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A BSRIA Guide

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The Illustrated Guide to Renewable Technologies

By Kevin Pennycook

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INTRODUCTION

Welcome to a new BSRIA illustrated guide to low energy and renewable technologies. The publication is the ideal primer for understanding the wide variety of innovative systems that provide cleaner and less environmentally damaging ways of heating, cooling and powering buildings.

This guide covers the majority of technologies that derive all or some of their power from renewable sources of energy, such as wind and biofuel. However biomass boilers can be used in conjunction with combined heat and power (CHP) and absorption refrigeration. As it's vital that clients and designers understand the relationships between conventional low energy systems and emerging renewable energy systems, the guide covers both types (although, for reasons of brevity, not all low energy systems were able to be included).

Renewable energy describes power obtained from sources that are essentially inexhaustible. This covers energy supplies such as wind power, geothermal power, biomass, and solar power including photovoltaics. Some renewable supplies can also be used to create secondary fuels, such as hydrogen for use in fuel cells.

Whether the motivation comes from tighter energy regulation, higher fuel prices, or greater corporate responsibility, clients and their design teams will be required to consider using such renewable forms of energy to partially or wholly offset the use of fossil fuels and mains electricity.

Some renewable energy sources are able to absorb naturally any carbon dioxide emitted as a consequence of their use or combustion. Biofuels, derived from plant crops, are a good example. The carbon dioxide emitted from burning wood chips or plant oils is absorbed very quickly by new growth. It stands to reason that burning oak is not as sustainable as burning coppiced wood, as the growth cycle is longer and the carbon dioxide emitted will hang around longer in the Earth's atmospheric systems to play its role in increasing the greenhouse effect.

Other systems, such as wind turbines and solar panels, emit no carbon dioxide when generating electricity. However, a considerable amount of carbon dioxide will have been emitted during product manufacture.

The distinction is important for designers who take a whole-life costing approach to construction. Embodied energy should influence both the basis of a building's design and the selection of products – including renewables. Photovoltaics, for example, contain precious materials that require considerable energy to manufacture and transport. Depending on their contribution to the building's energy needs, it might take 20 years or more for the photovoltaics to redeem the energy used in their manufacture. This needs to be considered during the specification stage.

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There is also a mistaken belief that buildings will automatically benefit from improved efficiency and lower carbon-dioxide emissions by being kitted-out with renewables technologies. This is a fallacy. Few technologies are truly fit-and-forget and work in a low energy mode straight out of the box. Renewable technologies, by and large, require greater attention at design, and can be demanding to manage and maintain. So when clients are being asked to invest in renewables technology, they need to know under what conditions the systems will perform, and what levels of diligence and expertise will be required in their facilities management. Fine-tuning of the renewables systems after occupation is also vital to ensure sustainable performance over the long-term.

So while renewable energy systems are certainly desirable compared with conventional fossil-fuel energy sources, the starting point is not a supplier's catalogue of gleaming solar panels or rooftop-mounted wind turbines.

The starting point is to reduce the loads in the building first, and then increase the efficiency of the heating, ventilating, cooling and lighting systems. This can be achieved by investing in passive design, building it properly, and through discerning product specification. The third step is to halve the carbon in the mains fuel supplies, perhaps by taking power from off-site wind turbines or district biomass-CHP. Community energy schemes using large-scale wind power, co or tri-generation and district heating make more environmental and economic sense than lots of separate, smaller renewable systems serving single buildings.

By following this process, designers can cut carbon-dioxide emissions to one-eighth of what they would otherwise be before need arises for specifying renewables technology.

As we head into a changing world where carbon neutrality will soon become a government objective, the mantra is this: keep it simple, do it well, finish things off properly, and only get clever with renewables where they are truly justified. And when you do, use this guide as your design primer.

Roderic Bunn
BSRIA, March 2008

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SUMMARY

Technology	Characteristics	Functionality	Cost effectiveness	Reliability	Maintenance requirement	CO_2 saving	Overall rating
Absorption cooling	Requires no mechanical vapour compression. Activated by external heat source	High. Waste heat from CHP source used to provide cooling source for air conditioning	Medium. More expensive than conventional chillers but uses waste heat	High. Few moving parts	Low	Medium – high	***
Biomass	Uses plant-derived organic material (relatively carbon neutral). Can produce heat or biogas depending on the type of technology	High. Direct combustion systems can replace gas/oil-fired boilers. Requires large fuel storage facility	Medium. More expensive than conventional boilers	High for direct combustion systems. Anaerobic digestion and gasification systems can be problematic	Medium. Direct combustion systems are partially self cleaning	High	*****
CHP	Generates both electricity and heat using fossil or renewable fuels	High. Requires predictable and relatively constant loads for best performance	Medium. Requires full utilisation of waste heat	Medium. Proven technology	Medium. Requires regular planned maintenance	Medium. Can be improved if biomass fuel is used	****
Fuel cells	Electrochemical device that produces electricity and heat on-site	High. Same as CHP	Low. Limited range of commercially available fuel cells, and expensive	Medium. Long-term reliability data not yet available. Expected to be reliable	Medium. Few moving parts. Fuel cell stack has finite life	Medium. Depends on full utilisation of generated heat and fuel source	**
Greywater recovery	Reuses waste water (bathing, washing, laundry) for toilet flushing, irrigation, and other non-potable uses	Medium. Requires match between waste water source and use	Low. Installation and on-going costs may not justify savings	Medium. Pumps, filters, and sensors can present problems	Medium. Requires planned maintenance regime to cover health risks	Low	**
Ground source systems – air	Uses heat from the ground to pre-condition the supply air to a building	High. Can pre-cool air in summer and pre-heat it in winter	Medium. Depends on cost of drilling or excavation to install pipes	High. No moving parts	Low. Providing steps are taken to pre-filter air and avoid water ingress	Medium	***
Ground source systems – water	Makes use of water from aquifers (either directly or indirectly) to provide cooling in summer	High. Can be combined with heat pump technology. Heat source can pre-heat ventilation air	Medium. Depends on cost of boreholes	High. However, open-loop systems are susceptible to blockages and biological fouling	Low for closed-loop systems	Medium	***
Ground source heat pumps	Takes up heat from ground and releases it at higher temperatures. Heat can be used for space heating and domestic hot water	High. Systems can be run in cooling mode	Medium	High. Relatively few moving parts. Proven technology	Low	Medium. High COPs are dependant on relatively low supply temperatures in heating mode	****

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Technology	Characteristics	Functionality	Cost effectiveness	Reliability	Maintenance requirement	CO_2 saving	Overall rating
Photovoltaics	Converts sunlight directly to DC electrical power. Requires inverter to convert to AC	Medium. Requires careful positioning for optimum performance. Wide range of installation options	Low. However, costs are predicted to improve	Medium. Associated inverters can cause problems	Low, but specialist	Low. Relative to high cost	***
Rainwater recovery	Collects and stores rainwater from roofs and other catchment areas for toilet flushing	Medium. Requires a balance between collected water and its use. Large storage tanks may be required	Low. Installation and on-going costs may not justify savings	Medium. Pumps, filters, and sensors can present problems	Medium. Requires inclusion in a planned maintenance regime	Low	**
Solar air heating	Collects solar energy to heat supply air. Can also heat re-circulated air	Medium. Relatively large number of techniques. Can also pre-heat domestic hot water	Medium. Solar collectors can be an integral part of the building fabric	High	Low. System cleaning required, so access can be an issue	Low – medium. Requires fan power, however this could be provided by photovoltaics	***
Solar cooling	Solar thermal energy used to drive absorption, adsorption or desiccant cooling	Medium. Requires matching of solar collector temperature with chiller operating temperature.	Low. Relatively high cost of absorption chillers and solar collectors	High	Low. Absorption chiller is low maintenance	Low – medium	*
Solar water heating	Solar energy used to heat water, usually for domestic hot water purposes	Medium. Proven technology with a range of collectors for different operational requirements	Medium	Medium – high. Circulation pump and valves are relatively reliable	Low	Medium. Circulating pumps can be PV powered	****
Surface water cooling	Uses pumped water from the sea, lakes or rivers to provide a cooling medium	Low. Relatively few buildings close to suitable water sources	Low – medium. Depends on the length of piping required	Medium – high. Filtration required to prevent heat exchanger fouling	Low	Medium. Depends on the pumping power required	***
Water conservation	Range of devices used to limit water consumption	Can be used in a wide range of applications and building types	Medium. Depends on device	Generally reliable, but some devices may be susceptible to hard water	Low – medium. Waterless urinals require regular and correct maintenance	Low	****
Wind	Turbine/ generator converts wind energy to electrical power	Best performance in open, non-urban locations. Can be installed on, or integrated into, a building	Low. Depends greatly on available wind conditions. Actual power output likely to be much less than the rated output	Medium. Turbulent air conditions associated with urban locations may reduce lifespan of components	Medium. Requires regular maintenance. Access may be an issue	Low – medium. Large sized turbines in non-urban or off-shore locations will be more effective	**

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Illustrated Guide to Renewable Technologies

The latest addition to BSRIA's series of illustrated guides is intended to assist technical dialogue between the client and the design team during the briefing process, and help clients to identify and raise technical questions that they feel are relevant to their organisation's specific needs. For constructional professionals, the guide provides a quick reference to sustainable and renewable systems and will complement existing knowledge.

Other guides in the series include *An Illustrated Guide to Electrical Building Services* and *An Illustrated Guide to Mechanical Building Services*. Both guides are complemented by *Handover, O&M Manuals and Project Feedback*, a toolkit for designers and contractors.

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ALPHABETICAL LIST OF SYSTEMS AND EQUIPMENT

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Benefits

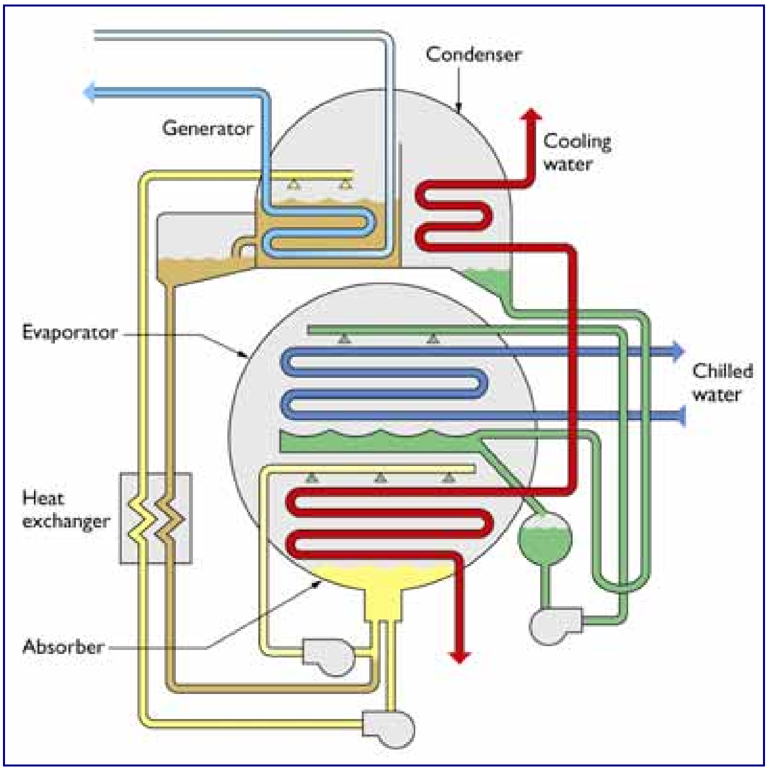
- Can make use of waste heat
- Refrigerants used have no global warming potential
- Quiet and vibration-free
- Reliable
- Relatively low maintenance costs

Limitations

- Low efficiency, and low coefficient of performance compared to conventional chillers
- Relatively high cost compared to vapour compressors
- Larger heat-rejection plant than conventional chillers
- Slower to start up and slower to respond to changing loads

ABSORPTION COOLING

System description



Schematic of absorption chiller.

In a conventional vapour-compression chiller an electric motor is used to drive a compressor. In an absorption chiller a heat source drives the cooling process. Heat sources can include hot water, steam, hot air or hot products of combustion (exhaust gases) from the burning of fuel.

In a conventional mechanical vapour-compression chiller the refrigerant evaporates at a low pressure and produces a cooling effect. A compressor is then used to compress the vapour to a higher pressure where it condenses and releases heat. In an absorption chiller the compressor is replaced by a chemical absorber, generator and a pump. The pump consumes much less electricity than a comparable compressor (approximately nine percent of that for a vapour compression plant). The majority of the energy required to drive the cooling process is provided by the external supply of heat.

Absorption cycles use two fluids: the refrigerant and the absorbent. The most common fluids are water for the refrigerant and lithium bromide for the absorbent. These fluids are separated and re-combined in the absorption cycle. The low-pressure refrigerant vapour is absorbed into the absorbent releasing heat. The liquid refrigerant/absorbent solution is pumped to a generator with high operating pressure. Heat is then added at the high-pressure generator which causes the refrigerant to desorb from the absorbent and vaporise. The vapours flow to a condenser, where heat is rejected and condensed to a high-pressure liquid. The liquid is then throttled through an expansion valve to the lower pressure in the evaporator where it evaporates by absorbing heat. This absorbing of heat is used to provide a useful cooling effect. The remaining liquid absorbent in the generator passes through a valve where its pressure is reduced and is then re-combined with the low-pressure refrigerant vapours returning from the evaporator. The cycle is then repeated.

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Absorption chillers have a number of advantages:

- They are activated by heat
- No mechanical vapour-compression is required
- The refrigerants used do not damage the atmosphere and have no global warming potential (some refrigerants used in vapour compression chillers have very high global-warming potential)
- Require no lubricants
- Quiet and vibration free.

System types

Absorption chillers can be classified based on the type of heat source, the number of effects and the chemicals used in the absorption process. Indirect-fired absorption chillers use waste/rejected heat from another process to drive the absorption process. Typical heat sources include steam, hot water or hot gases. Direct-fired chillers include an integral burner, usually operating on natural gas.

In a single-effect absorption chiller the heat released during the chemical process of absorbing refrigerant vapour into the liquid stream is rejected as waste heat. In a double-effect absorption chiller some of this energy is used to generate high-pressure refrigerant vapour. Using this heat of absorption reduces the demand for heat and boosts the chiller system efficiency.

Double-effect chillers use two generators paired with a single condenser, absorber and evaporator. Although they operate with a greater efficiency they require a higher temperature heat input compared with a single-effect chiller. The minimum heat source temperature for a double-effect chiller is 140°C. Double-effect chillers are more expensive than single-effect chillers. Triple-effect chillers are under development.

Two absorbent-refrigerant mixtures are widely used. These are lithium bromide water mixture and ammonia refrigeration mixture. In a lithium bromide water mixture the lithium bromide (a salt) is the absorbent and the water is the refrigerant. Lithium bromide systems are the most commonly used absorption system, particularly for commercial cooling. In an ammonia system the water is the absorbent and the ammonia is the refrigerant. Ammonia systems are typically used when low temperature cooling or freezing is required.

Lithium bromide water systems are widely available as packaged units with capacities ranging from 100 kW to several thousands of kilowatts. A practical limitation associated with this type of system is that the minimum chilled water temperature that can be produced is approximately 5°C. Ammonia refrigeration systems are available in small (30-100 kW), medium (100-1000 kW) and large (>1000 kW) sizes. Cooling temperatures down to -60°C are possible.

Allied technologies

- CHP
- Industrial processes producing waste heat
- Renewable sources producing heat.

Table 1: Absorption chiller range.

Chiller type	**Heat source**		
	Hot water (80-130°C) or steam (0·2-1·0 bar)	**Steam (3-9 bar)**	**Engine exhaust gases (280-800°C)**
Single-effect			
Refrigerant	Water	-	-
Condenser type	Water cooled	-	-
Co-efficient of performance	0·7	-	-
Double-effect			
Refrigerant	-	Water	Water
Condenser type	-	Water cooled	Water cooled
Co-efficient of performance	-	1·2	1·1

Source: *CIBSE Guide B4*

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Where to use

Absorption cooling can be considered as an alternative to traditional chillers if one of the following factors applies:

- An existing combined heat and power (CHP) unit is present and not all of the waste heat is being used
- A new CHP installation is being considered
- Waste heat is available from a process
- Renewable fuel sources can be used such as landfill gas.

The available heat source will determine the type of absorption chiller that is suitable for a specific application. Typical sources of heat include:

- Gas turbine CHP
- Reciprocating engine CHP
- Waste heat
- Hot water and steam.

With a gas turbine CHP, the exhaust gas from the gas turbine is used to raise steam in a waste heat boiler. The high-pressure steam available is suitable for supplying a double-effect absorption unit. The overall efficiency of the CHP can be enhanced if second stage heat recovery using the exhaust gases is used to heat water for domestic hot water and/or space heating uses.

Reciprocating engine CHP units typically provide hot water at 85-90°C. This can be used for a single-effect absorption chiller, although the performance of the chiller will have to be down-rated (single-effect absorption chillers normally work on a heat source at 102°C and above). Some CHP engines can produce water at higher temperatures, in which case the performance of the absorption chiller will be improved.

Waste heat from other sources such as industrial processes can also be used to drive absorption chillers. Low-pressure steam and water can be used with single-effect absorption chillers while higher pressure steam (7-9 bar) can be used to drive double-effect chillers.

In instances where boilers provide space heating and are required to supply a small load in summer, or where a large ring-main is used to supply a few users, the efficiency of the boiler system can be improved by using the heated water/steam to drive an absorption chiller. In practice, however, it may be more efficient to reconsider the heating strategy and install a number of small local boilers.

Application considerations

The factors that determine whether a heat source is suitable for an absorption cooling application are:

- Temperature of the source heat-stream
- Flow rate of the recovered heat-stream
- Chemical composition of the source heat-stream
- Intermittency of the recovered heat stream temperature and flow.

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The performance of an absorption chiller is dependent on the following:

- A higher chilled water temperature gives a higher coefficient of performance (COP) and cooling capacity
- A lower cooling water temperature gives a higher COP and cooling capacity
- A higher temperature heat source gives a similar COP but increases cooling capacity.

Using a lower heat source temperature, higher condenser water temperature or lower chiller water temperature will reduce the cooling output. This means that a larger, more expensive machine will be required.

The heat rejection from an absorption chiller will be greater than a conventional chiller with the same cooling capacity. This will require larger heat rejection units (such as dry air-coolers or wet cooling towers) for absorption chillers. The associated space and weight constraints on some sites may be an issue.

Absorption chillers are slower to start-up than mechanical vapour compression chillers. They are also slower to respond to changing loads. For large systems a buffer tank may be required to increase the inertia for the chilled water circuit. The frequent starting and stopping of absorption chillers should be avoided.

Absorption chillers have few moving parts and have correspondingly lower maintenance requirements compared to conventional chillers. Maintenance costs can be lower than conventional chillers.

An absorption chiller can be used to meet the base-load cooling demand in a building, while peak cooling loads can be met by a conventional chiller. This approach can be advantageous because conventional chillers usually cost less than the equivalent absorption chiller. Their use is therefore more cost-effective for limited running hours.

Designers should consider the requirements for a standby heat source should the normal heat source (such as a CHP unit) not be available. The requirement for standby capacity will depend on the criticality of the business function associated with the building. Designers should also consider whether it is more appropriate to size the absorption chiller on the available heat source or on the building's cooling demand. The temperature of the heat source will determine whether a single or double-effect chiller is appropriate.

An absorption chiller used in conjunction with a CHP unit will raise the viability and cost effectiveness of the CHP unit. Most CHP installations are sized on the basis of heat demand. This usually means that the building's electrical base load is higher than the CHP's electrical output. By using an absorption chiller the additional heat load allows increased running hours while reducing the electricity demand associated with conventional chillers.

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Glossary

Vapour-compression chiller
A refrigeration device that uses mechanical means (usually driven by an electric motor) to raise the pressure of a refrigerant

Combined heat and power system
A system that simultaneously generates electricity and heat in a single integrated unit. The heat (usually in the form of heated water or steam) can be used for building services-related processes. Also referred to as cogeneration

Dry-air coolers
A device used to reject heat from a refrigeration system. Air is passed over a heat exchanger (condenser)

Wet cooling towers
A heat-rejection device that extracts heat from a refrigeration system to the atmosphere through the cooling of a water stream to a lower temperature. Heat is lost through evaporation of some of the water. Also referred to as an evaporative cooling tower

Evaporator
A part of a refrigeration system in which the refrigerant evaporates and in so doing takes up external heat in its vicinity

Condenser
A part of a refrigeration system, which enables the refrigerant to condense, and in so doing gives up heat

Standards

None identified

References and further reading

An Introduction to Absorption Cooling, Good Practice Guide 256, Energy Efficiency Best practice Programme 2001

Application Guide for Absorption Cooling/Refrigeration using Recovered Heat, ASHRAE 1995, ISBN 1 88341326 5

ASHRAE Handbook – Refrigeration ASHRAE

Refrigeration and Heat Rejection, CIBSE Guide B4

Small-Scale Combined Heat and Power for Buildings, CIBSE AM12, 1999

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Benefits

- Biomass-fuels can be used to produce energy on a continuous basis (unlike renewables such as wind or solar energy)
- Biomass can be an economic alternative to fossil fuels
- Biomass is a potential source of both heat and electricity
- Biomass technology is flexible and scaleable, from a single boiler to a power station

Limitations

- Biomass fuels have a lower energy density compared to fossil fuels
- Biomass systems have particular design management and maintenance requirements associated with sourcing, transportation and storage
- Biomass can be less convenient to operate than mains-supplied fuels such as natural gas
- Biomass systems are more management intensive and require expertise in facilities management
- Sources of biomass can fluctuate, so boilers should be specified to operate on a variety of fuels without risk of overheating or tripping out

BIOMASS

System description

Biomass is any plant-derived organic material that renews itself over a short period. Biomass energy systems are based on either the direct or indirect combustion of fuels derived from those plant sources.

The most common form of biomass is the direct combustion of wood in treated or untreated forms. Other possibilities include the production and subsequent combustion of biogas produced by either gasification or anaerobic digestion of plant materials. Liquid biofuels such as bioethanol can also be used. The use of biomass is becoming increasingly common in some European countries (some countries such as Austria are heavily dependant on biomass). The environmental benefits relate to the significantly lower amounts of energy used in biomass production and processing compared to the energy released when they are burnt. This can range from a four-fold return for biodiesel to an approximate 20-fold energy return for woody biomass.

CHP systems and absorption chillers are discussed elsewhere in this guide.

Biomass system types

Direct combustion

The direct combustion of wood-based fuel sources is likely to be the most practical use of biomass in building applications. Potential fuel sources are wide ranging and include solid wood, wood off-cuts, woodchips, pellets and briquettes. Typical examples of woody biomass include willow short-rotation coppice and miscanthus (perennial grass).

BIOMASS SYSTEMS

Table 2: Typical properties.

Fuel	Energy density by mass	Energy density by mass	Bulk density	Energy density by volume	Energy density by volume
	GJ/tonne	KWh/kg	Kg/m³	MJ/m³	KWh/m³
Wood chips (very dependent on moisture content)	7 – 15	2 – 4	175 – 350	2000 – 3600	600 – 1000
Log wood (stacked – air dry 20% moisture content)	15	4·2	300 – 550	4500 – 8300	1 300 – 2300
Wood (solid oven dry)	18 – 21	5 – 5·8	450 – 800	8100 – 16 800	2300 – 4600
Wood pellets	18	5	600 – 700	10 800 – 12 600	3000 – 3500
Miscanthus (bail)	17	4·7	120 – 160	2000 – 2700	560 – 750

Table 3: An overview of biofuels, the feedstocks and processes used in their production.

Biofuel type	Specific name	Biomass feedstock	Production process
Bioethanol	Conventional bioethanol	Sugar beets, grains	Hydrolysis and fermentation
Vegetable oil	Pure vegetable oil	Oil crops (such as rapeseed, sunflower seeds)	Cold pressing and extraction
Biodiesel	Biodiesel from energy crops Rapeseed methyl ester (RME), fatty acid methyl/ethyl ester (FAME/FAEE)	Oil crops (such as rapeseed, sunflower seeds)	Cold pressing and extraction and transesterfication
Biodiesel	Biodiesel from waste (FAME/FAEE)	Waste, cooking and frying oil	Transesterfication
Biogas	Upgraded biogas	(Wet) biomass	Digestion
Bio-ETBE		Bioethanol	Chemical synthesis

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Biomass heaters range from small, simple wood-burning stoves to large fully automated boilers intended for large commercial/public buildings or community heating schemes. Features of a good large-scale boiler include the following:

- Thermal efficiency greater than 85%
- Emissions at full load less than 250 mg/m^3 CO, 150 mg/m^3 dust and 300 mg/m^3 NOx
- Automatic cleaning of the boiler heat-exchanger and automatic ash removal
- Remote monitoring of the boiler operating parameters.


Courtesy of Kohlbach Holding GmbH

An example of a 3D integrated biomass boiler and fuel delivery system.

Table 4: Large-scale biomass boilers are available in a range of combustion types.

Combustion type	Feed	Fuel	Power
Dual-chamber furnace	Mechanical	Woodchips, bark	35 kW – 3 MW
Underfeed furnace	Mechanical	Woodchips	20 kW – 2 MW
Stocker-fired furnace	Mechanical	Woodchips	From 200 kW
Cyclone furnace	Pneumatic		From 200 kW
Fluidized-bed combustion	Mechanical	Woodchips	From 10 MW

Source: *Planning and Installing Bioenergy Systems*.

A typical biomass boiler, installed in a UK primary school.

The operational characteristics of biomass boilers differ significantly from traditional boilers (such as gas-fired boilers). Start-up times are longer and heat retention within the boiler means that heat is transferred to the heated medium for a considerable period after boiler shutdown. Although most biomass boilers are designed to allow modulation of the boiler output down to typically 30% of the maximum output, they are not best suited to frequent modulation. For efficient, low emission combustion, biomass needs to be burned rapidly and at a high temperature. One approach to achieving optimum performance is to incorporate a buffer tank into the system. A large volume of water is used as a thermal store between the boiler and the load side of the heating system. When the load decreases the temperature of the water in the tank rises and when the load subsequently increases there is a store of hot water to satisfy demand until the boiler output rises.

Another possible approach is to size the biomass boiler to meet the building's base heating load and use a small conventional boiler to meet peak demands. This approach is also appropriate for dealing with seasonal variations in heating demand. However, care needs to be taken with the design and specification of the control system, which will be required to manage two boilers with very different operating characteristics.

A 400 kW district-heating biomass boiler.

Other considerations include types of biomass materials. Biomass boilers are available that are suitable for a wide range of woody fuel sources. Biomass should be selected for its local availability as well as for its combustion characteristics, as the environmental costs of transporting relatively bulky fuel over large distances will reduce the environmental benefits of biomass combustion. Alternative sources of supply are also very important.

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