09 Biomass CHP and HOP plants

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Qualitative description

Brief technology description

Energy conversion in CHP or HOP of biomass is the combustion of wood-chips from forestry and/or from wood industry, wood pellets or straw. The main technical differences between the two are the electricity production, which is produced in a CHP but not a HOP, and the resulting necessary operating temperatures.

CHP production from biomass has been used in an increasing scale for many years in Denmark utilizing different technologies. The typical implementation is combustion in a biomass boiler feeding a steam turbine. The energy output from the boiler is either hot water to be used directly for district heating or it could be (high pressure) steam to be expanded through a turbine.

Application of flue gas condensation for further energy generation is customary at biomass fired boilers, except at small plants below 1 - 2 $MW_{th\ input}$ due to the additional capital and O&M costs. Plants without flue gas condensation should only use fuels with less than 30% moisture content.

Flue gas condensation is available also for straw firing. The flue gas condensation may raise the efficiency with around 15%-points according to model calculations (at 40°C DH return temperature), representing advances in condensation efficiency and return temperature compared with previous indications of 5-10%. Currently in Denmark only a few straw-fired plants are equipped with flue gas condensation.

Straw-fired boilers are normally equipped with a bag filter for flue gas cleaning. Electro filters do not work as efficiently with straw firing as they do with wood firing due to deposits formed by salts in the straw.

Straw fired plants should be equipped with heat accumulation tanks due to their disability to produce at less than 40% of full load, as described under the section "Regulation ability".

<u>ORC plant</u>

An alternative type of plant is the organic rankine cycle plants (ORC plants). In this the (biomass-) boiler is used for heating (no evaporation) thermal oil to slightly above 300°C. This heated oil transfers the heat to an ORC plant which is similar to a steam cycle but it uses a refrigerant instead of water as working media.

The reason for an interest in ORC plants is that such equipment is delivered in standardized complete modules at an attractive price and in combination with ‘a boiler’ that only is used for heating oil, the investment is relatively modest.

The ORC technology is a waste heat recovery technology developed for low temperature and low-pressure power generation. The ORC unit is a factory assembled module – this makes them less flexible but cheap. This may make it financially attractive to build small scale CHP facilities. The ‘Rankine’ part indicates that it is a technology with similarities to water-steam (Rankine) based systems. The main difference being the use of a media i.e. a refrigerant or silicone oil (an organic compound that can burn but does not explode) with thermodynamic properties that makes it more adequate than water for low temperature power generation.

Common technology description for biomass and WtE is found in Introduction to Waste and Biomass plants. Also, flue gas condensation, combustion air humidification, fuels and an improved energy model for technology data is described there.

Input

The fuel input to biomass plants can in general be described as biomass; e.g. residues from wood industries, wood chips (from forestry), straw and energy crops. Combustion can in general be applied for biomass feedstock with average moisture contents up to 60% for wood chips and up to 25% for straw dependent on combustion technology. The three types of biomass feedstock considered here are: Wood chips, wood pellets (white pellets), and straw. They are in several ways very different (humidity, granularity, ash content and composition, grindability, and density).

Sometimes it is possible to change fuel at a plant from one type of biomass to another, but it should be explicitly guaranteed by the supplier of the plant. Below is a broad description of biomass fuels.

Wood (particularly in the form of chips) is usually the most favourable biomass for combustion due to its low content of ash, nitrogen and alkaline metals, however typically with 45 % moisture for chips and below 10% for pellets. Herbaceous biomass like straw, miscanthus and other annual/fast growing crops have higher contents of K, N, Cl, S etc. that lead to higher primary emissions of NO_x and particulates, increased ash generation, corrosion rates and slag deposits.

The amount of biomass available for energy production varies over time. From 2006 to 2014, the Danish straw production varied between 5.2 and 6.3 million tonnes per year (avg. 5.6 mil. t.), while the amount used for energy varied between 1.4 and 2 million tonnes (avg. 1.6 mil. t.).

Other exotic biomasses as empty fruit bunch pellets (EFB) and palm kernel shells (PKS) are available in the market; however, operating experience seems to be limited.

Forest residues are typically delivered as wood chips. Forest residues may also be delivered as pellets. During pellet production the fuel is dried to moisture content below 10%. As of today, the use of forest biomass for energy purposes accounts for only a small percentage of the total forest biomass production for, say, timber, paper, and other industrial purposes; thus typically biomass for energy purposes is (and must be) a residual product. This is also reflected by the fact that the current price per GJ for wood products for energy purposes is much lower than the price for industrial applications of wood. Further to this there seems to be a growing interest for utilizing other types of surplus biomass from industrial productions like Vinery, olive oil production, sugar production, and more.

Wood chips are wood pieces of 5-50 mm in the fibre direction, longer twigs (slivers), and a fine fraction (fines). The quality description is based on three types of wood chips: Fine, coarse, and extra coarse. The names refer to the size distribution only, not to the quality. Fine particles as well as thin, long fibres may cause problems (in case the boiler is using grate firing). In the table below can be seen some typical (commercial) requirements for wood chips.

Typical sizes in a sample:

Name	Withhold on sieve	Share w%
Fines	<3 mm	<12
Small	3 < X < 8 mm	<25
Coarse	8 < X < 16 mm	No requirm
Extra coarse	16 < X < 45 mm	No requirm
Over size	45 < X < 63 mm	< 3
Over long 10	> 63 mm	< 6
Over long 20	100-200 mm long	< 1.5

Table 1 General terms and commercial requirements for wood chips

Ash concentrations must not exceed 2% on dry basis.

Existing DH boilers in Denmark can burn wood-chips with up to 45-63% moisture content, depending on technology. In 2014-2015, the actual moisture content was 40% in average, varying between 25 and 55% [1]. Wood chips with high moisture content will often be mixed with dry wood chips.

Other possible fuels are chipped energy crops (e.g. willow and poplar) and chipped park and garden waste. The fuel quality must be in focus. Small particles must be avoided as well as long thin pieces. High moisture content of e.g. willow will increase the level of CO and PAH, so either the willow must be low in moisture content or it must be mixed with other fuels. Willow is known to take up Cadmium from the soil and thus increasing the concentrations in ash. The amount of cadmium up take is depending on where the willow is grown. Poplar has been found to give problems in the boiler like “popcorn” in a combustion test. Chipped Park and garden waste must be of a good quality with low content of non-combustible materials, because of risks of blocking the grate [1]. Difficult biomass residues are therefore often utilised in WtE facilities having available capacity.

Wood pellets are made from wood chips, sawdust, wood shavings and other residues from sawmills and other wood manufacturers. Pellets are produced in several types and grades as fuels for electric power plants and DH (low grade), and homes (high grade). Pellets are extremely dense (up to the double of the density of the basic material) and can be produced with a low humidity content (below 5% for high grade products) that allows easy handling (incl. long-term storage) and to be burned with high combustion efficiencies. When humidified, pellets are prone to auto-ignition. When exposed to mechanical treatment like conveyer transportation the pellets may break (or disintegrate) and release dust; this dust is highly explosive and therefore constitute a serious hazard.Danish plants using wood pellets or –chips must ensure the sustainability of the fuel. Both the disintegration of wood chips in hammer mills and the subsequent drying require energy and this must come from non-fossil sources (e.g. the wood itself).

Straw is a by-product from the growing of commercial crops, in North Europe primarily cereal grain, rape and other seed-producing crops. Straw is often delivered as big rectangular bales (Heston bales), typically approx. 5-700 kg each, from storages at the farms to the DH plants etc. during the year pursuant to concluded straw delivery contracts.

Output

The products from biomass CHP plants are electricity and heat as steam, hot (> 110°C) or warm (< 110°C) water.

The output from biomass HOP is hot water for district heat or low-pressure steam for industrial purposes. The total energy efficiency is identical for heat and CHP plants, except that some minor heat losses in the generator and turbine gearbox of the CHP plant are avoided. The heat production from a HOP is thus identical (or slightly higher) than the sum of produced electricity and heat from an equivalent CHP plant.

In case of flue gas condensation, excess condensate may be upgraded to high quality water useful for technical purposes such as boiler water or for covering water losses of the district-heating network.

Typical capacities

Large scale CHP:	> 100 $MW_{th\ input}$ (~>25 MW_e)
Medium scale CHP:	25 - 100 $MW_{th\ input}$ (~6-25 MW_e)
Small scale CHP:	1 – 25 $MW_{th\ input}$ (~0.1-6 MW_e)

The size classification for CHP's has been changed from previous editions of the catalogue. The boundary between small and medium-sized plants of 25 $MW_{th\ input}$ is selected based on the suppliers' experience. Large scale CHP may be constructed up to around 1000 $MW_{th\ input}$. and possibly even larger.

The capacities of CHP's supplying heat to district heating systems are primarily determined by the heat demands. Most plants are equipped with a facility to by-pass the turbine temporarily to increase the heat production at the expense of losing the electricity production; the by-pass is in use more often than it was 10-20 years ago.

For biomass HOP's the typical capacitites are 1 - 50 $MW_{th\ input}$. The majority of district heating plants are below 15 $MW_{th\ input}$ with an average size of 5-6 $MW_{th\ input}$ dependent of the fuel [11].

Regulation ability and other power system services

The CHP's can operate in a large range (15% to 100% for once-through suspension fired boilers). Biomass plants with drum type boilers (typical for grate fired boilers) can be operated in the range from 40-100% load. The lower end of the range is defined by the ability to generate super heated steam at the required temperature to operate the turbine and obtain reasonable electricity efficiency. For heat production only, the boiler could go to lower load. The CHP-range is likely to broaden slightly in the future, but the technology appears to have limitations.

Large plants may be designed for optional operation in pure electrical mode (condensing mode) with slightly higher electrical efficiency but without heat production. The condensing ability is mainly seen in large plants over 130 $MW_{th\ input}$ and primarily used today for large Pulverized Fuel (PF) plants.

Typical wood fired HOP's are regulated 25-100% of full capacity, without violating emission standards. The best technologies can be regulated 10-120% with fuel not exceeding 35% moisture content.

Straw fired HOP's should not be operated below approx. 40% of full load due to emission standards. Straw fired plants should accordingly be equipped with a heat accumulating tank allowing for optimal operational conditions.

Advantages/disadvantages

Some biomass resources, in particular straw, contain highly corrosive components such as chlorine which together with potassium forms deposits that are both corrosive and limits heat uptake. In order to avoid or reduce the risk of slagging and corrosion, boiler manufacturers have traditionally abstained from using similar steam pressure/temperatures in biomass-fired plants as in coal-fired plants. However, advances in materials and boiler design have enabled the newest plants to deliver fairly high steam data and power efficiencies. Straw fired boilers can be operated up to 540°C and wood fired boilers up to slightly above 560°C. In most cases the technical limits are somewhat above what is economically feasible. The availability of suited steam turbines might limit the steam temperature for smaller sized plants.

Space requirements

Generally, in the catalogue, all the investigated biomass plants are designed and priced with a very small fuel storage facility. Typically, it is sized to last for two days of full load operation. The size of the storage has for some fuels a major impact on the totally required space (area) and it also can have a serious impact on the total CAPEX; to avoid this influence the store is kept small. In order to calculate CAPEX for a different size of the store, the tables contain an entry called 'Fuel storage specific cost in excess of 2 days (M€/$MW_{th\ input}$/storage day) for biomass fuels.

The area to be used for the buildings containing the process equipment is estimated in various ways. Very little additional area is added, say for administration, canteen, garages, work shop, etc. independent of the size of the plant. Further to this, some additional area to be used for other fuel handling, manoeuvring and weighing of trucks, parking of vehicles, roads and other free area. In total, it is ensured to have a reasonable percentage of area usage.

Despite that the largest plants (wood chips and pellets) are so large that a harbour facility is most appropriate, this is not included neither in space requirements nor in cost in the data tables. Other infrastructure facilities like a rail road for fuel transport are not considered.

Environment

The main ecological footprints from biomass combustion are persistent toxicity, climate change (GHG potential), and acidification. However, the footprints are considered small [1]. It is, however, an area of both major concern and discussion. Further to this is also added a concern on the sustainability of using in particular wood-like biomasses for power production. It is not the intent of this catalogue to initiate such a discussion but merely to mention that biomass fuelled plants can reduce GHG emissions considerably compared to fossil fuel fired plants, but it is still discussed if it resource-wise globally is a viable long term solution.

Modern flue gas cleaning systems will typically include the following processes: $DeNO_x$ - ammonia injection (SNCR) or catalytic (SCR), SO_2 capture by injection of lime or the use of another SO_2 absorbing system, dust abatement by bag house filters.

NO_x emissions may be reduced, by about 60-70%, by selective non-catalytic reduction (SNCR) on wood chips fired boilers and 30-40% on straw fired boilers. NOx emission may be reduced by 80-90% by selective catalyst (SCR). SNCR is a relatively low-cost solution but it is not necessarily applicable for a boiler subject to large load variations and constructed with high cooling rates and super heaters in the area most suitable for ammonia injection. The SCR solution requires installation of a catalyst which can be either a high temperature location near or in the boiler (downstream a particle filter) or it could be a much more expensive tail-end solution requiring re-heat of the flue gas. Removal of particles is preferred to limit poisoning of the catalyst that could quickly reduce its activity.

Due to the cost of the catalyst SCR is used mainly at large facilities. NOx emission limit values are also lower for large facilities, giving further incentive to use SCR. SCR is rarely used in HOP because of their relatively small size, and their ability to reach below the NOx emission limit values without using SCR.

The limit values for NOx emissions are expected to be gradualy tightened over time in the future. The technology in terms of combustion control, boiler design and improvements in the SNCR technology may relieve the need of SCR, but the application of SCR is nonetheless expected to increase in the future.

This is reflected in the datasheets by adding the cost of a tail-end DeNOx to the medium (and larger) plants at a certain point in the future. Application of SCR in the respective scenarios appears from the notes.

Future plants above a certain capacity are required to have monitoring of air emissions of mercury, Hg. Generally, Hg is not a problem in straw fired units since Hg is oxidized by the chlorine in fuel and captured in the bag filter. Wood fired units might have a challenge with Hg if fired with woodchips from certain regions and only cleaning the flue gases with an electrostatic precipitator, ESP.

The EU Industrial Emission Directive (IED) [4], the directive on medium combustion plants [6], the BAT reference note on large combustion plants [5], the Danish guideline (Luftvejledningen), [7], and air dispersion modelling make up the basis for determining the emission limits for a specific plant in Denmark. It is expected that new, lower emission limits will be introduced with the future legislation initiated by the EU.

The emissions in the Data Sheets from 2020 and in the following years are based on proposed limits in the coming Best Available Technologies Air Emission Levels (BAT AELs) introduced by the EU BREF document for Large Combustion Plants [5] that is expected to come into force as of 2020. For small and medium scale plants, similar EU legislation is expected to come into force in the same timeframe, [6]. It is noted that emission limit values (ELV) for biomass plants are linked to the thermal input to the boiler in MW. More stringent requirements are valid for plants above 50 $MW_{th\ input}$ according to the EU IED [4] and air emission levels of the EU reference note on best available technique of large combustion plants, LCP BREF AEL [5].

Biomass units produce four sorts of residues: Flue gas, fly ash, bottom ash and possibly condensate from flue gas condensation.

All bottom ash and most fly ash from straw firing is recycled to farmland as a fertilizer.

Almost all ash from wood firing is deposited in landfills. Research is ongoing on how to meet environmental acceptance limits for recycling the ash to forests.

The condensate water from wood firing is usually treated to remove heavy metals, particularly cadmium, so that its content reaches 3 milligrams per m^3, or the level required for its discharge, which is usually the local municipal sewage system. The treatment may involve pH-adjustment, addition of polymers and flocculants and the use of belt filters for separation of the generated sludge. The treatment residue (sludge) must be deposited in a safe landfill. As described in the Introduction, condensate treatment may include electro deionization (EDI) and reverse osmosis to produce water that is virtually free of salts and pollutants. Hereby, it may be discharged to recipient or used for industrial purposes, such as topping up the water losses of the DH network. The condensate treatment is facilitated if an efficient particle separator is installed in the flue gas path upstream the flue gas condensation stage.

Condensate from straw-firing may be clean enough to be expelled without cleaning, since almost all cadmium is withheld with the fly ash in the bag filter.

Research and development perspectives

Research is ongoing in many areas relevant for bio mass units, e.g.:

Both CHP and HOP:

- Reduce the cost of fuel, by improved collection and pre-treatment, better characterisation and measurement methods.
- Improved combustion process for reduction of CO (that will also affect other unburned components e.g. PAH), NO_x, particles and SO_2

- Further development of secondary techniques for reduction of emissions of particles, aerosols, cadmium, NO_x and SO_2
- Improve boiler design and control of ammonia injection to allow efficient use of SNCR for deNOx as an alternative to tail end SCR.
- Environmentally safe recycling of ashes to forestry; e.g. by pellets to ensure slow release of nutrients, alternatively recovery of potassium for generation of potassium fertilizer
- Cleaning condensate for reuse and discharge to recipient

CHP:

- Improve control ability against fuel variations
- Reduce corrosion, in particular high-temperature corrosion
- Reduce slagging
- Improve steam cycle by introduction of steam reheat (>75 $MW_{th\ input}$)
- Optimise the use of ORC systems i a Danish environment, including collection of operating experiences

HOP:

- Handling and combustion of new types of fuels, such as energy crops and garden/park waste

New technology:

Instead of implementing the combustion process in the boiler vessel, an alternative Danish solution has been developed and demonstrated in three plants until now. The Dall Energy Biomass Furnace combines updraft gasification and gas combustion. Hereby several advantages are achieved: The plant becomes simpler and possibly less expensive, the reactor is fuel flexible, the emissions are reduced and the furnace can regulate between 10-100 % according to the supplier.

The Biomass Furnace delivers hot flue gas to a commercial boiler. This concept is promising and has already drawn attention in the energy sector.

It was originally used for HOP, but one plant under construction (2018) includes ORC that makes the technology usesful as CHP.

Prediction of performance and cost

Both biomass CHPs and HOPs represent today well-known technologies that has been erected in reasonably large numbers. Improvements can still be expected, but only at an incremental level. Therefore, the technology belongs to Category 4: *Commercial technologies, with large deployment*.

Development within this area is driven by possible prospects for being able to earn money and therefore also by the expected future prices on heat and power. Twenty years ago electric power was a valuable product and thus it was beneficial to aim at as high an electrical efficiency that could possibly be achieved. Today, power prices are in periods below prices of heat and this has a big impact on investment decisions; it is no longer certain that the electrical efficiency should be as high as possible. In years to come the difference between the units with highest electricity efficiency commercially available and the electricity efficiency of solutions actually bought will increase.

In the low capacity range (less than 25-30 $MW_{th\ input}$) the scale of economics effect is quite considerable and there is a very significant economical difference between steam (and thereby electricity) producing boilers and hot water (DH only) producing boilers. In particular boilers for the latter type can be series produced and are thus much cheaper than a boiler for producing super-heated steam for power production of similar size.

Wood chips heat only boilers (hot water) up to 20 MW thermal input have become very popular; they are produced in a more or less serial production and this lowers both capital and O&M cost.

Uncertainty

Biomass plants are fully commercial (Category 4) with small uncertainties for performances and costs. The trend of the recent years towards building large plants (>110 $MW_{th\ input}$ for CHPs and >25 $MW_{th\ input}$ for HOPs) including steam reheat (CHP only), absorption heat pumps for enhanced flue gas condensation, humidification of combustion air, more advanced flue gas cleaning etc., introduces a moderate increase of uncertainty. These advanced solutions are expected to be in Category 4 within a few years.

The real cost uncertainty is related to what extent the emission limits will be tightened. Further tightening of emissions requires development of more efficient combustions processes in the boiler and secondary flue gas cleaning systems. This will increase the capital costs and O&M cost.

Examples of market standard available technology

CHPs:

- Fyn Power Plant (DK), Unit 8; commissioned in 2009; 120 $MW_{th\ input}$, 35 MW_e ; 84 MW district heat. 170,000 tonnes of straw per year. Equipped with flue gas condenser. Retrofitted with SCR tail end.
- Sleaford (UK) commissioned 2014, 115 $MW_{th\ input}$ (straw/wood chips), 38.5 MW_e, net electrical efficiency 33%. 240,000 tonnes of straw per year.
- Lisbjerg (DK) commissioned 2016, 110 $MW_{th\ input}$. Energy efficiency 103% at CHP mode. Equipped with tail end SCR, combustion air humidification and flue gas condenser.
- Snetterton (UK), commission year 2017, 130 $MW_{th\ input}$ (straw/wood chips), 44 MWe, net electrical efficiency 34%. 270,000 tonnes of straw per year.
- Avedøre Power Plant (DK) Unit 2 is a multi-fuel CHP power plant that can operate on wood pellets, straw, oil (HFO), and natural gas. It was commissioned in 1999. It has a 100 $MW_{th\ input}$ separate biomass-fired boiler (ultra-super critical steam data – 290 bar, 540°C) supplying steam in parallel with the main boiler; 170,000 tonnes of straw per year. When the plant is running 100% on wood pellets in the main boiler and 100% straw, it is producing 425 MW_e in condensing mode, and 355 MW_e and 485 MW_{th} heat output in back pressure CHP mode.
- In Denmark the plants Studstrup 3 and Avedøre 1 have recently been converted from coal firing into wood pellets firing. In Skærbæk a gas fired unit is converted into firing wood chips by installing 2 new grate fired boilers supplying steam to the existing turbine
- There are a few new large CHP plants expected to be built in the coming years. The currently known projects are Amager 4 and Asnæs 6.
- Sindal, under construction 2018, Dall boiler with ORC, heat output 5 MW_{th}, electricity generation 800 kW_e

HOPs:

- Hobro district heating (DK) commissioned 2017, 11.3 MW_{th} input (wood chips) and 13 MW_{th} output
- Hasle district heating (DK) commissioned 2017, 12 MW_{th} input (wood chips) and 15 MW_{th} output
- Lemvig district heating (DK) commissioned 2016, 8 MW_{th} input (wood chips) and 10.4 MW_{th} output
- Sønderborg district heating (DK) installed a Dall Energy Biomass Furnace (varied biomass) commissioned 2015, 9 MW_{th} input and 9 MW_{th} output.

- Bogense utility company (DK) installed a Dall Energy Biomass Furnace (varied biomass) commissioned 2011, 8 MW_{th} input and 8 MW_{th} output.
- Hvidebæk district heating (DK) commissioned 2017, 7 MW_{th} input (straw) and 7 MW_{th} output
- Ørnhøj Grønbjerg district heating (DK) commissioned 2017, 1.7 4 MW_{th} input (straw) and 1.5 MW_{th} output
- Nexø halmvarmeværk (DK) commissioned 2016, with flue gas condensation and heatpump, 12 MW_{th} input (straw) and 15 MW_{th} output

Additional remarks

Despite the observation that straw is a much more difficult fuel than wood (chips/pellets) the electricity efficiencies of CHP's are almost equal. This reflects the fact that the development of straw-fired CHP's for many years was driven by power utilities focusing on high electricity efficiencies.

The deployment of small and medium-sized biomass fired CHP plants in DK was largely inactive for some years after 2000, but changed conditions for DH is changing the situation. There are several trends in the area of new biomass CHP plants:

1. They are being built in large sizes, mainly because of a better plant economy, but also to accommodate for an increase in the DH market.
2. The electrical efficiency is not in focus due to low electricity prices.

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Data sheets Wood Chips CHP, small

Technology	Small Wood Chips CHP, 20 MW feed									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	2.9	2.9	2.9	2.8	2.8	2.9	2.7	2.9	A	
Electricity efficiency, net (%), name plate	14.3	14.3	14.3	14.0	14	14	14	14	A, H	1
Electricity efficiency, net (%), annual average	13.5	13.5	13.6	13.3	13	14	12	14	A, H	1
Heat efficiency, net (%), name plate	97.3	97.3	97.3	97.6	71	98	69	98	B, H	1
Heat efficiency, net (%), annual average	98.1	98.1	98.0	98.3	72	98	71	99	B, H	1
Additional heat potential with heat pumps (% of thermal input)	2.0	2.0	2.0	2.0	2	28	2	30	C	1
Cb coefficient (40°C/80°C)	0.15	0.15	0.15	0.14	0.14	0.15	0.14	0.15		
Cv coefficient (40°C/80°C)	1	1	1	1	1	1	1	1	I	
Forced outage (%)	3	3	3	3	3	3	3	3		
Planned outage (weeks per year)	3.0	3.0	3.0	3.0	2.6	3.5	2.3	3.8		
Technical lifetime (years)	25	25	25	25	20	35	20	35		1
Construction time (years)	1	1	1	1	0.5	1.5	0.5	1.5		1
Space requirement (1000 m2/MWe)	0.7	0.7	0.7	0.7	0.6	0.8	0.5	0.9		
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	10	10	10	10	10	10	10	10	D	1
Minimum load (% of full load)	20	20	20	20	20	20	20	20	D	1
Warm start-up time (hours)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	G	1
Cold start-up time (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		1
Environment										
SO_2 (degree of desulphuring, %)	98.0	98.0	98.0	98.0	94.9	99.0	98.0	99.0	F	1
NO_X (g per GJ fuel)	90	63	41	32	41	81	20	41	F	1
CH4 (g per GJ fuel)	16	11	8	4	4	16	2	16	F	1
N2O (g per GJ fuel)	1	1	1	1	1	3	0	1	F	1
Particles (g per GJ fuel)	2.0	0.3	0.3	0.3	0.1	2.0	0.1	1.0	F	1
Financial data										
Nominal investment (M€/MWe)	6.7	6.5	6.2	6.0	5.7	7.7	4.7	8.1	E, J, K	1
- of which equipment	4.1	4.0	3.8	3.8	3.5	4.8	2.9	5.2	K	
- of which installation	2.5	2.5	2.3	2.2	2.1	2.9	1.8	3.0	K	
Fixed O&M (€/MWe/year)	292,700	288,900	280,500	277,900	252,000	331,000	215,600	347,000		
Variable O&M (€/MWh_e)	7.8	7.8	7.7	7.9	6.6	8.9	5.9	9.8		
Technology specific data										
Steam reheat	None	None	None	None	None	None	None	None		
Flue gas condensation	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Combustion air humidification	Yes	Yes	Yes	Yes	No	Yes	No	Yes		

Nominal investment (M€/MW fuel input)	0.95	0.93	0.88	0.84	0.81	1.09	0.66	1.14	J, K	1
- of which equipment	0.59	0.58	0.55	0.53	0.50	0.68	0.41	0.72	K	
- of which installation	0.36	0.35	0.33	0.30	0.31	0.41	0.25	0.42	K	
Fixed O&M (€/MW input/year)	41,800	41,200	40,200	39,000	35,300	47,800	29,600	50,100		
Variable O&M (€/MWh input)	1.1	1.1	1.1	1.1	0.9	1.3	0.8	1.4		
Fuel storage specific cost in excess of 2 days (M€/MW_input/storage day)	0.020	0.020	0.019	0.017	0.017	0.023	0.014	0.023	K	

Notes:

A The plant is directly producing hot water for District Heating by burning fuel on a grate. The electric power is produced by an ORC module (Organic Rankine Cycle; Waste Heat Recovery - WHR). Refer for instance to the following link for further information about technology and suppliers: http://www.enova.no/upload_images/36AC689098414B05A7112FA2EE985BDA.pdf . This is low temperature and low efficiency electric power but at an affordable price.

B Boilers up to 20 MW fuel input for hot water production are more or less standardized products with a high degree of fuel flexibility (type of biomass, humidity etc.)

C There are plants of this type with up to 110 % efficiency using flue gas condensation with moist wood chips and close to 120 % efficiency with both flue gas condensation and
absorption heat pumps activated. The colder the return temperature of the district heating, the higher the total efficiencyat direct condensation. Direct condensation and combustion air humidification are included in all cases except in lower range of 2020 and 2050.
Secondary regulation normally relates to power production; for this type of plant it may not be of importance. Though, the load control of the heat production is important and most units will perform better than the figure shown. Also, minimum load could be substantially lower.

E Since electricity generation is only a secondary objective for minor heat producers, it may make more sense to relate the total investment only to the heat production capacity.

F It is to be expected that necessary DeNOx can be accomplished using SNCR, except where anticipated emission levels are below 40 g/GJ

G Warm start is starting with a glowing fuel layer on the grate.

H The total efficiency is the sum of electricity efficiency and heat efficiency, applicable for "name plate" and "annual average", respectively. The "annual average" electricity efficiency is lower than "name plate" due to turbine outages and other incidents. The resulting lost power production is recovered as heat. This is why "annual average" heat efficiency is higher than "name plate" heat. Efficiencies refer to lower heating value. The parasitic electricity consumption has been subtracted in the listed electricity efficiencies.

I Cv=1 describes turbine by-pass operation. During operation the turbine can be by-passed fully or partly for direct district heating production, at operator choice.

J Investment applies to a standard plant. There could be cost related to the actual project or site that adds to the total investment, e.g. additional fuel storage, facilities for chipping of logs, conditions for foundation and harbour facilities. Financial data and Technological specific data are essentially the total cost either divided by the electric net capacity, i.e. corresponding to the indicated name plate efficiencies, or by the thermal input. This is to indicate that new plants may not fully take advantage of the technical capabilities for full electricity production capacity. The two cost for electricity and thermal input, respectively, are not to be added up!

K Note that investments include only two days fuel storage, and more may be optimal, depending on fuel supply opportunities and heat supply obligations, amongst other things.
The additional investment is listed in the bottom row.

References

1 Rambøll Danmark, internal model and evaluation based on either existing projects, supplier offers, or pre-project studies.

Data sheets Wood Chips CHP, medium

Technology	Medium Wood Chips CHP, 80 MW feed									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	23.1	23.1	23.2	22.8	21.8	30.9	22.4	31.8	A	
Electricity efficiency, net (%), name plate	28.9	28.9	29.0	28.5	27	39	28	40	A, H, F	1
Electricity efficiency, net (%), annual average	27.4	27.4	27.5	27.0	25	37	25	38	A, H, F	1
Heat efficiency, net (%), name plate	82.1	82.1	81.9	82.5	46	84	43	83	B, H	1
Heat efficiency, net (%), annual average	83.5	83.5	83.4	83.9	49	86	46	85	B, H	1
Additional heat potential with heat pumps (% of thermal input)	2.0	2.0	2.0	2.0	2	28	2	30	C	1
Cb coefficient (40°C/80°C)	0.35	0.35	0.35	0.35	0.33	0.47	0.34	0.48		
Cv coefficient (40°C/80°C)	1	1	1	1	1	1	1	1	I	
Forced outage (%)	3	3	3	3	3	3	3	3		
Planned outage (weeks per year)	3.0	3.0	3.0	3.0	2.6	3.5	2.3	3.8		
Technical lifetime (years)	25	25	25	25	20	35	20	35		1
Construction time (years)	2.5	2.5	2.5	2.5	2	3	1.5	3		1
Space requirement (1000 m2/MWe)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3		
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	4	4	4	4	4	4	4	4	D	1
Minimum load (% of full load)	20	20	20	20	20	20	20	20		
Warm start-up time (hours)	2	2	2	2	2	2	2	2	E+G	1
Cold start-up time (hours)	8	8	8	8	8	8	8	8		1
Environment										
SO_2 (degree of desulphuring, %)	98.0	98.0	98.0	98.0	94.9	99.0	98.0	99.0	F	1
NO_X (g per GJ fuel)	90	72	41	24	41	81	20	41	F	1
CH4 (g per GJ fuel)	3	2	2	1	1	3	0	3	F	1
N2O (g per GJ fuel)	1	1	1	1	1	3	0	1	F	1
Particles (g per GJ fuel)	2.0	0.3	0.3	0.3	0.1	2.0	0.1	1.0	F	1
Financial data										
Nominal investment (M€/MWe)	3.7	3.6	3.5	3.3	3.1	4.3	2.5	4.5	J, K	1
- of which equipment	2.5	2.4	2.3	2.2	2.0	2.9	1.7	3.0	K	
- of which installation	1.2	1.2	1.1	1.1	1.0	1.4	0.9	1.5	K	
Fixed O&M (€/MWe/year)	158,400	153,600	144,000	132,800	133,400	137,000	101,400	123,000		
Variable O&M (€/MWh_e)	3.8	3.8	3.8	3.9	3.3	4.4	2.9	4.9		
Technology specific data										
Steam reheat	None	None	None	None	None	Yes	None	Yes		
Flue gas condensation	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Combustion air humidification	Yes	Yes	Yes	Yes	No	Yes	No	Yes		

Nominal investment (M€/MW fuel input)	1.08	1.05	1.00	0.94	0.88	1.24	0.72	1.28	J, K	1
- of which equipment	0.72	0.71	0.67	0.64	0.58	0.83	0.47	0.87	K	
- of which installation	0.36	0.35	0.33	0.30	0.30	0.41	0.25	0.41	K	
Fixed O&M (€/MW input/year)	45,800	44,369	41,766	37,793	37,323	51,473	28,349	48,834		
Variable O&M (€/MWh input)	1.1	1.1	1.1	1.1	0.9	1.3	0.8	1.4		
Fuel storage specific cost in excess of 2 days (M€/MW_input/storage day)	0.015	0.015	0.014	0.013	0.013	0.017	0.010	0.017	K	

Notes:

A The boiler in the plant is a grate fired boiler producing steam to be used in a subsequent back pressure steam turbine. Though a grate is reasonable flexible with respect to combusting different fuels the fuel feed system will be dependent on the type of fuel. It is to be expected that it is necessary with a specific DeNOx plant (SNCR might not be sufficient).

B Through a turbine by-pass all the produced steam energy is used for District Heat production.

C Plants of this type may achieve up to 110 % efficiency using flue gas condensation with moist wood chips and 115 % efficiency with both flue gas condensation and absorption heat pumps activated. The colder the return temperature of the district heating, the higher the total efficiency at direct condensation. Direct condensation and combustion air humidification are included in all cases except in lower range of 2020 and 2050.

D Secondary regulation normally relates to power production; for this type of plant it may not be of importance since load will normally follow heat consumption.

E A limiting factor for the hot and cold start-up times is the size of the hot water tank (deaerator).

F It is to be expected that necessary DeNOx can be accomplished using SNCR, except where anticipated emission levels are below 40 g/GJ in which case SCR is used with slight adverse effect on electricity efficiency.

G Warm start is starting with a glowing fuel layer on the grate and a warm deaerator.

H The total efficiency is the sum of electricity efficiency and heat efficiency, applicable for "name plate" and "annual average", respectively. The "annual average" electricity efficiency is lower than "name plate" due to turbine outages and other incidents. The resulting lost power production is recovered as heat. This is why "annual average" heat efficiency is higher than "name plate" heat. Efficiencies refer to lower heating value. The parasitic electricity consumption has been subtracted in the listed electricity efficiencies.

I The Cv value does not exist for plants with a back pressure turbine or an ORC turbine

J Investment applies to a standard plant. There could be cost related to the actual project or site that adds to the total investment, e.g. additional fuel storage, facilities for chipping of logs, conditions for foundation and harbour facilities.
Financial data and Technological specific data are essentially the total cost either divided by the electric net capacity, i.e. corresponding to the indicated name plate efficiencies, or by the thermal input. This is to indicate that new plants may not fully take advantage of the technical capabilities for full electricity production capacity. The two cost for electricity and thermal input, respectively, are not to be added up!

K Note that investments include only two days fuel storage, and more may be optimal, depending on fuel supply opportunities and heat supply obligations, amongst other things.
The additional investment is listed in the bottom row.

References

1 Rambøll Danmark, internal evaluation based on either existing projects, supplier offers, or pre-project studies.

Data sheets Wood Chips CHP, large

Technology	**Large Wood Chips CHP, 600 MW feed**									
	2015	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data					**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	176.5	176.9	177.5	174.4	162.9	235.0	170.9	242.6	A	
Electricity efficiency, net (%), name plate	29.4	29.5	29.6	29.1	27	39	28	40	A, H	1
Electricity efficiency, net (%), annual average	27.9	28.0	28.1	27.6	24	37	26	38	A, H	1
Heat efficiency, net (%), name plate	82.0	82.2	82.0	82.6	45	84	43	83	B, H	1
Heat efficiency, net (%), annual average	83.5	83.6	83.5	84.0	47	86	46	85	B, H	1
Additional heat potential with heat pumps (% of thermal input)	2.0	1.9	1.9	1.9	2	30	2	30	C	1
Cb coefficient (40°C/80°C)	0.36	0.36	0.36	0.35	0.33	0.48	0.34	0.49		
Cv coefficient (40°C/80°C)	1	1	1	1	1	1	1	1		
Forced outage (%)	3	3	3	3	3	3	3	3		
Planned outage (weeks per year)	3.0	3.0	3.0	3.0	2.6	3.5	2.3	3.8		
Technical lifetime (years)	25	25	25	25	20	35	20	35		1
Construction time (years)	5	5	5	5	4.5	5.5	4	5.5		1
Space requirement (1000 m2/MWe)	0.08	0.08	0.08	0.09	0.07	0.10	0.06	0.11		1
Primary regulation (% per 30 seconds)	2	2	2	2	2	2	2	2		
Secondary regulation (% per minute)	4	4	4	4	4	4	4	4	D	1
Minimum load (% of full load)	45	45	45	45	45	45	45	45		
Warm start-up time (hours)	2	2	2	2	2	2	2	2	E+G	1
Cold start-up time (hours)	12	12	12	12	12	12	12	12		1
Environment										
SO_2 (degree of desulphuring, %)	98.0	98.0	98.0	98.0	94.9	99.0	98.0	99.0	F	1
NO_X (g per GJ fuel)	30	24	20	12	12	30	8	20	F	1
CH4 (g per GJ fuel)	3	2	2	1	1	3	0	3	F	1
N2O (g per GJ fuel)	10	8	6	5	5	10	3	10	F	1
Particles (g per GJ fuel)	0.3	0.3	0.3	0.3	0.1	2.0	0.1	1.0	F	1
Financial data										
Nominal investment (M€/MWe)	3.5	3.4	3.2	3.0	2.9	4.1	2.4	4.2	J, K	1
- of which equipment	2.3	2.2	2.1	2.0	1.8	2.7	1.5	2.7	K	
- of which installation	1.2	1.2	1.1	1.0	1.0	1.4	0.9	1.4	K	
Fixed O&M (€/MWe/year)	100,500	97,600	92,300	86,300	86,600	89,600	67,200	81,300		
Variable O&M (€/MWh_e)	3.8	3.8	3.7	3.8	3.2	4.3	2.9	4.8		
Technology specific data										
Steam reheat	None	None	None	None	None	Yes	None	Yes		
Flue gas condensation	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Combustion air humidification	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Nominal investment (M€/MW fuel input)	1.03	1.00	0.95	0.88	0.85	1.20	0.70	1.21	J, K	1
- of which equipment	0.66	0.65	0.62	0.58	0.54	0.78	0.44	0.79	K	

- of which installation	0.36	0.35	0.34	0.30	0.31	0.42	0.25	0.42	K	
Fixed O&M (€/MW input/year)	29,500	28,800	27,300	25,100	24,300	33,900	19,100	32,900		
Variable O&M (€/MWh input)	1.1	1.1	1.1	1.1	0.9	1.3	0.8	1.4		
Fuel storage specific cost in excess of 2 days (M€/MW_input/storage day)	0.010	0.010	0.009	0.008	0.009	0.012	0.007	0.012	K	

Notes:

A The boiler in the plant is a circulating fluid bed boiler (CFB) producing steam to be used in a subsequent back pressure turbine without steam re-heat.

B Through a turbine by-pass all the produced steam energy can be used for District Heat production.

C Plants of this type may achieve up to 110 % efficiency using flue gas condensation with moist wood chips and 115 % efficiency with both flue gas condensation and absorption heat pumps activated. The colder the return temperature of the district heating, the higher the total efficiency at direct condensation. Direct condensation and combustion air humidification are included in all cases except in lower range of 2020 and 2050.

D Secondary regulation normally relates to power production; for this type of plant it may not be of importance since load will normally follow heat consumption.

E A limiting factor for the hot and cold start-up times is the size of the hot water tank (deaerator). Warm start-up time is particularly low for fluid bed types of plants.

F It is to be expected that the NOx level is low from the CFB, and that the necessary DeNOx can be accomplished using SNCR, except where anticipated emission levels are below 20 g/GJ, in which case SCR is used.

G Warm start is starting with a glowing bed and a warm deaerator.

H The total efficiency is the sum of electricity efficiency and heat efficiency, applicable for "name plate" and "annual average", respectively. The "annual average" electricity efficiency is lower than "name plate" due to turbine outages and other incidents. The resulting lost power production is recovered as heat. This is why "annual average" heat efficiency is higher than "name plate" heat. Efficiencies refer to lower heating value. The parasitic electricity consumption has been subtracted in the listed electricity efficiencies.

I Financial data and Technological specific data are essentially the total cost either divided by the electric net capacity or by the net heat capacity, i.e. corresponding to the indicated name plate efficiencies. This is to indicate that new plants may not fully take advantage of the technical capabilities for either full electricity production capacity or heat production capacity. The two cost for electricity and heat, respectively, are not to be added up!

J Investment applies to a standard plant. There could be cost related to the actual project or site that adds to the total investment, e.g. additional fuel storage, facilities for chipping of logs, conditions for foundation and harbour facilities.
Financial data and Technological specific data are essentially the total cost either divided by the electric net capacity, i.e. corresponding to the indicated name plate efficiencies, or by the thermal input. This is to indicate that new plants may not fully take advantage of the technical capabilities for full electricity production capacity. The two cost for electricity and thermal input, respectively, are not to be added up!

K Note that investments include only two days fuel storage, and more may be optimal, depending on fuel supply opportunities and heat supply obligations, amongst other things.
The additional investment is listed in the bottom row.

References

1 Rambøll Danmark, internal evaluation based on either existing projects, supplier offers, or pre-project studies.

Data sheets Wood Pellets CHP, small

Technology	Small Wood Pellets CHP, 20 MW feed									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	3.0	3.0	3.0	3.0	2.9	3.0	2.9	3.0	A	
Electricity efficiency, net (%), name plate	15.1	15.1	14.9	14.9	15	15	15	15	A, H	1
Electricity efficiency, net (%), annual average	14.4	14.4	14.2	14.2	13	14	13	14	A, H	1
Heat efficiency, net (%), name plate	82.2	82.2	82.4	82.4	71	83	72	83	B, H	1
Heat efficiency, net (%), annual average	83.0	83.0	83.1	83.1	73	84	73	84	B, H	1
Additional heat potential with heat pumps (% of thermal input)	1.7	1.7	1.7	1.7	2	12	2	12	C	1
Cb coefficient (40°C/80°C)	0.18	0.18	0.18	0.18	0.18	0.19	0.18	0.18		
Cv coefficient (40°C/80°C)	1	1	1	1	1	1	1	1	I	
Forced outage (%)	3	3	3	3	3	3	3	3		
Planned outage (weeks per year)	3.0	3.0	3.0	3.0	2.6	3.5	2.3	3.8		
Technical lifetime (years)	25	25	25	25	20	35	20	35		1
Construction time (years)	1	1	1	1	0.5	1.5	0.5	1.5		1
Space requirement (1000 m2/MWe)	0.5	0.5	0.5	0.5	0.4	0.6	0.4	0.6		
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	10	10	10	10	10	10	10	10	D	1
Minimum load (% of full load)	20	20	20	20	20	20	20	20	D	1
Warm start-up time (hours)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	G	1
Cold start-up time (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		1
Environment										
SO_2 (degree of desulphuring, %)	98.3	98.3	98.3	98.3	95.6	99.1	98.3	99.1	F	1
NO_X (g per GJ fuel)	90	54	35	28	35	70	18	35	F	1
CH4 (g per GJ fuel)	0	0	0	0	0	0	0	0	F	1
N2O (g per GJ fuel)	1	1	1	1	1	3	0	1	F	1
Particles (g per GJ fuel)	2.0	0.3	0.3	0.3	0.1	2.0	0.1	1.0	F	1
Financial data										
Nominal investment (M€/MWe)	6.3	6.2	6.2	5.6	5.4	7.6	4.7	7.7	E,J,K	1
- of which equipment	4.1	4.0	4.1	3.8	3.5	5.0	3.2	5.1	K	
- of which installation	2.2	2.1	2.1	1.9	1.9	2.5	1.6	2.6	K	
Fixed O&M (€/MWe/year)	280,900	275,900	274,800	257,800	243,500	322,400	204,700	329,400		
Variable O&M (€/MWh_e)	3.4	3.4	3.4	3.4	2.9	3.9	2.6	4.3		
Technology specific data										
Steam reheat	None	None	None	None	None	None	None	None		
Flue gas condensation	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Combustion air humidification	Yes	Yes	Yes	Yes	No	Yes	No	Yes		

Nominal investment (M€/MW fuel input)	0.96	0.93	0.93	0.84	0.81	1.14	0.71	1.15	E,J,K	1
- of which equipment	0.63	0.61	0.62	0.56	0.53	0.76	0.47	0.76	K	
- of which installation	0.33	0.32	0.31	0.28	0.28	0.38	0.23	0.39	K	
Fixed O&M (€/MW input/year)	42,500	41,700	41,100	38,500	35,700	49,100	30,000	49,500		
Variable O&M (€/MWh input)	0.51	0.51	0.51	0.51	0.43	0.59	0.38	0.64		
Fuel storage specific cost in excess of 2 days (M€/MW_input/storage day)	0.004	0.004	0.004	0.003	0.003	0.005	0.003	0.005	K	

Notes:

A The plant is directly producing hot water for District Heating by burning fuel on a grate. The electric power is produced by an ORC module (Organic Rankine Cycle; Waste Heat Recovery - WHR). Refer for instance to the following link for further information about technology and suppliers: http://www.enova.no/upload_images/36AC689098414B05A7112FA2EE985BDA.pdf . This is low temperature and low efficiency electric power but at an affordable price.

B Boilers up to 20 MW fuel input for hot water production are more or less standardized products with a high degree of fuel flexibility (type of biomass, humidity etc.)

C There are plants of this type with up to 110 % efficiency using flue gas condensation with moist wood chips and close to 120 % efficiency with both flue gas condensation and absorption heat pumps activated. The colder the return temperature of the district heating, the higher the total efficiency at direct condensation. Direct condensation and combustion air humidification are included in all cases except in lower range of 2020 and 2050.

D Secondary regulation normally relates to power production; for this type of plant it may not be of importance. Though, the load control of the heat production is important and most units will perform better than the figure shown. Also, minimum load could be substantially lower.

E Since electricity generation is only a secondary objective for minor heat producers, it may make more sense to relate the total investment only to the thermail input.

F It is anticipated that for the smaller units the supplier has a SNCR solutiuon to avoid NOx emissions sufficiently. Little SO2, CH4 and N2O are emitted when combusting wooddy biomass.

G Warm start is starting with a glowing fuel layer on the grate.

H The total efficiency is the sum of electricity efficiency and heat efficiency, applicable for "name plate" and "annual average", respectively. The "annual average" electricity efficiency is lower than "name plate" due to turbine outages and other incidents. The resulting lost power production is recovered as heat. This is why "annual average" heat efficiency is higher than "name plate" heat. Efficiencies refer to lower heating value. The parasitic electricity consumption has been subtracted in the listed electricity efficiencies.

I The Cv value does not exist for plants with a back pressure turbine or an ORC turbine

J Investment applies to a standard plant. There could be cost related to the actual project or site that adds to the total investment, e.g. additional fuel storage, facilities for chipping of logs, conditions for foundation and harbour facilities. Financial data and Technological specific data are essentially the total cost either divided by the electric net capacity, i.e. corresponding to the indicated name plate efficiencies, or by the thermal input. This is to indicate that new plants may not fully take advantage of the technical capabilities for full electricity production capacity. The two cost for electricity and thermal input, respectively, are not to be added up!

K Note that investments include only two days fuel storage, and more may be optimal, depending on fuel supply opportunities and heat supply obligations, amongst other things.
The additional investment is listed in the bottom row.

References

1 Rambøll Danmark, internal evaluation based on either existing projects, supplier offers, or pre-project studies.

Data sheets Wood Pellets CHP, medium

Technology	Medium Wood Pellets CHP, 80 MW feed									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	24.1	24.1	23.9	23.9	23.2	32.5	23.5	32.7	A	
Electricity efficiency, net (%), name plate	30.2	30.2	29.8	29.8	29	41	29	41	A, H, F	1
Electricity efficiency, net (%), annual average	28.6	28.6	28.3	28.3	26	39	26	39	A, H, F	1
Heat efficiency, net (%), name plate	66.5	66.5	66.8	66.8	44	69	44	68	A, H, F	1
Heat efficiency, net (%), annual average	68.0	68.0	68.3	68.3	47	71	47	70	B, H	1
Additional heat potential with heat pumps (% of thermal input)	1.7	1.7	1.7	1.7	2	12	2	12	C	1
Cb coefficient (40°C/80°C)	0.45	0.45	0.45	0.45	0.44	0.61	0.44	0.61		
Cv coefficient (40°C/80°C)	1	1	1	1	1	1	1	1	I	
Forced outage (%)	3	3	3	3	3	3	3	3		
Planned outage (weeks per year)	3.0	3.0	3.0	3.0	2.6	3.5	2.3	3.8		
Technical lifetime (years)	25	25	25	25	20	35	20	35		1
Construction time (years)	1	1	1	1	0.5	1.5	0.5	1.5		1
Space requirement (1000 m2/MWe)	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2		
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	10	10	10	10	10	10	10	10	D	1
Minimum load (% of full load)	15	15	15	15	15	15	15	15		
Warm start-up time (hours)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	E	1
Cold start-up time (hours)	8	8	8	8	8	8	8	8		1
Environment										
SO_2 (degree of desulphuring, %)	98.3	98.3	98.3	98.3	95.6	99.1	98.3	99.1	F	1
NO_X (g per GJ fuel)	78	62	35	21	35	70	18	35	F	1
CH4 (g per GJ fuel)	0	0	0	0	0	0	0	0	F	1
N2O (g per GJ fuel)	1	1	1	1	1	3	0	1	F	1
Particles (g per GJ fuel)	2.0	0.3	0.3	0.3	0.1	2.0	0.1	1.0	F	1
Financial data										
Nominal investment (M€/MWe)	3.2	3.1	3.1	2.8	2.6	3.7	2.2	3.8	J,K	1
- of which equipment	2.0	2.0	2.0	1.8	1.6	2.4	1.4	2.5	K	
- of which installation	1.1	1.1	1.1	1.0	1.0	1.3	0.8	1.3	K	
Fixed O&M (€/MWe/year)	130,800	127,100	123,300	110,800	110,600	110,700	85,800	104,200		
Variable O&M (€/MWh_e)	1.7	1.7	1.7	1.7	1.4	1.9	1.3	2.1		
Technology specific data										
Steam reheat	None	None	None	None	None	Yes	None	Yes		
Flue gas condensation	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Combustion air humidification	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Nominal investment (M€/MW fuel input)	0.95	0.93	0.91	0.83	0.77	1.12	0.66	1.13	J,K	1
- of which equipment	0.61	0.59	0.59	0.54	0.48	0.73	0.42	0.73	K	

- of which installation	0.34	0.33	0.32	0.29	0.29	0.40	0.24	0.40	K	
Fixed O&M (€/MW input/year)	39,500	38,300	36,800	33,100	32,100	45,000	25,200	42,700		
Variable O&M (€/MWh input)	0.51	0.51	0.51	0.51	0.43	0.59	0.38	0.64		
Fuel storage specific cost in excess of 2 days (M€/MW_input/storage day)	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.003	K	

Notes:

A The boiler in the plant is a suspension fired boiler producing steam to be used in a subsequent back pressure steam turbine. It is possible to pulverize wood pellets and use it for suspension firing but it has not been possible to find an appropriate reference.

B Through a turbine by-pass all the produced steam energy is used for District Heat production.

C Since wood pellets are relatively dry there is often only a minor efficiency advantage in using flue gas condensation. There is though an environmental advantage in having a scrubber in the flue gas stream. Direct condensation is assumed in all cases. Combustion air humidification is included except in lower range of 2020 and 2050. Direct condensation and combustion air humidification are included in all cases except in lower range of 2020 and 2050.

D Secondary regulation normally relates to power production; for this type of plant it may not be of importance since load will normally follow heat consumption.

E A limiting factor for the hot and cold start-up times is the size of the hot water tank (deaerator).

F SNCR is assumed at NOx emissions at no less than 40 g/GJ. At lower NOx-levels it is chosen to include a tail-end SCR catalyst with slight adverse effect on electricity efficiency.

G Warm start is starting with a glowing fuel layer on the grate and a warm deaerator.

H The total efficiency is the sum of electricity efficiency and heat efficiency, applicable for "name plate" and "annual average", respectively. The "annual average" electricity efficiency is lower than "name plate" due to turbine outages and other incidents. The resulting lost power production is recovered as heat. This is why "annual average" heat efficiency is higher than "name plate" heat. Efficiencies refer to lower heating value. The parasitic electricity consumption has been subtracted in the listed electricity efficiencies.

I The Cv value does not exist for plants with a back pressure turbine or an ORC turbine

J Investment applies to a standard plant. There could be cost related to the actual project or site that adds to the total investment, e.g. additional fuel storage, facilities for chipping of logs, conditions for foundation and harbour facilities.
Financial data and Technological specific data are essentially the total cost either divided by the electric net capacity, i.e. corresponding to the indicated name plate efficiencies, or by the thermal input. This is to indicate that new plants may not fully take advantage of the technical capabilities for full electricity production capacity. The two cost for electricity and thermal input, respectively, are not to be added up!

K Note that investments include only two days fuel storage, and more may be optimal, depending on fuel supply opportunities and heat supply obligations, amongst other things.
The additional investment is listed in the bottom row.

References

1 Rambøll Danmark, internal evaluation based on either existing projects, supplier offers, or pre-project studies.

Data sheets Wood Pellets CHP, large

Technology	Large Wood Pellets CHP, 800 MW feed									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	260.6	261.2	261.9	261.9	258.5	338.5	258.5	338.5	A	
Electricity efficiency, net (%), name plate	32.6	32.6	32.7	32.7	32	42	32	42	A, H	1
Electricity efficiency, net (%), annual average	30.9	31.0	31.1	31.1	29	40	29	40	A, H	1
Heat efficiency, net (%), name plate	63.8	63.9	63.8	63.8	43	64	43	64	B, H	1
Heat efficiency, net (%), annual average	65.4	65.5	65.4	65.4	47	66	47	66	B, H	1
Additional heat potential with heat pumps (% of thermal input)	1.7	1.7	1.7	1.7	2	12	2	12	C	1
Cb coefficient (40°C/80°C)	0.51	0.51	0.51	0.51	0.51	0.66	0.51	0.66		
Cv coefficient (40°C/80°C)	1	1	1	1	1	1	1	1	I	
Forced outage (%)	3	3	3	3	3	3	3	3		
Planned outage (weeks per year)	3.0	3.0	3.0	3.0	2.6	3.5	2.3	3.8		
Technical lifetime (years)	25	25	25	25	20	35	20	35		1
Construction time (years)	1	1	1	1	0.5	1.5	0.5	1.5		1
Space requirement (1000 m2/MWe)	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1		
Primary regulation (% per 30 seconds)	2	2	2	2	2	2	2	2		
Secondary regulation (% per minute)	4	4	4	4	4	4	4	4	D	1
Minimum load (% of full load)	15	15	15	15	15	15	15	15		1
Warm start-up time (hours)	2	2	2	2	2	2	2	2	G	1
Cold start-up time (hours)	12	12	12	12	12	12	12	12	E	1
Environment										
SO_2 (degree of desulphuring, %)	98.3	98.3	98.3	98.3	95.6	99.1	98.3	99.1		1
NO_X (g per GJ fuel)	20	21	18	11	11	26	7	18	C+F	
CH4 (g per GJ fuel)	0	0	0	0	0	0	0	0		
N2O (g per GJ fuel)	1	1	1	1	1	3	0	1		
Particles (g per GJ fuel)	0.3	0.3	0.3	0.3	0.1	2.0	0.1	1.0		
Financial data										
Nominal investment (M€/MWe)	2.4	2.3	2.2	2.0	2.0	2.7	1.6	2.7	J,K	1
- of which equipment	1.3	1.3	1.2	1.1	1.1	1.5	0.9	1.5	K	
- of which installation	1.0	1.0	1.0	0.9	0.9	1.2	0.7	1.2	K	
Fixed O&M (€/MWe/year)	65,700	64,000	61,000	55,900	54,500	57,300	43,800	56,400		
Variable O&M (€/MWh_e)	1.6	1.6	1.6	1.6	1.3	1.8	1.2	1.9		
Technology specific data										
Steam reheat	None	None	None	None	None	Yes	None	Yes		
Flue gas condensation	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Combustion air humidification	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Nominal investment (M€/MW fuel input)	0.77	0.75	0.72	0.65	0.64	0.89	0.53	0.89	J,K	1
- of which equipment	0.43	0.42	0.40	0.36	0.35	0.49	0.29	0.50	K	
- of which installation	0.34	0.33	0.32	0.29	0.29	0.39	0.24	0.40	K	

Fixed O&M (€/MW input/year)	21,400	20,900	20,000	18,300	17,600	24,300	14,100	23,900		
Variable O&M (€/MWh input)	0.51	0.51	0.51	0.51	0.43	0.59	0.38	0.64		
Fuel storage specific cost in excess of 2 days (M€/MW_input/storage day)	0.003	0.002	0.002	0.002	0.002	0.003	0.002	0.003	K	

Notes:

A The boiler in the plant is a suspension fired boiler producing steam to be used in a subsequent steam turbine. Currently, the steam turbine is expected to be a back pressure turbine with no re-heat. In some of the future scenarios it is assumed that the prices on electricity will allow for an increased electrical efficiency and subsequently re-heating of steam is introduced.

B Through a turbine by-pass all the produced steam energy can be used for District Heat production.

C Since wood pellets are relatively dry there is often only a minor efficiency advantage in using flue gas condensation. There is though an environmental advantage in having a scrubber in the flue gas stream. Direct condensation and combustion air humidification are included in all cases except in lower range of 2020 and 2050.

D This is given by grid code (Energinet.dk)

E A limiting factor for the hot and cold start-up times is the size of the hot water tank (deaerator).

F This plant is equiped with an SCR catalyst for DeNOx and an electrostatic precipitator for catching dust/fly ash

G Warm start is starting with the steam system being pressurized.

H The total efficiency is the sum of electricity efficiency and heat efficiency, applicable for "name plate" and "annual average", respectively. The "annual average" electricity efficiency is lower than "name plate" due to turbine outages and other incidents. The resulting lost power production is recovered as heat. This is why "annual average" heat efficiency is higher than "name plate" heat. Efficiencies refer to lower heating value. The parasitic electricity consumption has been subtracted in the listed electricity efficiencies.

I The Cv value may vary according to the optimization of the plant. A modest value representing a choice with current power/heat prices is shown but an approximate BAT value is given as 'UPPER'

J Investment applies to a standard plant. There could be cost related to the actual project or site that adds to the total investment, e.g. additional fuel storage, facilities for chipping of logs, conditions for foundation and harbour facilities.
Financial data and Technological specific data are essentially the total cost either divided by the electric net capacity, i.e. corresponding to the indicated name plate efficiencies, or by the thermal input. This is to indicate that new plants may not fully take advantage of the technical capabilities for full electricity production capacity. The two cost for electricity and thermal input, respectively, are not to be added up!

K Note that investments include only two days fuel storage, and more may be optimal, depending on fuel supply opportunities and heat supply obligations, amongst other things.
The additional investment is listed in the bottom row.

References

1 Rambøll Danmark, internal evaluation based on either existing projects, supplier offers, or pre-project studies.

Data sheets Straw CHP, small

Technology	Small Straw CHP, 20 MW feed									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	3.0	3.0	3.0	3.0	3.0	3.0	2.9	3.0	A	
Electricity efficiency, net (%), name plate	15.0	15.0	15.0	14.8	15	15	15	15	A, H	1
Electricity efficiency, net (%), annual average	14.2	14.2	14.3	14.1	13	14	13	14	A, H	1
Heat efficiency, net (%), name plate	84.2	84.2	84.2	84.4	72	85	71	85	B, H	1
Heat efficiency, net (%), annual average	85.0	85.0	84.9	85.1	74	85	73	86	B, H	1
Additional heat potential with heat pumps (% of thermal input)	1.7	1.7	1.7	1.7	2	13	2	14	C	1
Cb coefficient (40°C/80°C)	0.18	0.18	0.18	0.18	0.18	0.18	0.17	0.18		
Cv coefficient (40°C/80°C)	1	1	1	1	1	1	1	1	I	
Forced outage (%)	4	4	4	4	4	4	4	4		
Planned outage (weeks per year)	4.0	4.0	4.0	4.0	3.4	4.6	3.0	5.0		
Technical lifetime (years)	25	25	25	25	20	35	20	35		1
Construction time (years)	1	1	1	1	0.5	1.5	0.5	1.5		1
Space requirement (1000 m2/MWe)	1.0	1.0	1.0	1.0	0.9	1.2	0.8	1.3		
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	10	10	10	10	10	10	10	10	D	1
Minimum load (% of full load)	50	50	50	50	50	50	50	50	D	1
Warm start-up time (hours)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	G	1
Cold start-up time (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		1
Environment										
SO_2 (degree of desulphuring, %)	95.5	96.4	99.1	99.8	90.9	99.8	95.5	99.9	F	1
NO_X (g per GJ fuel)	90	72	55	44	55	90	44	55	F	1
CH4 (g per GJ fuel)	16	11	8	4	4	16	2	16	F	1
N2O (g per GJ fuel)	1	1	1	1	1	3	0	1	F	1
Particles (g per GJ fuel)	2.0	0.3	0.3	0.3	0.1	2.0	0.1	1.0	F	1
Financial data										
Nominal investment (M€/MWe)	7.0	6.8	6.4	6.2	5.9	8.0	5.2	8.4	E,J,K	1
- of which equipment	3.9	3.8	3.6	3.6	3.3	4.5	3.0	4.9	K	
- of which installation	3.0	3.0	2.8	2.6	2.6	3.5	2.1	3.6	K	
Fixed O&M (€/MWe/year)	323,800	318,200	306,800	298,000	276,300	365,100	235,200	378,700	J	
Variable O&M (€/MWh_e)	4.0	4.0	4.0	4.0	3.4	4.6	3.0	5.1	J	
Technology specific data										
Steam reheat	None	None	None	None	None	None	None	None		
Flue gas condensation	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Combustion air humidification	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Nominal investment (M€/MW fuel input)	1.05	1.02	0.97	0.92	0.89	1.20	0.77	1.25	E,J,K	1

- of which equipment	0.59	0.58	0.55	0.53	0.50	0.68	0.45	0.72	K	
- of which installation	0.46	0.44	0.42	0.38	0.39	0.52	0.32	0.53	K	
Fixed O&M (€/MW input/year)	48,600	47,700	46,100	44,100	40,800	55,300	34,200	56,500	J	
Variable O&M (€/MWh input)	0.60	0.60	0.60	0.60	0.51	0.69	0.45	0.75	J	
Fuel storage specific cost in excess of 2 days (M€/MW_input/storage day)	0.080	0.078	0.074	0.067	0.068	0.092	0.056	0.093	K	

Notes:

A The plant is directly producing hot water for District Heating by burning fuel on a grate. The electric power is produced by an ORC module (Organic Rankine Cycle; Waste Heat Recovery - WHR). Refer for instance to the following link for further information about technology and suppliers: http://www.enova.no/upload_images/36AC689098414B05A7112FA2EE985BDA.pdf . This is low temperature and low efficiency electric power but at an affordable price.

B Boilers up to 20 MW fuel input for hot water production are more or less standardized products with a high degree of fuel flexibility (type of biomass, humidity etc.)

C Since straw is relatively dry there is often only a minor efficiency advantage in using flue gas condensation. There is though an environmental advantage in having a scrubber in the flue gas stream. Direct condensation and combustion air humidification are included in all cases except in lower range of 2020 and 2050.

D Secondary regulation normally relates to power production; for this type of plant it may not be of importance. Though, the load control of the heat production is important and most units will perform better than the figure shown. Also, minimum load could be substantially lower.

E Since electricity generation is only a secondary objective for minor heat producers, it may make more sense to relate the total investment only to the heat production capacity.

F It is anticipated that for the smaller units the supplier has a SNCR solutiuon to limit NOx emissions. SO2, CH4 and N2O emissions are low when combusting biomass.

G Warm start is starting with a glowing fuel layer on the grate.

H The total efficiency is the sum of electricity efficiency and heat efficiency, applicable for "name plate" and "annual average", respectively. The "annual average" electricity efficiency is lower than "name plate" due to turbine outages and other incidents. The resulting lost power production is recovered as heat. This is why "annual average" heat efficiency is higher than "name plate" heat. Efficiencies refer to lower heating value. The parasitic electricity consumption has been subtracted in the listed electricity efficiencies.

I The Cv value does not exist for plants with a back pressure turbine or an ORC turbine

J Investment applies to a standard plant. There could be cost related to the actual project or site that adds to the total investment, e.g. additional fuel storage, facilities for chipping of logs, conditions for foundation and harbour facilities. Financial data and Technological specific data are essentially the total cost either divided by the electric net capacity, i.e. corresponding to the indicated name plate efficiencies, or by the thermal input. This is to indicate that new plants may not fully take advantage of the technical capabilities for full electricity production capacity. The two cost for electricity and thermal input, respectively, are not to be added up!

K Note that investments include only two days fuel storage, and more may be optimal, depending on fuel supply opportunities and heat supply obligations, amongst other things.
The additional investment is listed in the bottom row.

References

1 Rambøll Danmark, internal evaluation based on either existing projects, supplier offers, or pre-project studies.
NOTICE: There are to our knowledge no references on ORC plants running on straw.

Data sheets Straw CHP, medium

Technology	Medium Straw CHP, 80 MW feed									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	24.8	24.4	24.5	24.5	23.5	25.1	24.1	25.2	A	
Electricity efficiency, net (%), name plate	31.0	30.5	30.6	30.6	29	31	30	32	A, H	1
Electricity efficiency, net (%), annual average	29.4	29.0	29.1	29.1	26	30	27	30	A, H	1
Heat efficiency, net (%), name plate	67.3	67.7	67.6	67.6	54	69	54	68	B, H	1
Heat efficiency, net (%), annual average	68.8	69.3	69.2	69.2	57	71	57	70	B, H	1
Additional heat potential with heat pumps (% of thermal input)	1.7	1.7	1.7	1.7	2	14	2	14	C	1
Cb coefficient (40°C/80°C)	0.46	0.45	0.45	0.45	0.43	0.46	0.45	0.47		
Cv coefficient (40°C/80°C)	1	1	1	1	1	1	1	1	I	
Forced outage (%)	4	4	4	4	4	4	4	4		
Planned outage (weeks per year)	4.0	4.0	4.0	4.0	3.4	4.6	3.0	5.0		
Technical lifetime (years)	25	25	25	25	20	35	20	35		1
Construction time (years)	2.5	2.5	2.5	2.5	2	3	1.5	3		1
Space requirement (1000 m2/MWe)	0.3	0.3	0.3	0.3	0.2	0.3	0.2	0.4		
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	4	4	4	4	4	4	4	4	D	1
Minimum load (% of full load)	40	40	40	40	40	40	40	40		
Warm start-up time (hours)	2	2	2	2	2	2	2	2	E	1
Cold start-up time (hours)	8	8	8	8	8	8	8	8		1
Environment										
SO_2 (degree of desulphuring, %)	95.5	96.4	99.1	99.8	90.9	99.8	95.5	99.9	F	1
NO_X (g per GJ fuel)	87	70	47	29	18	87	7	47	F	1
CH4 (g per GJ fuel)	0	0	0	0	0	0	0	0	F	1
N2O (g per GJ fuel)	1	1	1	1	1	3	0	1	F	1
Particles (g per GJ fuel)	2.0	0.3	0.3	0.3	0.1	2.0	0.1	1.0	F	1
Financial data										
Nominal investment (M€/MWe)	3.7	3.8	3.6	3.3	3.1	4.5	2.6	4.5	J,K	1
- of which equipment	2.3	2.3	2.2	2.0	1.8	2.7	1.6	2.8	J,K	1
- of which installation	1.5	1.5	1.4	1.3	1.3	1.7	1.0	1.7	J,K	1
Fixed O&M (€/MWe/year)	150,400	149,900	141,100	126,300	129,400	168,700	98,000	158,100	J	1
Variable O&M (€/MWh_e)	1.9	2.0	2.0	2.0	1.7	2.3	1.5	2.4	J	1
Technology specific data										
Steam reheat	None	None	None	None	None	None	None	None		
Flue gas condensation	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Combustion air humidification	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Nominal investment (M€/MW fuel input)	1.16	1.16	1.10	1.00	0.95	1.36	0.81	1.37	J,K	1

- of which equipment	0.70	0.71	0.68	0.62	0.56	0.84	0.49	0.84	K	
- of which installation	0.46	0.45	0.42	0.38	0.39	0.53	0.32	0.53	K	
Fixed O&M (€/MW input/year)	46,600	45,800	43,200	38,700	38,000	53,000	29,600	49,900	J	
Variable O&M (€/MWh input)	0.60	0.60	0.60	0.60	0.51	0.69	0.45	0.75	J	
Fuel storage specific cost in excess of 2 days (M€/MW_input/storage day)	0.070	0.068	0.065	0.059	0.060	0.081	0.049	0.081	K	

Notes:

A The boiler in the plant is grate fired producing steam to be used in a subsequent back pressure steam turbine. Though a grate is reasonable flexible with respect to combusting different fuels the fuel feed system will be dependent on the type of fuel used.

B Through a turbine by-pass all the produced steam energy can be used for District Heat production.

C Since straw is relatively dry there is often only a minor efficiency advantage in using flue gas condensation. There is though an environmental advantage in having a scrubber in the flue gas stream. Direct condensation and combustion air humidification are included in all cases except in lower range of 2020 and 2050.

D Secondary regulation normally relates to power production; for this type of plant it may not be of importance since load will normally follow heat consumption.

E A limiting factor for the hot and cold start-up times is the size of the hot water tank (deaerator).

F For NOx-emissions no lower than 40 g/GJ SNCR is assumed. It is probably necessary to include a tail-end SCR catalyst to fulfill expected BREF requirements, particularly after year 2030. This has slight adverse effect on the electricity efficiency.

G Warm start is starting with a glowing fuel layer on the grate and a warm deaerator.

H The total efficiency is the sum of electricity efficiency and heat efficiency, applicable for "name plate" and "annual average", respectively. The "annual average" electricity efficiency is lower than "name plate" due to turbine outages and other incidents. The resulting lost power production is recovered as heat. This is why "annual average" heat efficiency is higher than "name plate" heat. Efficiencies refer to lower heating value. The parasitic electricity consumption has been subtracted in the listed electricity efficiencies.

I The Cv value does not exist for plants with a back pressure turbine or an ORC turbine

J Investment applies to a standard plant. There could be cost related to the actual project or site that adds to the total investment, e.g. additional fuel storage, facilities for chipping of logs, conditions for foundation and harbour facilities.
Financial data and Technological specific data are essentially the total cost either divided by the electric net capacity, i.e. corresponding to the indicated name plate efficiencies, or by the thermal input. This is to indicate that new plants may not fully take advantage of the technical capabilities for full electricity production capacity. The two cost for electricity and thermal input, respectively, are not to be added up!

K Note that investments include only two days fuel storage, and more may be optimal, depending on fuel supply opportunities and heat supply obligations, amongst other things.
The additional investment is listed in the bottom row.

References

1 Rambøll Danmark, internal evaluation based on either existing projects, supplier offers, or pre-project studies.

Data sheets Straw CHP, large

Technology	Large Straw CHP, 132 MW feed									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	40.7	40.7	40.9	40.9	39.1	53.4	40.3	54.5	A	
Electricity efficiency, net (%), name plate	30.9	30.9	30.9	30.9	30	40	30	41	A, H	1
Electricity efficiency, net (%), annual average	29.3	29.3	29.4	29.4	27	38	27	39	A, H	1
Heat efficiency, net (%), name plate	67.9	67.9	67.8	67.8	45	69	44	68	B, H	1
Heat efficiency, net (%), annual average	69.5	69.5	69.4	69.4	48	71	47	70	B, H	1
Additional heat potential with heat pumps (% of thermal input)	1.7	1.7	1.7	1.7	2	14	2	14	C	1
Cb coefficient (40°C/80°C)	0.45	0.45	0.46	0.46	0.44	0.60	0.45	0.61		
Cv coefficient (40°C/80°C)	1	1	1	1	1	1	1	1	I	
Forced outage (%)	3	3	3	3	3	3	3	3		
Planned outage (weeks per year)	3	3	3	3	2.6	3.5	2.3	3.8		
Technical lifetime (years)	25	25	25	25	20	35	20	35		1
Construction time (years)	3	3	3	3	2.5	3.5	2	3.5		1
Space requirement (1000 m2/MWe)	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.3		
Primary regulation (% per 30 seconds)	2	2	2	2	2	2	2	2		
Secondary regulation (% per minute)	4	4	4	4	4	4	4	4	D	1
Minimum load (% of full load)	40	40	40	40	40	40	40	40		
Warm start-up time (hours)	2	2	2	2	2	2	2	2	E	1
Cold start-up time (hours)	8	8	8	8	8	8	8	8		1
Environment										
SO_2 (degree of desulphuring, %)	95.5	96.4	99.1	99.8	90.9	99.8	95.5	99.9	F	1
NO_X (g per GJ fuel)	84	67	36	18	18	84	7	36	F	1
CH4 (g per GJ fuel)	0	0	0	0	0	0	0	0	F	1
N2O (g per GJ fuel)	1	1	1	1	1	3	0	1	F	1
Particles (g per GJ fuel)	0.3	0.3	0.3	0.3	0.1	2.0	0.1	1.0	F	1
Financial data										
Nominal investment (M€/MWe)	3.5	3.5	3.3	3.0	2.9	4.1	2.4	4.1	J,K	1
- of which equipment	2.2	2.1	2.0	1.8	1.8	2.5	1.5	2.5	J,K	
- of which installation	1.4	1.3	1.3	1.1	1.2	1.6	0.9	1.6	J,K	
Fixed O&M (€/MWe/year)	128,700	124,900	117,300	104,700	109,600	110,400	81,500	101,600	J	
Variable O&M (€/MWh_e)	1.9	1.9	1.9	1.9	1.7	2.2	1.5	2.4	J	
Technology specific data										
Steam reheat	None	None	None	None	None	Yes	None	Yes		
Flue gas condensation	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Combustion air humidification	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Nominal investment (M€/MW fuel input)	1.09	1.07	1.01	0.92	0.90	1.25	0.74	1.26	J,K	1
- of which equipment	0.67	0.66	0.63	0.57	0.55	0.77	0.45	0.78	K	

- of which installation	0.42	0.41	0.39	0.35	0.36	0.48	0.29	0.48	K	
Fixed O&M (€/MW input/year)	39,700	38,500	36,300	32,400	32,500	44,600	24,900	41,900	J	
Variable O&M (€/MWh input)	0.60	0.60	0.60	0.60	0.51	0.69	0.45	0.75	J	
Fuel storage specific cost in excess of 2 days (M€/MW_input/storage day)	0.065	0.063	0.060	0.055	0.055	0.075	0.045	0.075	K	

Notes:

A The boiler in the plant is grate fired producing steam to be used in a subsequent back pressure steam turbine. Though a grate is reasonable flexible with respect to combusting different fuels the fuel feed system will be dependent on the type of fuel used.

B Through a turbine by-pass all the produced steam energy can be used for District Heat production.

C Since straw is relatively dry there is often only a minor efficiency advantage in using flue gas condensation. There is though an environmental advantage in having a scrubber in the flue gas stream. Direct condensation and combustion air humidification are included in all cases except in lower range of 2020 and 2050.

D Secondary regulation normally relates to power production; for this type of plant it may not be of importance since load will normally follow heat consumption.

E A limiting factor for the hot and cold start-up times is the size of the hot water tank (deaerator).

F For NOx-emissions no lower than 40 g/GJ SNCR is assumed. It is probably necessary to include a tail-end SCR catalyst to fulfill expected BREF requirements, particularly after year 2030.
This has slight adverse effect on the electricity efficiency.

G Warm start is starting with a glowing fuel layer on the grate and a warm deaerator.

H The total efficiency is the sum of electricity efficiency and heat efficiency, applicable for "name plate" and "annual average", respectively. The "annual average" electricity efficiency is lower than "name plate" due to turbine outages and other incidents. The resulting lost power production is recovered as heat. This is why "annual average" heat efficiency is higher than "name plate" heat. Efficiencies refer to lower heating value. The parasitic electricity consumption has been subtracted in the listed electricity efficiencies.

I The Cv value does not exist for plants with a back pressure turbine or an ORC turbine

J Investment applies to a standard plant. There could be cost related to the actual project or site that adds to the total investment, e.g. additional fuel storage, facilities for chipping of logs, conditions for foundation and harbour facilities.
Financial data and Technological specific data are essentially the total cost either divided by the electric net capacity, i.e. corresponding to the indicated name plate efficiencies, or by the thermal input. This is to indicate that new plants may not fully take advantage of the technical capabilities for full electricity production capacity. The two cost for electricity and thermal input, respectively, are not to be added up!

K Note that investments include only two days fuel storage, and more may be optimal, depending on fuel supply opportunities and heat supply obligations, amongst other things.
The additional investment is listed in the bottom row.

References

1 Rambøll Danmark, internal evaluation based on either existing projects, supplier offers, or pre-project studies.

Data sheets Wood Chips, HOP

Technology	Wood Chips, HOP, 6 MW feed									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat generation capacity for one unit (MW)	6.9	6.9	6.9	6.9	5.3	6.9	5.3	6.9	A	1
Total efficiency, net (%), name plate	114.9	114.9	114.9	114.9	89	115	89	115	B,C	1
Total efficiency , net (%), annual average	114.9	114.9	114.9	114.9	89	115	89	115	B,C	1
Additional heat potential with heat pumps (% of thermal input)	2.0	2.0	2.0	2.0	2	28	2	28	D	1
Auxiliary electricity consumption (% of heat gen)	2.3	2.3	2.3	2.3	2.2	2.5	1.8	2.5	C,K	
Forced outage (%)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0		
Planned outage (weeks per year)	2.0	2.0	2.0	2.0	1.7	2.3	1.5	2.5		
Technical lifetime (years)	25.0	25.0	25.0	25.0	20.0	35.0	20.0	35.0		1
Construction time (years)	1.0	1.0	1.0	1.0	0.5	1.5	0.5	1.5		1
Space requirement (1000 m2/MWth heat output)	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.3		
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	10,0	10,0	10,0	10,0	10,0	10,0	10,0	10,0	E	1
Minimum load (% of full load)	20	20	20	20	20	20	20	20	E	1
Warm start-up time (hours)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	H	1
Cold start-up time (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		1
Environment										
SO_2 (degree of desulphuring, %)	98.0	98.0	98.0	98.0	89.9	99.0	98.0	99.0	G	1
NO_X (g per GJ fuel)	90	63	49	41	41	81	28	41	I	
CH4 (g per GJ fuel)	16	11	8	4	4	16	2	16	I	
N2O (g per GJ fuel)	4	3	3	1	1	4	1	4	I	
Particles (g per GJ fuel)	2.0	0.3	0.3	0.3	0.1	2.0	0.1	1.0	I	
Financial data										
Nominal investment (M€/MWth - heat output)	0.70	0.68	0.65	0.59	0.60	0.81	0.49	0.81	F, L	
- of which equipment	0.41	0.40	0.38	0.34	0.35	0.47	0.28	0.47	F, L	
- of which installation	0.30	0.29	0.27	0.25	0.25	0.34	0.21	0.34	F, L	
Fixed O&M (€/MWth/year), heat output	32,800	32,200	31,200	29,300	35,800	37,300	29,300	37,600		
Variable O&M (€/MWh) heat output	1.0	1.0	1.0	1.0	0.8	1.1	0.7	1.2		
Technology specific data										
Flue gas condensation	Yes	Yes	Yes	Yes	No	Yes	No	Yes	J, L	
Combustion air humidification	Yes	Yes	Yes	Yes	No	Yes	No	Yes	J, L	
Nominal investment (M€/MW fuel input)	0.81	0.79	0.75	0.68	0.69	0.93	0.56	0.94	J, L	1
- of which equipment	0.47	0.46	0.43	0.39	0.40	0.54	0.32	0.54	L	
- of which installation	0.34	0.33	0.32	0.29	0.29	0.39	0.24	0.39	L	
Fixed O&M (€/MW input/year)	37,700	37,100	35,900	33,700	31,700	42,900	26,000	43,300		
Variable O&M (€/MWh input)	2.5	2.7	3.4	3.7	2.4	3.0	2.9	4.3		
- of which is electricity costs (€/MWh)	1.4	1.6	2.3	2.6	1.5	1.7	2.1	2.9	C	
- of which is other O&M costs (€/MWh)	1.1	1.1	1.1	1.1	0.9	1.3	0.8	1.4		

Fuel storage specific cost in excess of 2 days (M€/MW_input/storage day)	0.020	0.020	0.019	0.017	0.017	0.023	0.014	0.023	L	

Notes:

A The plant is directly producing hot water for District Heating by burning fuel on a grate.

B Boilers up to 20 MW fuel input for hot water production are more or less standardized products with a high degree of fuel flexibility (type of biomass, humidity etc.)

C Efficiencies refer to lower heating value. The stated total efficiency does NOT consider auxiliary electricity consumption. It describes the total net amount of heat produced at the plant. This is contrary to CHP where the auxiliary electricity is subtracted from the production to yield the net electricity efficiency. Instead the cost of auxiliary electricity consumption is included in variable O&M and is calculated using the following electricity prices in €/MWh: 2015: 63, 2020: 69, 2030: 101, 2050: 117. These prices include production costs and transport tariffs, but not any taxes or subsidies for renewable energy.

D There are plants of this type with up to 108 % efficiency using flue gas condensation with moist wood chips and close to 115 % efficiency with both flue gas condensation and absorption heat pumps activated. The colder the return temperature of the district heating, the higher the total efficiency at direct condensation. Direct condensation and combustion air humidification are included in all cases except in lower range of 2020 and 2050.

E Load control of the heat production is important and units of this size can make rapid load variations. Similarly, the minimum load is quite low

F Reference to heat output because of the lack of electricity production

G assuming content of sulphur in fuel of 20 g/GJ

H Warm start is starting with a glowing fuel layer on the grate.

I Estimated from: Nielsen, M., Nielsen, O.-K., Plejdrup, M. & Hjelgaard, K., 2010: Danish Emission Inventories for Stationary Combustion Plants. Inventories until 2008. National Environmental Research Institute, Aarhus University, Denmark. 236 pp. – NERI Technical Report No. 795. http://www.dmu.dk/Pub/FR795.pdf.

J The nominal investment is in the range 0.6 to 1.1 M€/Mwth

K Result of model calculation, there are reports of DH plants operating at lower power consumption, down to 1% of heat generation.

L Note that investments include only two days fuel storage, and more may be optimal, depending on fuel supply opportunities and heat supply obligations, amongst other things.
The additional investment is listed in the bottom row.

References

1 Rambøll Danmark, internal evaluation based on either existing projects, supplier offers, or pre-project studies.

Data sheets Wood Pellets, HOP

Technology	Wood Pellets, HOP, 6 MW feed									
	2015	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data					Lower	Upper	Lower	Upper		
Heat generation capacity for one unit (MW)	6.0	6.0	6.0	6.0	5.4	6.0	5.4	6.0	A	1
Total efficiency, net (%), name plate	100.1	100.1	100.1	100.1	90	100	90	100	B,C	1
Total efficiency , net (%), annual average	100.1	100.1	100.1	100.1	90	100	90	100	B,C	1
Additional heat potential with heat pumps (% of thermal input)	1.7	1.7	1.7	1.7	2	12	2	12	D	1
Auxiliary electricity consumption (% of heat gen)	2.1	2.1	2.1	2.1	1.8	2.3	1.4	2.3	C,K	
Forced outage (%)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0		
Planned outage (weeks per year)	3.0	3.0	3.0	3.0	2.6	3.5	2.3	3.8		
Technical lifetime (years)	25.0	25.0	25.0	25.0	20.0	35.0	20.0	35.0		1
Construction time (years)	1.0	1.0	1.0	1.0	0.5	1.5	0.5	1.5		1
Space requirement (1000 m2/MWth heat output)	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.2		
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	E	1
Minimum load (% of full load)	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	E	1
Warm start-up time (hours)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	H	1
Cold start-up time (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		1
Environment										
SO_2 (degree of desulphuring, %)	98.3	98.3	98.3	98.3	91.3	99.1	98.3	99.1	G	1
NO_X (g per GJ fuel)	90	54	42	35	35	70	25	35	G	1
CH4 (g per GJ fuel)	0	0	0	0	0	0	0	0	G	1
N2O (g per GJ fuel)	1	1	1	1	1	3	0	1	G	1
Particles (g per GJ fuel)	2.0	0.3	0.3	0.3	0.1	2.0	0.1	1.0	G	1
Financial data										
Nominal investment (M€/MWth - heat output)	0.74	0.72	0.69	0.67	0.63	0.90	0.57	0.91	F, L	
- of which equipment	0.45	0.44	0.42	0.43	0.38	0.57	0.36	0.57	F, L	
- of which installation	0.29	0.28	0.27	0.24	0.25	0.33	0.20	0.34	F, L	
Fixed O&M (€/MWth/year), heat output	34,000	33,000	31,300	29,200	31,700	39,200	25,600	37,400	F	
Variable O&M (€/MWh) heat output	0.5	0.5	0.5	0.5	0.4	0.6	0.4	0.6	F	
Technology specific data										
Flue gas condensation	Yes	Yes	Yes	Yes	No	Yes	No	Yes	J	
Combustion air humidification	Yes	Yes	Yes	Yes	No	Yes	No	Yes	J	
Nominal investment (M€/MW fuel input)	0.74	0.72	0.69	0.67	0.63	0.90	0.57	0.91	J, L	1
- of which equipment	0.45	0.44	0.42	0.43	0.38	0.57	0.36	0.57	L	
- of which installation	0.29	0.28	0.27	0.24	0.25	0.34	0.20	0.34	L	
Fixed O&M (€/MW input/year)	34,000	33,100	31,300	29,300	28,300	39,300	22,900	37,500		
Variable O&M (€/MWh input)	1.8	1.9	2.6	2.9	1.6	2.2	2.1	3.3		

- of which is electricity costs (€/MWh)	1.3	1.4	2.1	2.4	1.2	1.6	1.7	2.7	C	
- of which is other O&M costs (€/MWh)	0,5	0,5	0,5	0,5	0,4	0,6	0,4	0,6		
Fuel storage specific cost in excess of 2 days (M€/MW_input/storage day)	0,004	0,004	0,004	0,003	0,003	0,005	0,003	0,005	L	

Notes:

A The plant is directly producing hot water for District Heating by burning fuel on a grate.

B Boilers up to 20 MW fuel input for hot water production are more or less standardized products with a high degree of fuel flexibility (type of biomass, humidity etc.)

C The stated total efficiency does NOT consider auxiliary electricity consumption. It describes the total net amount of heat produced at the plant. This is contrary to CHP where the auxiliary electricity is subtracted from the production to yield the net electricity efficiency. Instead the cost of auxiliary electricity consumption is included in variable O&M and is calculated using the following electricity prices in €/MWh: 2015: 63, 2020: 69, 2030: 101, 2050: 117. These prices include production costs and transport tariffs, but not any taxes or subsidies for renewable energy.

D There are plants of this type with up to 108 % efficiency using flue gas condensation with moist wood chips and close to 115 % efficiency with both flue gas condensation and absorption heat pumps activated. The colder the return temperature of the district heating, the higher the total efficiency at direct condensation. Direct condensation and combustion air humidification are included in all cases except in lower range of 2020 and 2050.

E Load control of the heat production is important and units of this size can make rapid load variations. Similarly, the minimum load is quite low

F Reference to heat output because of the lack of electricity production

G Emissions shall comply with Danish EPA guideline, Luftvejledningen. It is anticipated that for the smaller units the supplier has an SNCR solutiuon to reduce NOx emissions sufficiently.

I Warm start is starting with a glowing fuel layer on the grate.

J The nominal investment is in the range 0.6 to 1.1 M€/Mwth

K Result of model calculation, there are reports of DH plants operating at lower power consumption

L Note that investments include only two days fuel storage, and more may be optimal, depending on fuel supply opportunities and heat supply obligations, amongst other things. The additional investment is listed in the bottom row.

References

1 Rambøll Danmark, internal evaluation based on either existing projects, supplier offers, or pre-project studies.

Data sheets Straw, HOP

Technology	**Straw, HOP, 6 MW feed**									
	2015	**2020**	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data					**Lower**	**Upper**	**Lower**	**Upper**		
Heat generation capacity for one unit (MW)	6.1	6.1	6.1	6.1	5.4	6.1	5.4	6.1	A	1
Total efficiency, net (%), name plate	102.1	102.1	102.1	102.1	89	102	89	102	B,C	1
Total efficiency , net (%), annual average	102.1	102.1	102.1	3.0	89	102	89	102	B,C	1
Additional heat potential with heat pumps (% of thermal input)	1.7	1.7	1.7	1.7	2	14	2	14	D	1
Auxiliary electricity consumption (% of heat gen)	2.1	2.1	2.1	2.1	1.9	2.3	1.5	2.3	C,J	
Forced outage (%)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0		
Planned outage (weeks per year)	4.0	4.0	4.0	4.0	3.4	4.6	3.0	5.0		
Technical lifetime (years)	25.0	25.0	25.0	25.0	20.0	35.0	20.0	35.0		1
Construction time (years)	1.0	1.0	1.0	1.0	0.5	1.5	0.5	1.5		1
Space requirement (1000 m2/MWe)	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.3		
Primary regulation (% per 30 seconds)	NA	NA	NA	NA	NA	NA	NA	NA		
Secondary regulation (% per minute)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	E	1
Minimum load (% of full load)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	E	1
Warm start-up time (hours)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	H	1
Cold start-up time (hours)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		1
Environment										
SO_2 (degree of desulphuring, %)	95.5	96.4	99.1	99.8	90.9	99.8	95.5	99.9	G	1
NO_X (g per GJ fuel)	90	72	73	73	36	90	18	73	G	1
CH4 (g per GJ fuel)	16	11	8	4	4	16	2	16	G	1
N2O (g per GJ fuel)	4	3	2	1	1	4	1	4	G	1
Particles (g per GJ fuel)	2.0	0.3	0.3	0.3	0.1	2.0	0.1	1.0	G	1
Financial data										
Nominal investment (M€/MWth - heat output)	0.91	0.89	0.84	0.76	0.77	1.09	0.63	1.10	F,K	
- of which equipment	0.44	0.43	0.41	0.37	0.37	0.56	0.31	0.56	F,K	
- of which installation	0.47	0.46	0.43	0.39	0.40	0.54	0.32	0.54	F,K	
Fixed O&M (€/MWth/year), heat output	52,900	51,300	48,400	43,300	50,200	60,200	38,000	56,200	F	
Variable O&M (€/MWh) heat output	0.6	0.6	0.6	0.6	0.5	0.7	0.4	0.7	F	
Technology specific data										
Flue gas condensation	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Combustion air humidification	Yes	Yes	Yes	Yes	No	Yes	No	Yes		
Nominal investment (M€/MW fuel input)	0.93	0.90	0.86	0.78	0.79	1.12	0.64	1.12	I,K	1
- of which equipment	0.45	0.44	0.42	0.38	0.38	0.57	0.31	0.57	K	
- of which installation	0.48	0.46	0.44	0.40	0.41	0.55	0.33	0.55	K	
Fixed O&M (€/MW input/year)	54,000	52,400	49,400	44,200	44,800	61,600	33,900	57,500		
Variable O&M (€/MWh input)	1.9	2.1	2.7	3.1	1.8	2.3	2.2	3.5		
- of which is electricity costs (€/MWh)	1.3	1.5	2.1	2.5	1.3	1.6	1.7	2.7	C	

- of which is other O&M costs (€/MWh)	0.6	0.6	0.6	0.6	0.5	0.7	0.5	0.8		
Fuel storage specific cost in excess of 2 days (M€/MW_input/storage day)	0.080	0.078	0.074	0.067	0.068	0.092	0.056	0.093	K	

Notes:

A The plant is directly producing hot water for District Heating by burning fuel on a grate.

B Boilers up to 20 MW fuel input for hot water production are more or less standardized products with a high degree of fuel flexibility (type of biomass, humidity etc.)

C The stated total efficiency does NOT consider auxiliary electricity consumption. It describes the total net amount of heat produced at the plant. This is contrary to CHP where the auxiliary electricity is subtracted from the production to yield the net electricity efficiency. Instead the cost of auxiliary electricity consumption is included in variable O&M and is calculated using the following electricity prices in €/MWh: 2015: 63, 2020: 69, 2030: 101, 2050: 117. These prices include production costs and transport tariffs, but not any taxes or subsidies for renewable energy.

D There are plants of this type with up to 108 % efficiency using flue gas condensation with moist wood chips and close to 115 % efficiency with both flue gas condensation and absorption heat pumps activated. The colder the return temperature of the district heating, the higher the total efficiency at direct condensation. Direct condensation and combustion air humidification are included in all cases except in lower range of 2020 and 2050.

E Load control of the heat production is important and units of this size can make rapid load variations. Similarly, the minimum load is quite low

F Reference to heat output because of the lack of electricity production

G Emissions shall comply with Danish EPA guideline, Luftvejledningen.
It is anticipated that for the smaller units the supplier has an SNCR solutiuon to reduce NOx emissions sufficiently.

I Warm start is starting with a glowing fuel layer on the grate.

J The nominal investment is in the range 0.6 to 1.1 M€/Mwth

K Result of model calculation, there are reports of DH plants operating at lower power consumption

L Note that investments include only two days fuel storage, and more may be optimal, depending on fuel supply opportunities and heat supply obligations, amongst other things.
The additional investment is listed in the bottom row.

References

1 Rambøll Danmark, internal evaluation based on either existing projects, supplier offers, or pre-project studies.