pressures or temperatures;
- Prevent possible contamination or debris in an older existing distribution system from entering the boiler circuits (although systems should be fully cleaned and flushed before commissioning);
- Facilitate maintenance of individual load (secondary or tertiary) circuits without affecting the heat supply to other loads;
- Ensure that a failure of the biomass system does not affect backup conventional boilers (on the secondary side of the heat exchanger) or the loads; and
- Provide a boundary where responsibilities for the operation/maintenance of biomass plant and the load distribution system are with different parties.

**Figure 7.1: Typical plate heat exchanger**

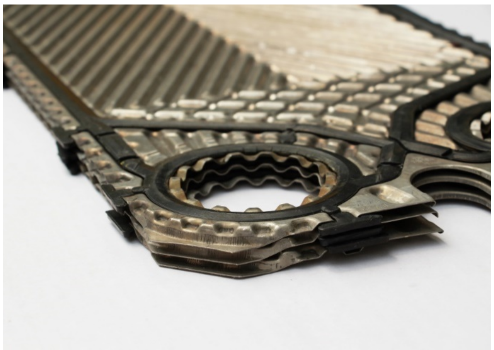
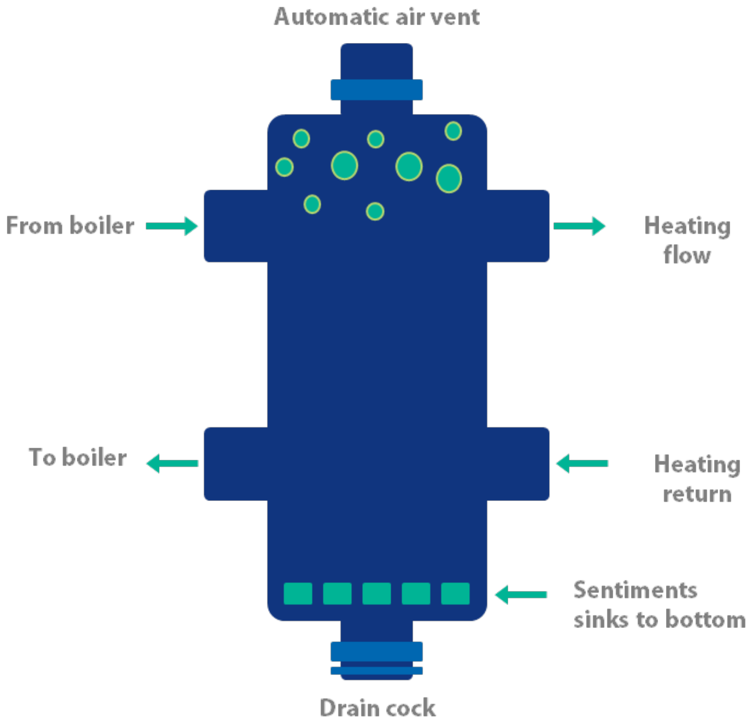


**Figure 7.2: Plate heat exchanger installed with system pumps**

### 7.3.2 Low loss headers

These enable boilers to be controlled at their own flowrate compared to the flowrate of load systems that may vary. They enable several boiler and load connections to be made. The design of headers can be complex and should be undertaken by an experienced heating system design engineer. Some existing systems may already have a low-loss header to which the biomass system can be connected.

**Figure 7.3: A low-loss header**




## 7.4 System monitoring and control

### 7.4.1 Biomass boiler efficiency

Heat output from a biomass CHP system should be metered to allow, along with records of fuel use, the boiler efficiency to be calculated. Also, depending on the system, the heat output data may be required under any financial support schemes.

If there are conventional boilers within the installation, then it is good practice to monitor the heat output and fuel use of these as well so that the relative contributions from biomass and fossil fuels can be analysed.

### 7.4.2 Boiler primary circuit

Flow rate will usually be constant through the primary circuit, and temperature sensors will measure the boiler flow and return temperatures.

If there is a buffer vessel or thermal store in the system, then further temperature sensors will be used to monitor combined flow temperatures. In addition, two or more sensors will monitor temperatures within the thermal store to determine whether the biomass boiler should be started up or shut down.

### 7.4.3 Secondary circuits

Secondary circuits will have their own measurement and control systems including variable speed drives to allow the system to respond to demands for heat.

## 7.5 Heat and steam metering

### 7.5.1 Meter types and principles of operation

It is good practice to measure heat output and heat use, and most biomass CHP installations will require some heat metering. There are many reasons for measuring heat in biomass CHP installations including:

- Determining heat output of the boiler to monitor boiler efficiency;
- Determining the heat use of particular loads;
- Providing diagnostic information in the event of a system fault;
- Providing control signals for the firing of top-up and standby boilers;
- Billing heat users, particularly for systems where there are several users; and
- Meeting the requirements of financial support schemes.

There are various manufacturers providing heat meter systems suitable for biomass CHP systems. Selecting an appropriate heat meter depends on:

- The working fluid;
- The operating ranges for flow rate and temperature;
- Pipe diameter;
- Whether it is to be battery or mains powered;
- Whether it is to be installed in the flow or return pipe; and
- The ambient temperature.

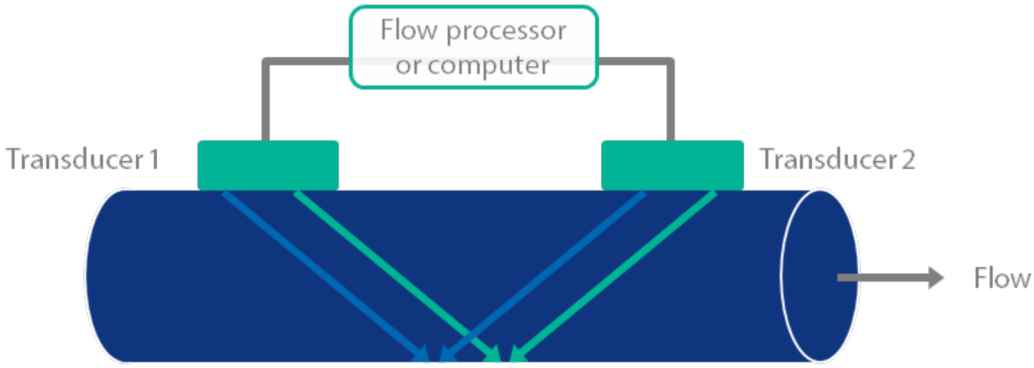
A heat or steam meter system normally comprises a flow measurement device (flowmeter), temperature sensor(s) and an integrator (or calculator) with display. Steam meters also require pressure sensors.

#### 7.5.1.1 Flow sensors

There are various types of flow sensor available, the most commonly used in heat meters being:

- Ultrasonic flow sensors – these measure the transit time of the ultrasound in the moving fluid between an upstream and downstream sensor. They are non-invasive and low maintenance. However, they need relatively long unimpeded upstream pipework to ensure accurate measurement.
- Fluid oscillatory flow sensors – these fall into two groups (vortex shedding flow sensors and fluidic oscillatory flow sensors). Both of these measure responses to meter bodies placed in the fluid flow. The frequency of these responses is proportional to the main fluid flow velocity.

**Figure 7.1: Ultrasonic flow sensor**



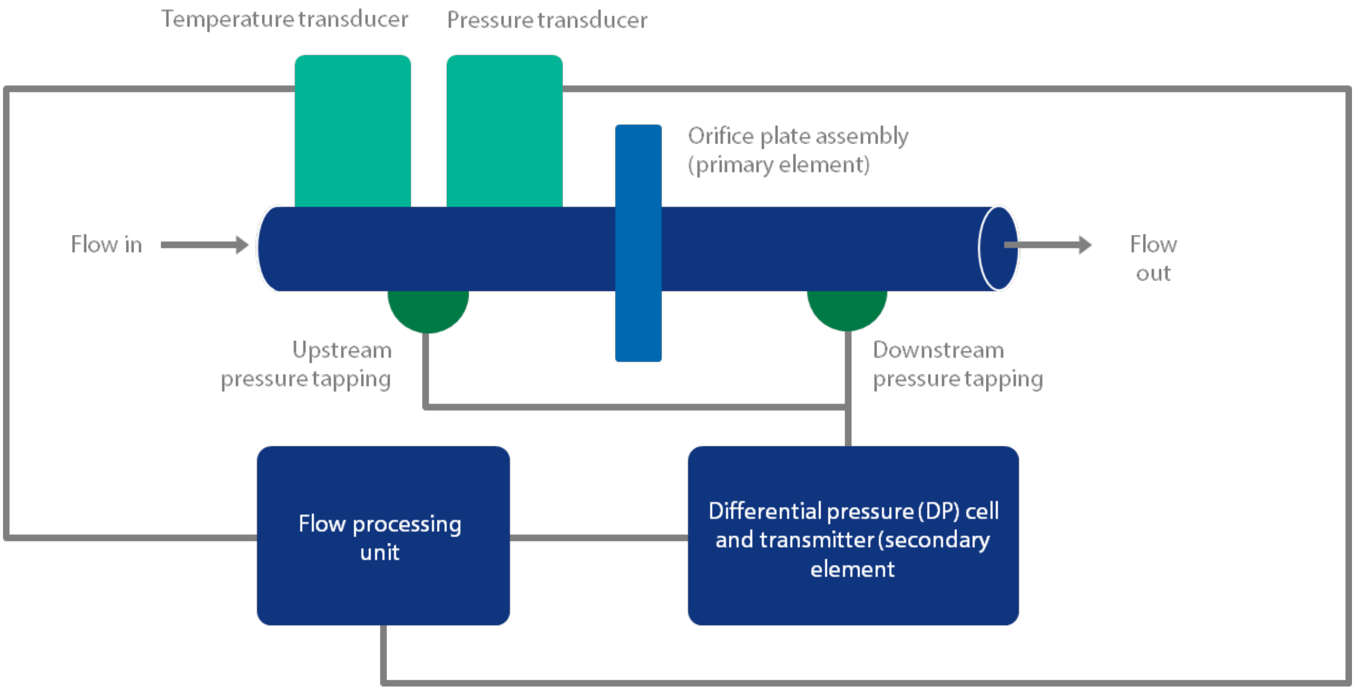

The choice of flow sensor will depend on the heating medium, the accuracy required, the cost and practicalities in terms of positioning within the installation.

There are many types of flowmeter suitable for steam applications, including:

- Orifice plate;
- Turbine;
- Pitot tube; and
- Vortex shedding.

Each type has its own advantages and limitations, so it is essential that the selected type is matched to the steam conditions, flow and applications.

**Figure 7.2: Example of steam flow metering (orifice plate system)**



### 7.5.1.2 Temperature and pressure sensors

Temperature sensors for heat meters are supplied as matched pairs and are calibrated to minimise the error in measuring the temperature difference between flow and return streams. Temperature sensors are normally of the platinum resistance temperature detector type Pt100 or Pt500.[18] To maintain accuracy, it is important that the temperature sensors are installed correctly, usually within thermal pockets and that their cables provided by the manufacturer are not altered.

**Figure 7.3: Matched pair of heat meter temperature sensors on flow (right) and return (left) pipes**

Pressure sensors in steam metering applications are essential to allow proper correction for the steam density, which varies with pressure and dryness fraction. Some steam metering systems do not use a density compensation and are specified to operate at a fixed line pressure. This is acceptable where the line pressure does not vary, but even small variations in pressure can affect flowmeter accuracy. Where the fluid is superheated steam, then temperature must be measured as well as pressure, as the relationship between steam pressure and steam temperature is not fixed as it is with saturated steam.

**Figure 7.4: Pressure sensors**

### 7.5.1.3 Integrators

The heat meter integrator determines the instantaneous heat flow from the flow rate of the heating fluid, the temperature difference between the flow and return, and the specific heat capacity of the heating fluid. Integrating this over time gives the cumulative heat consumption of the heating circuit in question (in kWh, MWh or GJ).

As well as being able to display the heat consumption, most integrators can provide other useful parameters such as:

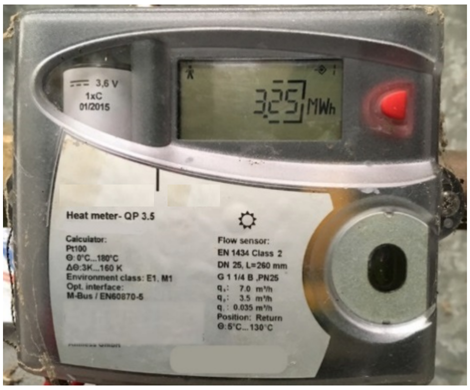
- The instantaneous rate of heat use;
- Flow and return temperatures; and
- The flow rate of the heating fluid.

Furthermore, many integrators can store a certain amount of data (e.g. 18 months of month-end cumulative heat data) and output/download the data to other monitoring systems such as building management systems.

18 Pt100 means that the RTD has a resistance of 100Ω at 0ºC. A Pt500 RTD has a resistance of 500Ω at 0ºC. Higher resistance RTDs have lower errors for the same cable types, which is important where longer cable lengths are needed.

Depending on the manufacturer, heat meters can be configured for a number of communications protocols (such as Meter-Busand RS 232) by the addition of modules to the integrator.

**Figure 7.5: Typical heat meter integrator (hot water and steam)**





Steam meter integrators determine the mass flow from the flowmeter, temperature and pressure sensors. Some integrators use built-in look-up tables for enthalpy enabling them to determine the instantaneous heat (kW) or consumption (kWh).

## 7.5.2 Meter classifications

Heat meter calibration, depending on meter type, must be specific to the heat transfer fluid in the circuit being measured.

This is normally water but can be water with antifreeze and/or a corrosion inhibitor. Generally, corrosion inhibitors do not require meter recalibration, but glycol antifreeze mixtures do. In either case, the heat meter supplier or manufacturer should be consulted. If meters have been specifically calibrated for the presence of certain additives, it is important to maintain that level of concentration. Automatic systems can be used to check and top up levels.

Some meters are specifically manufactured for use with water-glycol mixtures, and the glycol concentration can be entered directly into the meter rather than having to be calibrated by the manufacturer or authorised agent.

Heat meters should meet the requirements of the Measuring Instruments Directive (2014/32/EU). If they comply, then they will have a CE mark. IS EN 1434:2015 Parts 1 to 6 is the Irish implementation of EN 1434:2015, which is harmonised to directive. Part 1 (General requirements) and Part 6 (Installation, commissioning, operational monitoring and maintenance) will be of most value to readers of this guide.

In addition, heat meter accuracy is specified by the Measuring Instruments Directive class notation, where accuracy is defined in terms of Classes 1, 2 or 3 – Class 1 being the most accurate. The accuracy of the meter in practice will also depend on its correct installation.

Steam meter accuracy is specified in a manufacturer's guidance and by traceable calibration systems. Each component of the metering system (flow devices, pressure sensors, temperature sensors and integrators) should be calibrated and the overall uncertainty should be maintained below an acceptable value. This may be set by the requirements of incentive/benefit systems.

Key considerations when selecting and installing heat or steam meters include:

- The accuracy class, which defines accuracy (if installed correctly);
- The need for the flow sensor, temperature sensors and integrator to be matched;
- Being suitable for the static pressures and flow rates of the circuits where they are to be installed;
- Whether a glycol-based additive is required in the hydronic circuit to be metered;
- Correct positioning of flow sensors in relation to pumps, bends, etc. and flow sensor orientation in accordance with the manufacturer's guidance;
- Installation of temperature sensors in accordance with the manufacturer's guidance.

For open-vented systems, low pressure and the presence of air can mean that an ultrasonic flow sensor is not appropriate.

### 7.5.3 Installation

Generally, meter integrators need to be protected from outside elements. This can be achieved by installing them on pipework in buildings or, if outside installation is necessary, housing within weatherproof boxes unless suitably International Protection[19] rated.

Accurate measurement of the target heat flow depends on meter components having been installed according to the manufacturers' specifications. For example:

- In horizontal pipe runs, ultrasonic flowmeters must normally be installed with the sensor head oriented within ±45° to the horizontal.
- Flowmeters may also be sensitive to the direction of flow. In such cases, the flowmeter will have direction marks on the body of the meter. These should match the direction of flow.
- Heat meter manufacturers will specify whether the flow sensor should be installed in the flow or return pipework.

Flowmeters may also have restrictions in terms of where they can be fitted in the pipework system. Examples are:

- Mechanical meters should not be located within five pipe diameters of bends or other disturbances.
- Ultrasonic meters should not be placed where there is a risk of air build-up, such as at high points in the distribution system, or near to a pump inlet or discharge.

Temperature sensors supplied as matching pairs should have matching serial numbers on the hot and cold temperature sensors. The sensors should be installed within appropriate thermal pockets. Thermal paste can be used to ensure good contact between the sensor and the wall of the thermal pocket.

Pressure sensors should be correctly installed at the appropriate location on the pipe and be free from damage and leaks.

Sensors (temperature or pressure) should not be able to move once they are installed. Sensors and calculators should be fitted with security tags by the meter installer. This gives confidence that the meter has not been tampered with and may be a requirement of any financial support scheme.

Sensors and their leads are particularly susceptible to mechanical damage; care should be taken in the siting of thermal pockets and in the positioning and securing of the sensor leads.

Part of the detailed design and installation will be to ensure that the sensors are sited so that the intended heat flow is measured. Incorrect siting of one or both sensors will lead to erroneous measurements.

19 IP stands for International Protection, but is commonly referred to as Ingress Protection

### 7.5.4 Maintenance and calibration

Meters should be supplied with calibration certificates for each component as appropriate, ideally valid for a set time period. 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 or EN1434 to do so. In the absence of guidance from the manufacturer, a period of no more than five years between recalibrations is recommended.

The calibration should be appropriate to the heating medium. For example, if it is to be used to measure the flow of a water-glycol mixture, then the flowmeter should have been calibrated for that mixture.

It is the flowmeter that is the most likely to lose accuracy over time. Recalibration usually requires that it is removed and returned to the manufacturer or test house approved by the manufacturer. This will result in downtime for the installation (drain-down, refill and re-pressurisation) unless there is a method of bypassing the meter. It may well be more economical to simply purchase a new meter, perhaps as an exchange with the manufacturer.

Records of all meter calibrations, repairs and changes should be maintained.

# 8. Electrical system design

The CHP unit's generator must be connected to a site's electrical distribution system at an appropriate location. This may be via a spare breaker cubicle on an existing busbar or a new bus-section. Where a standby (island mode) facility is required, the maximum load imposed under island mode conditions must be within the generator's rated capacity.

In all cases, the site's electrical distribution system and grid in-feed must be checked to ensure that system fault levels are satisfactory and that switchgear is appropriately rated. There are requirements to be met when connecting a generator to any part of the public electricity supply. Further details can be found in the accompanying Implementation Guide.

Figure 8.6: Scheme switchgear

The power generated by a CHP plant is often three-phase alternating current at 50Hz, usually at 415V. Where the site electrical system at the point of connection is at a higher voltage (e.g. 11kV), then a generator of that voltage may be used. Alternatively, a 415V generator may be used and linked to a step-up transformer, the latter supplying electricity to the site at a higher voltage (e.g. 11kV).

## 8.1 Operation modes

There are usually two modes for setting up the electrical supply connections:

- Parallel mode; and
- Island mode.

### 8.1.1 Parallel mode

Parallel mode operation occurs in most CHP plants: the ability to have top-up and backup power is regarded as an essential facility to ensure security of site power supplies.

The site on which a CHP package is installed is almost always connected to the local area electricity supply system, and the CHP generator's output power must be synchronised with this system. This is achieved by having the electrical switchgear connections between the CHP plant, the site and the local area system all closed, with the CHP plant and the local area system operating electrically locked together. This is known as 'parallel mode' operation, and has a number of operational benefits:

- The local area supply system can provide any site power demands that are in excess of the power output of the CHP plant – this is known as 'top-up' power.
- The local area supply system can instantaneously meet the total site demand in the event of the CHP plant shutting down suddenly: this is known as 'backup' or 'standby' power. Backup is normally achieved without any loss of site power supply.
- Power can be passed from the site into the local area supply system if the CHP plant is generating more power than required on site – this is known as 'export' power. This requires special metering facilities to be incorporated in the connection between the site and the local area system (the grid connection). The cost of implementation of grid connection and associated metering, compared with the possibility of resulting revenues from sale of export power, can often make export an uneconomic option.

It is essential to discuss the implications of installing a CHP package for parallel mode operation with the distribution system operator. There is a formal application process that you must follow to begin these discussions and obtain the distribution system operator's approval.

The distribution system operator will need to carry out basic studies to assess the impact of any generation plant connected to its network. It will also usually stipulate any design and operating requirements deemed necessary for safe system operation.

Installation of a CHP package and its operation in parallel mode may involve modifications to the site's electricity grid connection. In a few instances, it may be necessary to increase the capacity of the connection. These requirements will depend on the design and operating characteristics of the local area system and the CHP plant, and their purpose is to protect equipment on either side of the connecting point from the effects of a fault occurring with the CHP system.

The technical requirements should be discussed with the distribution system operator before submitting a formal application to gain a preliminary appreciation of the costs and any issues involved. Once the application has been submitted, the operator will put together a development team that will produce the detailed connection designs and costings of the project. The team will also oversee the construction phase, monitoring the project delivery and advising the applicant on any changes or cost implications. For further information on the application process for obtaining a grid connection in Ireland, please refer to the accompanying Implementation Guide.

For a CHP system to operate in parallel mode, there are important features that must be incorporated in the design of the system and the site electrical system:

- The CHP package must be fitted with synchronising equipment, so that the phasing of electrical power from the generator can be matched with that of the local supply system.
- The site electrical system must be equipped with suitable protection equipment so that the generator is automatically and instantaneously disconnected in the event of any problems with the electrical system. This protection equipment typically monitors conditions such as voltages, currents and the positions of automatic switches and circuit breakers.
- The site electrical equipment, including the CHP package, must not be capable of causing excessively high peak currents in the event of a major system fault, such as accidental damage to cabling or switchgear. If the anticipated peak currents are in excess of the capacity of the switchgear and other equipment in the local area supply system, the CHP plant may need specific design and operating procedures.

### 8.1.2 Island mode

Where a site has sufficient on-site switching facilities within its electrical system, a CHP package can operate in island mode and provide power during an outage in the local area system. This requires the site to have the ability to disconnect from the local area system, and to ensure that the load connected to the CHP package is within its generating capacity. Under these conditions, the CHP package can be operated in island mode to meet some of the site demands.

If the site has specific demands where loss of power for a prolonged period would cause significant loss or disruption, the CHP package should be connected to the appropriate part of the site electrical system so that it can provide the backup power when necessary but this system may lead to a slow response time.

## 8.2 Power metering

### 8.2.1 Meter types and principles of operation

Electricity meters operate by continuously measuring the instantaneous voltage (volts) and current (amperes) to give energy used (in joules or kilowatt-hours).

Meters for smaller services (such as small residential customers) can be connected directly in-line between source and customer. For larger loads, more than about 200 amperes of load, current transformers are used, so that the meter can be located other than in line with the service conductors. The meters fall into two basic categories – electromechanical and electronic.

#### 8.2.1.1 Electromechanical meters

The most common type of electricity meter is the electromechanical watt-hour meter. On a single-phase alternating current (AC) supply, the electromechanical meter registers the number of revolutions of its non-magnetic, but electrically conductive metal disc. The disc rotates at a speed proportional to the power passing through the meter, so the number of revolutions is proportional to the energy used. The voltage coil consumes a small and relatively constant amount of power, typically around two watts, which is not registered on the meter. The current coil similarly consumes a small amount of power in proportion to the square of the current flowing through it, typically up to a couple of watts at full load, which is registered on the meter. Different phase configurations use additional voltage and current coils.

The disc is supported by a spindle which has a worm gear that drives the register. The register is a series of dials that record the amount of energy used. The dials may be of the cyclometer type, an odometer-like display that is easy to read where, for each dial, a single digit is shown through a window in the face of the meter, or of the pointer type where a pointer indicates each digit. With the dial pointer type, adjacent pointers generally rotate in opposite directions due to the gearing mechanism.

**Figure 8.1: Electromechanical power meter**

#### 8.2.1.2 Electronic meters

Electronic meters display the energy used on an LCD or LED display, and some can also transmit readings remotely. In addition to measuring energy used, electronic meters can record other parameters of the load and supply such as instantaneous and maximum rate of use demands, voltages, power factor and reactive power used. They can also support time-of-day billing (recording the amount of energy used during on-peak and off-peak hours).

The meter provides the voltage and current inputs and has a voltage reference, samplers and signal processors followed by an analogue-to-digital converter section to yield the digitised equivalents of all the inputs. These inputs are then processed using a digital signal processor to calculate the various metering parameters.

**Figure 8.2: Electronic power meter**


### 8.2.2 Meter classifications

Power meters should meet the requirements of the Measuring Instruments Directive (2014/32/EU). If compliant, they will carry a CE mark.

### 8.2.3 Installation

Power meters need to be protected. If installed outside, the meter must be housed within a weatherproof cabinet unless it is suitably International Protection rated.

If the meter is recording imported electricity from the grid, the installation must comply with the distribution system operator requirements. The operator will lay out guidelines for the location of the outdoor cabinet, access requirements and some design details of its fixings. Upon installing a new import meter, developers will need to request a Meter Point Reference Number from their energy supplier or distribution system operator and provide this on their completion certificate of the electrical works.[20]

All energy meter displays should be installed at an appropriate location so that readings can be easily taken (e.g. at eye level). Care must be taken when installing a current transformer to ensure their correct orientation. If it is installed in reverse, the energy readings taken will be inaccurate.

In all cases, the energy meter(s) should be installed by a suitably qualified electrician.

### 8.2.4 Maintenance and calibration

Meters should be supplied with calibration certificates for each component as appropriate, ideally valid for a set time period. However, manufacturers do not always state recalibration intervals or expected meter lifetimes, even on their calibration certificates.

Electricity meters on individual power outputs require calibration and accuracy checks to be carried out on a schedule as set out in the relevant legislation in Ireland. This may require calibrations to be carried out at 5, 10 or 15-year intervals depending on the metering system installed. It may well be more economical to simply purchase a new meter, perhaps as an exchange with the manufacturer. Records of all meter calibrations, repairs and changes should be maintained.

20 ESB Networks: National Code of Practice for Customer Interface, 4th edition, March 2008: https://www.esbnetworks.ie/docs/default-source/publications/national-code-of-practice

# 9. Control systems

## 9.1 Fuel monitoring

In many biomass boiler installations, fuel consumption is monitored by visual checks of the amount of fuel remaining in the store. For enclosed stores, one or more sight glasses or windows are usually fitted to avoid the need to open or enter the store. Ultrasonic or laser fuel-level sensing systems provide a remote-monitoring function and can be connected to a building management system. This can alert the operator or fuel supplier when the fuel level has reached the reorder point. For more information, refer to the Technology Guide in the accompanying set of guides on biomass boilers.

## 9.2 Biomass CHP system monitoring

Control systems are usually based on high-integrity programmable logic controllers and include all the metering, control and protection systems required for the safe start-up, operation and normal shutdown of the combined heat and power plant.

All safety interlocks for emergency shutdown are normally hard-wired between the plant items and their own control panels. The individual equipment programmable logic controllers may be linked to a distributed control system or a supervisory control and data acquisition system with data processing units, data storage, and operator and engineer interfaces located in a main control room.

The main components of a CHP installation each have their own dedicated control systems with panels that may be local to the equipment or in a control room. Prime mover controls usually incorporate condition-monitoring equipment, which provides warnings and automatic shutdown in the event of component malfunction, and which also assists in the long-term management and operation of the plant.

The distributed control system may monitor and have full control of the operation of some equipment (for example, the electrical switchgear or the boiler) but more limited control functions for other equipment such as the generating set. A supervisory control and data acquisition system communicates with equipment programmable logic controllers and other control systems, and provides a user interface, data storage and connection to other software such as an optimisation package. Control and monitoring functions, apart from safety interlocks, are transmitted to and from the data processing units through serial links.

There may also be remote access to current and historical operating data, and the annunciation of alarm conditions. This can even permit some control functions to be carried out remotely.

Performance monitoring is a key function of modern process control systems. Monitoring a wide range of parameters can be used for a variety of purposes:

- To detect faults, malfunctions, under-performance, etc. at the earliest possible stage so that they can be rectified promptly.
- To enable fine tuning and optimisation of the equipment.
- To facilitate modifications in response to alterations in site energy loads, new or amended electricity supply tariffs, fuel price/availability fluctuations, etc.
- To audit the return on investment.

Optimisation takes the monitoring and control of a CHP system one step further by seeking to maximise the economic benefits of the installation. Optimisation may be online (using continuously updated real-time data) or offline (using a snapshot of current or historical data, or manual data input). Online optimisation may be open loop, advisory mode only or closed loop where the optimiser is allowed to adjust the operating parameters of the CHP system.

The logic for achieving this optimum is not inherently complex. However, because benefit levels can vary markedly over short periods of time (for example, with changes in site energy demand and heat-to-power ratio), complexity inevitably increases. The price of bought-in electricity is the main yardstick for profitability, and CHP electricity produced during off-peak times is less competitive, as is surplus exported electricity.

### 9.2.1 Boiler monitoring and control

For further information on the monitoring and control of biomass boilers, refer to the Technology Guide in the accompanying set of guides on biomass boilers.

### 9.2.2 Power generation monitoring and control

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

- Plant condition monitoring – to ensure optimum reliability and performance;
- Efficiency of energy conversion and recovery; and
- 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 plant also incorporates heat transfer systems that must be correctly controlled to ensure the safe, long-term operation of the equipment, and to recover heat for beneficial use. Furthermore, a CHP plant may incorporate auxiliary equipment such as supplementary firing and gas compression.

There are four main types of control system considered, which are:

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

# 10. References and other sources of information

A substantial amount of guidance on biomass systems has been published over recent years. Not all of this 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.

## 10.1 General

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

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

## 10.2 Energy efficiency

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

## 10.3 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

## 10.4 Sustainability legislation

Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast)
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

## 10.5 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

## 10.6 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/

## 10.7 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

# Glossary

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| Absorption chiller | Refrigeration plant that uses heat instead of electricity as the driving energy source. Heat can be in the form of hot water or steam. Various working fluids are utilised, such as water, ammonia or lithium bromide. |
| Alternator | A machine whose shaft is driven by an engine or turbine and converts mechanical energy into alternating current (AC) electricity. See also 'Generator'. |
| 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. |
| Auger | An Archimedean (a rod with a helical projection) screw used to transfer material that is in a particle form. |
| Base load | The minimum heat demand from a system that is maintained throughout a defined period. |
| Backup boiler | An alternative boiler used to provide heat when the primary system is out of service. |
| 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. |
| Buffer vessel | A form of thermal storage used to capture residual heat on boiler shutdown to improve system efficiency and to protect the boiler. Must be sized to have sufficient thermal capacity to absorb residual heat on boiler shutdown. Smaller than a thermal store. |
| Bulk density | Measure of the mass of the fuel divided by its volume (e.g. $kg/m^3$). |
| Calorific value – 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 of the fuel. |
| Calorific value – 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 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. |
| Coefficient of performance | For a chiller, the ratio of cooling effect to the total energy input to the system. |
| 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 |

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| | electrical generation or mechanical equipment and a means of recovering heat for useful purposes. |
| Combined cooling heat and power | 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'. |
| Combustion efficiency | The optimum balance of air to fuel in a combustion process. |
| Commissioning | The process of verifying that new heating plant meets the performance specifications as per design and called for in the installation contract. |
| Energy crops | Crops grown specifically for energy production purposes (e.g. miscanthus). |
| Energy density | Measure of the energy contained within a unit/volume of fuel, typically expressed in $MJ/m^3$. |
| Expander | A device that transforms pressure in a working fluid (such as steam) into mechanical energy. |
| Fault level | The maximum current that would flow in case of a short circuit fault at that point on the network. The magnitude of the fault level affects the choice and design of equipment. |
| Feedstock | The raw biomass material subsequently used as a fuel. |
| 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 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 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. |

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| Heat-to-power ratio | The amounts of heat energy and electricity produced by a cogeneration scheme, expressed as a ratio. |
| High temperature hot water | Pressurised hot water at 120°C and above. |
| 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 | 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 | Pressurised hot water at 95°C to 120°C. |
| Moisture content | Percentage, by weight, of biomass fuel that contains water. For example, wood pellets typically have a moisture content of less than 10%. Wood chips and logs are likely to have a more variable moisture content of between 20% and 60%. |
| 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 sulphur (SOx) | Produced by the combustion of sulphur 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 kWth or MWth. Used to size heating systems. |
| 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. |
| Short rotation coppice | Dense growth of small trees or bushes regularly trimmed back for regrowth. Willow or poplar grown as an agricultural crop on a short (two to five years) rotation cutting cycle and at a planting density of 10,000 to 20,000 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. |
| Steam – superheated | Steam at a temperature that is higher than its vaporisation (boiling) point at the absolute pressure. It is steam that is formed at the temperature which exceeds that of saturated steam at the same pressure. |
| Steam – saturated | Saturated steam occurs at temperatures and pressures where steam and water can coexist, which is when the rate of water vaporisation is equal to the rate of condensation |

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| Stratification | Thermal stratification describes the gradient of temperatures seen over the height of a thermal store. Thermal stores are effectively layered, with warmer water stored at the top of the cylinder and colder at the bottom. |
| 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'. |
| 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. |
| Virgin wood | Wood as cut or harvested prior to any treatment. |

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