Technology Collaboration Programme
by iea

INTERNATIONAL ENERGY AGENCY
TECHNOLOGY COLLABORATION PROGRAMME ON
DISTRICT HEATING AND COOLING

IEA DHC ANNEX TS5
INTEGRATION OF RENEWABLE ENERGY SOURCES INTO EXISTING DISTRICT HEATING AND COOLING SYSTEMS

TECHNICAL FACT SHEETS – BIOMASS CHP

REVISION 02

Image Source (Frontpage):

Friis & Moltke Architects, Lisbjerg Biomasse anlæg

Citation:

Please refer to this report as:

Borup L., Komoszynska M., Guddat M.G.A, Sørensen P.A., Technical Fact Sheets. IEA DHC Annex TS5 RES in DHC Report, 2021.

Reviewed by Salzmann M., Ferla G.

CONTENT

1 BIOMASS CHP

This fact sheet summarises the key technical information about the construction and operation principles of large biomass CHP that find an application in the district heat supply. The findings are based on the experience from the Danish projects representing the North Europe market.

1.1 TECHNOLOGY DESCRIPTION

1.1.1 BIOMASS CHP

Energy conversion in CHP (combined heat and power) from biomass consists in the combustion of woodchips from forestry and/or from wood industry. The typical implementation is a combustion in a biomass boiler and then feeding a steam turbine to produce electricity.

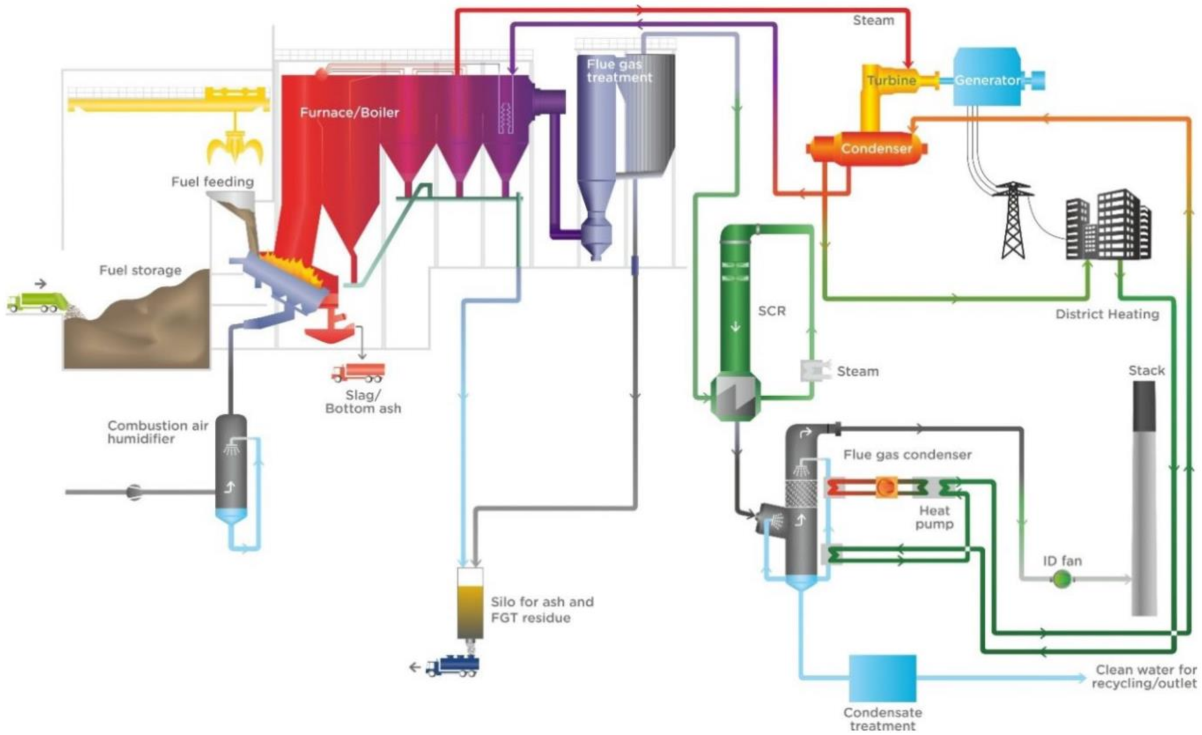

Figure 1: CHP plant (Danish Energy Agency 2020).

The fuel is injected into the furnace. The typical furnace technologies can be divided into:

- grate firing,
- different types of fluidised beds (FB)
- and suspension firing.

Grate combustion is a well-known and robust technology suitable for many types of biomass. There are size limits for grate fired plants, which is up to 200 MW output. Above that suspension firing and FB boilers are more suitable, The boiler is where the energy content of the flue gas is transferred to the heat carrier, which is superheated steam. The energy output from the boiler (high pressure steam) is expanded through a turbine. The turbine can be either a backpressure or an extraction turbine. The backpressure turbine expands into the DH condensers e.g. at 0.4 bar pressure, where the extraction unit expands to the lowest pressure possible e.g. at 0.025 bar pressure, this is provided by water-cooled condensers.

The extraction unit is capable of both running in backpressure and condensing mode as well as a combination of the two, as shown in Figure 2.

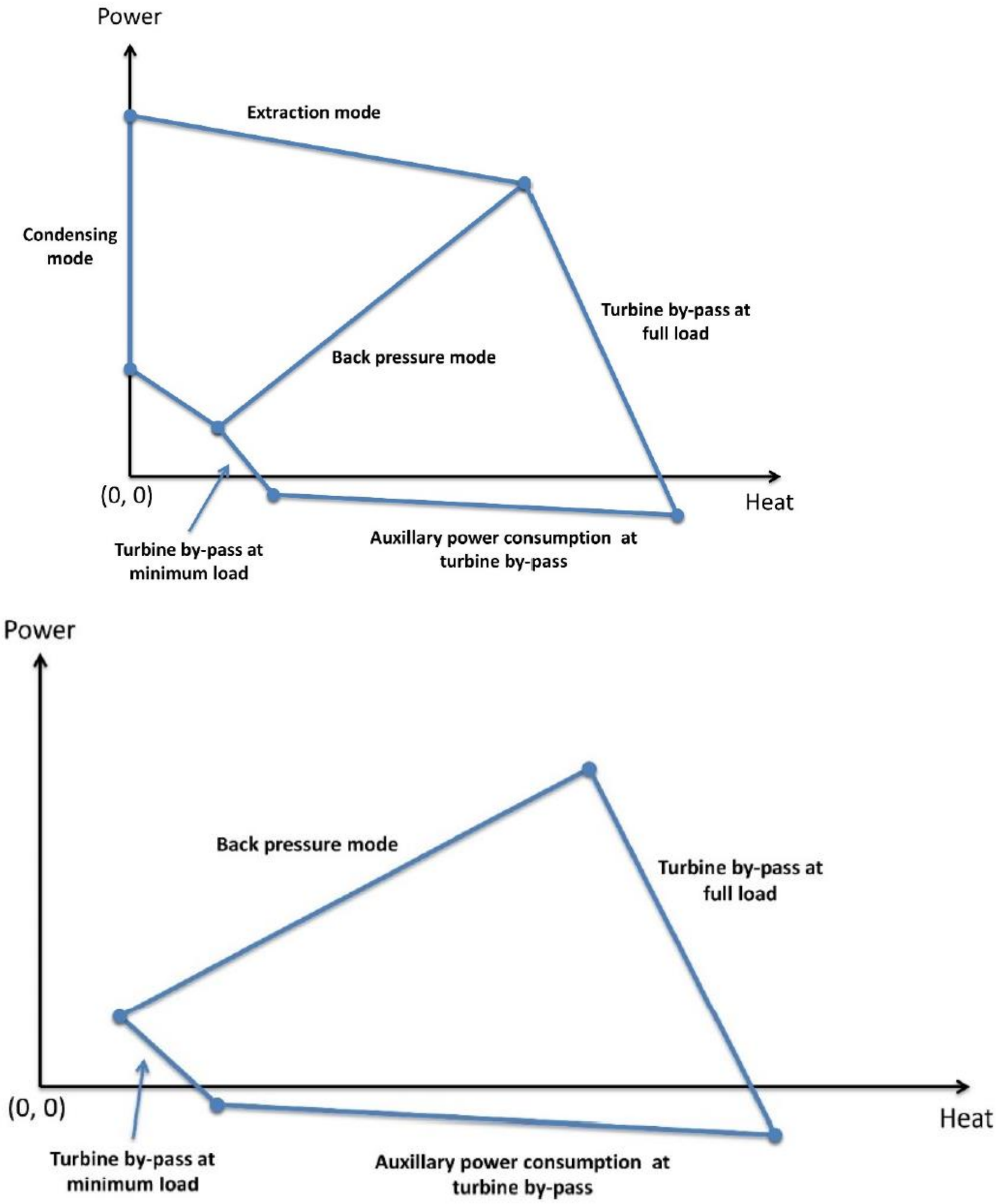

Figure 2 Generic PQ diagrams for back pressure CHP (to the left) and extraction CHP (to the right) (Danish Energy Agency 2020).

1.1.2 EFFICIENCY

The efficiency depends on the heating value (HV) of the biomass. Taken in consideration the lower heating value (LHV) for a biomass configuration including flue gas condensation and access to different district heating temperature total efficiencies can be up to 110 % which is demonstrated in Table 1.

Table 1 Efficiency of biomass HOPs depending on the DH return temperature and moisture content of the biomass input (Danish Energy Agency 2020).

Input	**LLV [MJ/kg]**	**HHV [MJ/kg]**	**DH T_{return} 50 °C**	**DH T_{return} 40 °C**	**DH T_{return} 30 °C**
Wood chips (40 % moisture)	10.3	12.0	102.5 %	107.7 %	110.0 %
Wood pellets (5% moisture)	17.7	19.0	94.3 %	99.0 %	101.9 %
Straw (11 % moisture)	15.0	16.4	95.8 %	100.6 %	103.6 %

A flue gas condensation system can be installed to increase the heat recovery through condensation of the water vapours of the flue gas. This can increase the efficiency by 20% (already included in table 1). The flue gas condensation is relevant when using biomass types with high moisture content e.g., wood chips, and waste.

1.2 TRL

Biomass CHP are generally well-known technologies that have been widely used for electricity and heat production. CHP production from biomass have recently been widely used in Denmark to convert old coal fired plants into biomass CHP plants implementing the green transition.

1.3 CAPEX AND OPEX NOW AND EXPECTED DEVELOPMENT

The investment costs (CAPEX) and maintenance costs (OPEX) for the biomass CHP depends on the type biomass feed-in, capacity and the DH return temperature.

The CAPEX for biomass CHP consist of the following overall parts:

- Steam boiler,
- Steam turbine and generator,
- Furnace,
- Fuel storage and feeding system,
- Flue gas treatment,
- Connection to a power grid (including transformers etc.),

- Connection to existing DH network,
- Buildings,
- Advisors,
- Storage capacity for two days.

The following cost examples are based on plants with approx. 8,200 annual operating hours and an operational lifetime of more than 25 years. The systems are optimised for a DH supply and return temperature of 80°C and 40°C respectively.

NORTHERN EUROPE

Table 2 Investment costs and operation costs per unit capacity of the technology in Northern Europe.

Biomass CHP size and type	CAPEX (M€/MW)	OPEX (€/MWh)
20 MW feed (wood chips, wood pellets, straw)	(6.3, 6.1, 4.5)	(9.3, 3.9, 4.5)
80 MW feed (wood chips, wood pellets, straw)	(3.5, 3.0, 3.6)	(4.5, 1,9, 2.1)
Wood chips 600 MW, wood pellets 800 MW, straw -132 MW)	(3.3, 2.25, 3.4)	(4.4, 1.7, 2.1)

SOUTHERN EUROPE

Table 3 Investment costs and operation costs per unit capacity of the technology in Southern Europe.

Biomass CHP size and type	CAPEX (M€/MW)	OPEX (€/MWh)
Thermal power 4-14 MW and Electric power 0.5 - 1 MW (based on an Italian sample)	1 – 3 (per thermal MW)	7 - 30 (per thermal MWh)

Note: results are affected by the fact that, due to the existing supporting mechanisms, CHP plants operate mainly as electric driven, with different local conditions and costs

NORTH AMERICA

Table 4 Investment costs and operation costs per unit capacity of the technology in North America.

Biomass CHP size and type	CAPEX (M€/MW)	OPEX (€/MWh)
Typical range of biomass CHP installations in Canada (<10MW)	$1,700 to $2,000 CAD/kWth	n/a

	1.26 to 1.48 M€/MW

1.4 REGULATION CAPACITY AND VELOCITY

The regulation ability of biomass CHP decides on how the technology can be operated and on which electricity markets it can participate.

The requirements to join the spot or regulation electricity markets vary from country to country, it is expected that biomass CHP will satisfy most of them and therefore run-on equal conditions in different locations.

The technical limitations for regulation of biomass CHPs are shown in the table below.

Table 5: Regulation ability of the biomass CHP (Danish Energy Agency 2020).

Biomass CHP size and type	**Regulation speed (% per minute)**	**Turndown ratio (Minimum of % of full load)**	**Warm start-up (hours)**	**Cold star-up (hours)**
20 MW feed (wood chips, wood pellets, straw)	10	20	0,25	0,5
80 MW feed (wood chips, wood pellets, straw)	(4,10,4)	(20,15,40)	(2,0,25,2)	8
(Wood chips 600 MW, wood pellets 800 MW, straw -132 MW)	4	(45,15,40)	2	(12,12,8)

1.5 INPUT FUELS AND CAPACITIES

1.5.1 INPUT

Wood chips, wood pellets and straw are considered for biomass plants. Other types of biomasses could also be relevant as energy source e.g., garden waste, saw dust and nut shells. The other types of biomass set different technical requirements for the plant, and this is not addressed in this fact sheet. It is possible to change the type of biomass feed-in, but this should be guaranteed by the supplier of the plant.

Combustion is in general applicable with an average moisture content up to 60 % for wood chips and 25 % for straw.

1.5.2 OUTPUT

The output from the biomass CHP plants are electricity and heat as steam (>110 °C) or warm (<110 °C) water for DH applications.

1.5.3 TYPICAL CAPACITIES

The capacity of biomass CHPs are mainly determined by the heat demands in the DH system.

- Large scale CHP > 100 $MW_{th\ input}$
- Medium scale CHP 25 – 100 $MW_{th\ input}$
- Small scale CHP 1 – 25 $MW_{th\ input}$

1.6 SUSTAINABILITY

Biomass for energy purposes can take many forms such as wood, biodegradable waste, straw etc. Depriving from different sectors e.g., forestry, industry, general waste, and farming. This report focuses on sustainability of biomass from forestry as the large share of the biomass for energy purposes in Denmark is therefrom. Imported biomass has to a high degree substituted coal in the production of heat and electricity in Denmark which means that a high share of biomass is adopted in the Danish energy system. The goal is to reduce the use of imported biomass for energy purposes.

There the Danish government has set sustainability criteria for the use of biomass. These sustainability criteria implement the REDII (Renewable Energy Directive) 2018/2001/EU within the Danish legislation. The sustainability criteria are mandatory for all plants delivering electricity, heating and/or cooling for DH purposes with a capacity of 5 MW or more.

When used for energy purposes, such as DH, biomass must meet a set of sustainability criteria, such as:

- re-establishment of biodiversity and LULUCF (Land-Use, Land-Use Change and Forestry.)
- conservation of the carbon sink on a long and medium term.
- protection of valuable areas and species

The biomass criteria can also be met if the biomass is certified after an optional certification scheme approved by the European Commission.

1.7 SUPPLIERS

The largest biomass CHP manufacturers and suppliers popular in different part of the world are described below.

NORTHERN EUROPE

The direct biomass CHP producers common in the Danish market are

- Aalborg Energie technic
- BWSC
- Dall Energy

There are also ‘turnkey’ type suppliers using the biomass CHP technologies from the earlier listed producers and these include:

- AEA
- Tjæreborg
- Verdo

SOUTHERN EUROPE

Referring in particular to the Italian market, it is possible to list the following main producers and installers:

- Andritz (BFB / CFB combustion and gasification)
- BERTSCHenergy (grate combustion, BFB combustion)
- Agro Forst & Energietechnik (grate combustion)
- Binder Energietechnik (grate combustion)
- Kohlbach (grate combustion)
- Polytechnik (combustion)
- Syncraft engineering (gasification)
- Urbas Energietechnik (combustion and gasification)
- Turboden (ORC), the most adopted solution
- ESPE (pyro-gasification)
- Heliex Power (CHP unit with twin-screw steam expander, few examples)

NORTHERN AMERICA

List of some of the major technology suppliers in Canada is shown in Table 6.

Table 6: List of the major technology suppliers in Canada.

Technology Supplier	Technology type	1 – 10 MW	>10 MW
Andritz	BFB / CFB combustion and gasification		x
B&W	BFB / CFB combustion and gasification		x
Binder	Grate combustion	x	
Combustion Expert	Grate combustion	x	x
Enerkem	CFB gasification	x	
KMW	Grate combustion	x	x
Lin-ka	Grate combustion for straw	x	
Nexterra Systems	Fixed bed Gasification	x	
Outotec	BFB gasification	x	x
Turboden	ORC	x	
Uniconfort	Grate combustion	x	x
Valmet	Grate and BFB / CFB combustion and gasification		x
Veissmann	Grate combustion	x	
Vyncke	Grate combustion	x	x
Wellons	Grate combustion		x
Xylowatt	Modular gasification	x	

1.8 DEMO EXAMPLES

This section present examples for the installed and operative systems with the biomass CHP plants in different environmental conditions collected from experience in different part of the world.

NORTHERN EUROPE

1.8.1 LISBJERG

The municipal-owned energy utility in Arhus has built a new 110 MW straw-fired CHP. The plant is mainly aimed at burning local straw, but due to recent straw shortage it is possible to co-incinerate up to 50 % wood chips. The plant annually processes 237,000 tonnes of straw equivalent and 181,000 tonnes of wood chips as well as garden and park waste. The key parameters of the plant are listed in Table 7.

The plant consists of a straw-fired boiler and furnace, a turbine and a flue gas treatment section. All is placed in a 45 meters tall building of 1,750 m^2. A large storage tank enable to produce both electricity and heat in periods with no/low heat demand, which gives flexibility to operate on electricity markets. Additionally, the plant comprehends a large in- and out- door storage for biomass, an indoor straw storage, and an outdoor wood chips storage. The storage capacity is four days (16,000 m^3 of straw).

The plant is connected to a 150/60 kV transmission network.

The green transition of the plant contributes to meet the Aarhus goal of becoming carbon neutral 2030 with a reduction in CO_2 emission 13,000 tonnes compared to their current supply.

Table 7: Technical specification of the biomass CHP plant in Lisbjerg.

Parameter	Value
Capacity	110 MW
Straw-feed	27.3 ton/h
DH return temp.	42,4 °C
DH supply temp.	100 °C
Efficiency	(heat: 73.4, electricity 29.8, total: 103.2) %

SOUTHERN EUROPE

1.8.2 DH PROMETHEUS (CESANO BOSCONE, MI, IT)

Figure 3: Site Picture.

The case study described is located in Casano Boscone, a peripheral town close to Milan (IT). It was founded in 2009 to find an alternative solution to the traditional natural gas-fueled heating system in a district located near Milan, in a quite densely populated urban area. From 2012 the plant is powered by wood chips (about 22,000 t/year), coming from the same region.

The co-generative BDHS, through a high temperature thermal network approximately 4 km long, provides SH to almost 2000 users while producing electricity, which is directly fed into the national grid.

The management is aimed at maximizing the electricity production through the ORC module to be sold to the national grid. The heat produced in the co-generative module is used to heat up the DHN delivering heat to 5 substations for SH only, while no DHW heating is provided.

The central unit is mainly composed by a 9.6 MW thermal oil woodchips boiler connected to an ORC module providing nominal powers of 1 MW_{el} and 4.2 MW_{th}. The cold side of the ORC's condenser is directly plugged into the primary water circuit and operates between 90 °C and 60 °C in nominal conditions. The generation unit is completed by a 3 MW_{th} auxiliary flat plate HX (oil/water) that recovers heat from the thermal oil leaving the ORC module.

An auxiliary biomass boiler (5 MW) and gas boiler (12 MW) are included into the central plant but during operative conditions along the year they are never used and hence they will not be included in the model. The grid presents a tree-like configuration connecting 5 substations with different nominal installed power to the central unit, for a total trench length around 4 km.

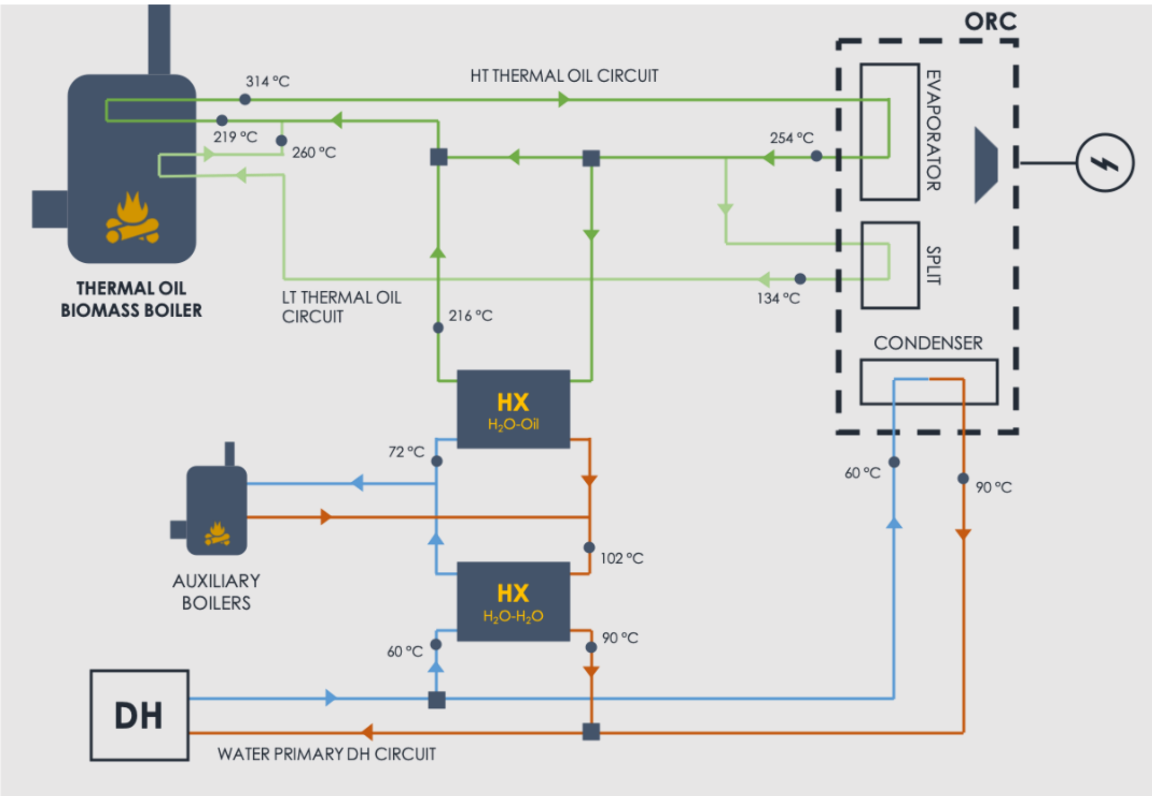

Figure 4 Scheme of the central plant.

Thanks to the transition toward renewable energy (installation of biomass boiler and CHP unit), the DH system just described is able to save about the 60% in terms of fossil primary energy production and about 45% of CO_2 emissions every year compared to the previous operative scenario based on natural gas.'

Table 8: Technical specification of the biomass CHP plant DH prometheus i Cesano Boscone.

Parameter	Value
Heating capacity	13 MW
DHN length	4 km
Nominal supply temp.	90 °C
Nominal return temp.	60 °C
Yearly biomass consumption	21,000 t/a

1.8.3 DORNBIRN (AUSTRIA) (ÖBMV 2019)

Figure 5. Biomass CHP plant in Dorbirn, Hatlerdorf.(Energieautonomie)

Dornbirn is a city in the westernmost Austrian state of Vorarlberg. It has a district heating network that is constantly growing. This case study describes the CHP plant in the location Hatlerdorf, one of several plants supplying the district heating network. It was built in 2014 and is fuelled with forestry residues from the region surrounding Dornbirn.

The plant consists of a 650 kW biomass gasification unit, a so-called floating-fixed-bed gasifier. The product gas is treated in a hot gas filter, where charcoal is being separated. Afterwards the gas is cooled, washed and fed to a gas engine, that produces 180 kW electricity. Heat is extracted in the gas cooler and the gas engine and provides 350 kW thermal power. The key parameters of the plant are collated in Table 9. Besides heat and power, the plant also produces a high-quality charcoal that is used in biogas plants or slurry pits for odour control, as animal feed supplement and as BBQ charcoal. A principal scheme of the plant is presented in Figure 6.’

Table 9: Technical specification of the biomass CHP plant in Dorbirn, Hatlerdorf.

Parameter	Value
Heating capacity	350 kW
Electrical capacity	180 kW
Biomass consumption	7,000 bcm / a
Nominal supply temp.	95 °C
Nominal return temp.	50 °C

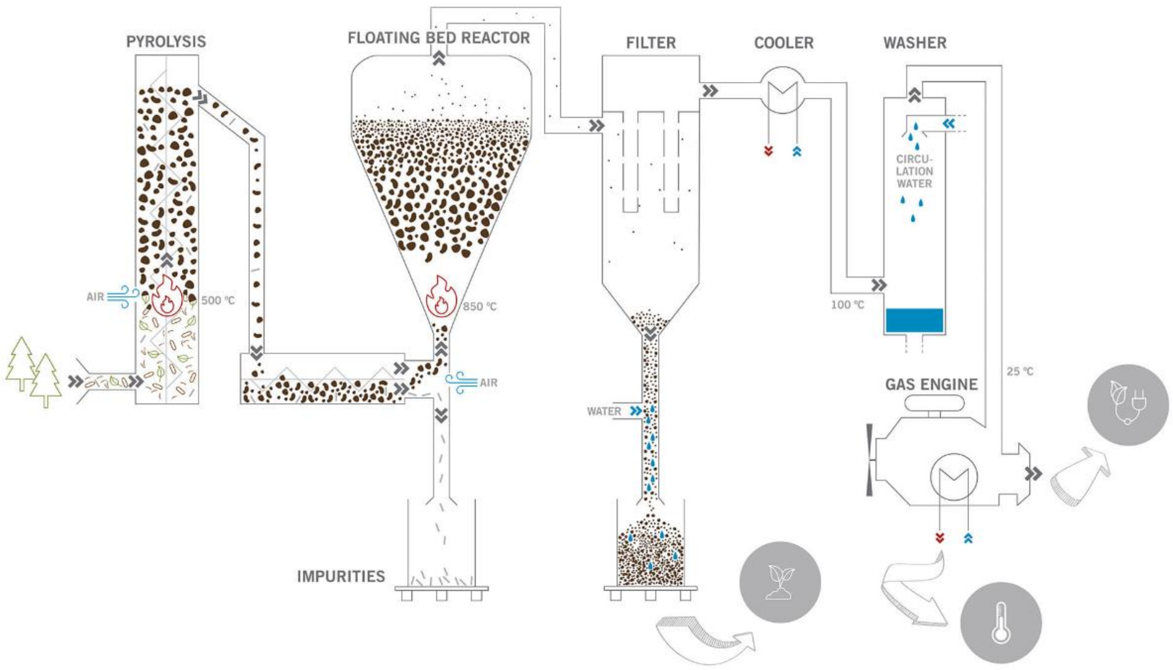

Figure 6. Scheme of the biomass CHP plant (Syncraft)

NORTH AMERICA

1.8.4 CANADIAN CHP CONTEXT

Large-scale CHP installations are not common in Canada, due to a general lack of large heating networks and to the typical operating structure of the various electricity grids, which varies from province to province. Beside some exceptions, most of the provincial electricity markets were established and continue to operate as vertically-integrated, crown corporations, which historically limited the ability for private sector generation access. However, in recent years, most of provinces have separated the generation, transmission, and distribution portions of the electrical system into separate operational entities, enabling greater ability for independent power producers participate in the generation market.

1.8.5 DALHOUSIE UNIVERSITY AGRICULTURAL CAMPUS

Figure 5: Biomass handling system at the Dalhousie University Agricultural Campus (Dal's Biomass Plant).

Many of the existing heating networks in Canada are located on institutional campuses, some of which include small-scale CHP operation. One recent small-scale biomass CHP example is at the Dalhousie University Agricultural Campus located in Truro, Nova Scotia.

The 30 years old biomass boiler and the over 40 years old steam network at the Agricultural Campus (AC) provided heating to more than 95% of main campus buildings (708,894 ft^2, 65,858 m^2) through a district steam/condensate system. In 2014, the University applied for and received approval for the installation of a small-scale biomass co-generation under a Nova Scotia government Community Feed-In Tariff (COMFIT) program, with a contract rate of $175 (CAD) per MWh_e. COMFIT projects in Nova Scotia are required to meet efficiency, air quality standards and biomass fuel specific requirements.

In 2015, the University began a comprehensive renewal project to upgrade the steam distribution system and steam generating thermal plant. The Project was substantially complete in 2018 and complete with commissioning in 2019-2020.

The project helped to:

- address facilities renewal costs of existing end-of-life equipment and systems,
- support university and community sustainability goals,
- Improve air quality systems,
- purchase local biomass supply that meets our comprehensive biomass values standards,
- incorporate some research, teaching and operations synergies, and

- support local economic development through the construction of the project and ongoing supply.

Through the project, the steam distribution network has been replaced with a district hot water network which is 30% more energy efficient. The old woody biomass steam boiler has been replaced with a biomass-fired based thermal oil heater. The thermal oil heat feeds the Organic Rankine Cycle (ORC) which drives a 1 MW turbine generator to produce electricity. This efficient ORC system is the first installation of its kind at a University campus in North America. Process thermal energy is used for heating the campus. A new air emissions management system was added along with two fuel storage bays. High efficiency pumps have been integrated to circulate hot water. Smart meters and controls were installed to monitor and optimize plant performance and support investigation regarding life cycle emissions and new opportunities.

Key Features:

Conversion of the steam/condensate distribution to hot-water. Overall annual thermal savings of over 11,000 MWh_t. This included:

- replacing steam and condensate lines from buildings to the plant with hot water lines (2.6 km),
- upgrading 16 building energy transfer stations from steam to hot water,
- converting specialized steam-based equipment such as sterilizers and humidifiers to propane or electric,
- converting an existing steam boiler to hot water, preserving the remaining life of this asset.

Fuel handling. Two new fuel storage bins have been created. Having two bins offers flexibility to mix different products, including reserve fuel.

New biomass fuel thermal oil heater. A 5.4 MWth biomass heater (Wellons) has been installed. Fuel is drawn into the thermal oil heater from the fuel handling system. The new thermal oil heater enables a more consistent and higher heat burn creating less ash and more efficient use of biomass to make heat.

Organic Rankine Cycle (ORC) System. The 1 MW Turboden 10 CHP system produces over 8,000 MWh annually, roughly 75% of the campus electricity needs. Electricity is exported to the local Nova Scotia Power grid (as per the requirements of any COMFIT agreement).

Electrostatic precipitator (ESP) is specifically designed for cleaning flue gases from wood-fired energy systems. Wellons proprietary ESP has particulate emission guarantee of 35 mg/normal cubic meters @ 8% O2 per COMFIT or below. The treatment time of emissions is 6.7 seconds. The stack height is 44 feet.

Wood Ash Management. In the past, wood ash stayed on the campus farm using campus vehicles to transport the ash in carts during the winter months. With the production of more ash all-year round (estimated at 350 tonnes per year), it is now held in custom designed wood ash bins and transported to a local farm for use as fertilizer.

Fuel supply. The University created a biomass value statement that outlines standards for biomass supply. Biomass supply must meet the conditions of COMFIT regulations (COMFIT Directive 002.pdf (novascotia.ca)). The statement and standards provide direction on topics such as fuel type, trucking distance (distance of fuel 175 km or less), and land uses. Each year, the University submits a COMFIT report that outlines where fuel comes from and calculates contributions to silviculture programs through The Registry of Buyers. Presently, there is a three-year contract with two vendors for the supply of sawmill residue only.

Project Capital Costs: $26.5 million CAD (~19.4 million Euro)

SYMBOLS, ABBREVIATIONS, INDIZES

ABBREVIATIONS

Abbreviation	Meaning
BCM	Bulk Cubic Meter
CHP	Combined Heat and Power
DEA	Danish Energy Agency
DH	District Heating
HHV	Higher Heating Value
LLV	Lower Heating Value

DEFINITIONS

The following table includes terms that are uncommon and require a definition for precise understanding.

Term	Definition
Up regulation	To balance production and demand of electricity in all hours the TSO request some producers to provide up regulation by producing more electricity.
Down regulation	To balance production and demand of electricity in all hours the TSO request some producers to provide up regulation by producing less electricity.
Grate firing	Horizontal moving grate for solid biomass.
Grate firing	Horizontal moving grate for solid biomass
Fluidised bed	The biomass particles are suspended in hot bubbling fluidity bed of particles e.g., ash, sand, and limestone. The particles are via inlets of air blown upwards to provide oxygen for the combustion and gasification.

REFERENCES

NORTHERN EUROPE

Danish Energy Agency 2020	Danish Energy Agency, Energinet. „Technology Data Generation of Electricity and District Heating – Energy Plants for Electricity and District heating generation“. First published 2016, Reviewed 2020. Denmark, 2020.
Aarhus Municipal, 2017	Environmental assessment https://www.aarhus.dk/media/7555/vvm_miljoerapport_biokvlisbjerg.pdf.
Friis & Moltke Architects, 2022)	Downloaded from: https://friis-moltke.dk/arkitektur/off-byggerier/lisbjerg-biomasse-anlaeg/

SOUTHERN EUROPE

Syncraft 2022.	SynCraft Engineering GmbH, https://en.syncraft.at/wood-power-plants/overview, accessed on July 5, 2022
Syncraft	https://en.syncraft.at/wood-power-plants/overview
ÖBMV 2019..	Österreicher Biomasse-Verband, Bioenergie Atlas Österreich, Vienna, 2019
Energieautonomie	source: www.energieautonomie-vorarlberg.at

NORTH AMERICA

Natural Resources Canada (NRCan) 2022	Boulter, Raymond., personal communication with TorchLight Bioresources, 2022.
Dalhousie University 2022	Dalhousie University Agricultural Campus case example information provided by Rochelle Owen, 2022. Additional information: https://www.dal.ca/news/2018/11/21/a--bio-massive-achievement--new-ag-campus-energy-plant-a-north-a.html
Dal's Biomass Plant	https://www.dal.ca/news/2018/11/21/a--bio-massive-achievement--new-ag-campus-energy-plant-a-north-a.html