Chapter 4
Flexible Power Generation from Solid Biofuels

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Abstract Flexible and demand-based production of electricity and heat (combined heat and power – CHP) from solid biomass is an extremely interesting concept for a renewable energy system as the used fuel shows excellent storability. However, conversion and power generation technology limit flexibility for several reasons.

Combined heat and power plants for the production of solid biomass are today designed for base load operation. The most common systems are steam cycles, organic Rankine cycles (ORC) and combinations of gasification and gas engines. Other available technologies include Stirling engines, fuel cells and thermoelectric generators (TEGs). Some technologies are already able to provide flexibility in power production. Extracting turbines, for example, are able to change the power-to-heat ratio of the system. It is possible to increase flexibility by using additional or upgraded units such as heat or gas storages, new steam turbines or new control systems. Potential solutions for increasing flexibility in combined heat and power production from solid biomass are expected to include micro-CHP systems and gasification units with high flexibility and high power-to-heat ratio. Larger plants may show less flexibility due to their thermal inertness (which sometimes has been part of the design, e.g. to stabilize combustion of fuels with low heating values).

4.1 Introduction

Flexible and demand-based production of electricity and heat (combined heat and power – CHP) from solid biomass is an extremely interesting concept for a renewable energy system as the used fuel shows excellent storability, including an existing infrastructure for logistics and pretreatment (e.g. pelletizing) [1]. Nevertheless, this has as of yet not been realized by operating units. The following chapter will therefore analyse the challenges and opportunities presented by this technical development.

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The flexibility of combined heat and power generation from solid biomass relies on three main factors – thermo-chemical conversion process(es), intermediate energy carriers and power generation technologies. For a systematic approach to increasing flexibility, the next section will give an overview on different technologies used for the generation of power through the use of solid biomass, including at least two basic process steps: Within the first stage, one or more thermo-chemical conversion processes take place (Sect. 4.2). The second stage is focused on power generation through thermodynamic cycles or similar processes (Sect. 4.3). Concepts for power generation and the status quo in Germany are discussed in the following chapter (Sects. 4.4 and 4.5).

Using this classification, the existing flexibility and the potential for its improvement will be discussed in the following chapter. The existing flexibility of and possible improvements that can be made to state-of-the-art technologies will also be evaluated (Sect. 4.6). Future concepts will be discussed in Sect. 4.7. Finally, conclusions regarding the frame conditions will be discussed in Sect. 4.8.

4.2 Thermo-chemical Conversion Processes

In general, the process of thermo-chemical conversion of solid biomass includes the following steps [2, 3]:

- pretreatment (e.g. drying)
- pyrolysis
- gasification
- combustion

It should be noted that the product range of different thermo-chemical processes strongly depends not only on the chosen process steps itself, but also on other parameters such as pressure, gas phase and particle residence time as well as the reaction environment (e.g. inert media, hot sand, hydrothermal environment) [2].

Before starting the thermo-chemical conversion process, **pretreatment** of biomass is very common. This may include chipping, grinding, pelletizing, briquetting or washing. Drying is a thermal treatment with temperatures low enough to induce only minor chemical changes but high enough to evaporate moisture contained within the fuel. Higher flexibility for pretreatment and drying processes is important for changing fuels in terms of type and amount. Furthermore, since some of the processes may require electrical or heat power (e.g. pelletizing, drying), these energy consuming units can be included in an energy management system, e.g. for the purpose of grid stabilization.

In **pyrolysis**, biomass is decomposed by thermally activated chemical processes within an inert environment. The main product energy carriers, depending on the process parameters, are either solids with a higher energy density than the original fuel (e.g. by torrefaction or slow pyrolysis), liquids (e.g. pyrolysis oil) or sometimes gases (pyrolysis gases). Since the solid and gaseous products can usually be stored, in terms of output the process does not need to be more flexible. However, in terms of input, the degree of flexibility should be comparable to that of the pretreatment processes. This often requires advanced process technology and process control.

Gasification is the reaction of the fuel (including solid, liquid or gaseous products of previous pyrolysis) to mainly gaseous products with significant heating values (e.g. mixtures of hydrogen and carbon monoxide). There are several gasification processes, including moving bed gasification (sometimes also called fixed bed gasification), fluidized bed gasification and entrained flow gasification. Depending on the specific gasification process, flexibility differs greatly. While moving bed gasifiers require a relatively long time to start-up due to the slow heat-up rate of the reactor lining, fluidized bed gasification involves a more efficient start-up process [4]. However, fluidized bed gasification start-up also requires some time (and energy) to heat up the bed sand. In the process of entrained flow gasification, the start-up time depends on the amount of ash the gasification reactor has been designed for since the design of the reactor hull (e.g. reactor lining vs. cooling jacket) heavily influences the time required to heat-up. Turndown of gasification processes is restricted, in particular for downdraft and fluidized bed gasification. However, operation in part load mode is possible with a range as high as 20–110 % for moving bed and 50–120 % for fluidized bed gasification [4].

In **combustion**, all fuel components are oxidized to the maximum. Commonly used technologies for combustion include different grate firings, fluidized bed combustion and dust firing. For more information on the flexibility of small scale solid biomass combustion technologies, see Chap. 6. Fluidized bed combustion, in particular for larger scale combustion (>1 MW), shows higher load change rates when compared to grate firing. Start-up for fluidized bed combustion usually requires more time and energy than for grate firings. This is mainly due to the required heat-up time of the bed material [5].

In Table 4.1, different thermo-chemical conversion processes are compared in the context of flexible power production. Start-stop-behavior, ramping ability and load range are evaluated for typical examples for the respective technology. Their classification is based on the expected demands for flexibility, e.g. for secondary and tertiary control (see Chap. 2).

4.3 Power Generation Technologies

Power generation technologies transfer thermal or chemical energy into electricity. This may happen via thermodynamic cycles (e.g. Rankine, Stirling or Brayton cycles) or by direct power production (e.g. by thermoelectric or electrochemical effects).

The following classification of these power generation technologies is based on the main energy carrier from the last thermo-chemical conversion process to the power generation unit. They can be based on steam (water or organic, usage of phase conversion enthalpy), chemical energy (fuel gas, synthesis gas, synthetic

Table 4.1 Comparison of thermo-chemical conversion processes for flexible power generation

Process	Main product	Technology Readiness Level[a] (TRL)	Start-stop-behavior	Ramping (load change) ability	Load range (from nominal power)
Combustion	Heat (Flue gas)	9	o	o/+	30–110 %
Gasification	Syngas	9	o/+	+/++	50–110 %
Slow pyrolysis	Charcoal	9	–	o	50–110 %
Torrefaction	Torrefied biomass	7–8	o	o/+	(70–100 %)
Flash pyrolysis	Pyrolysis oil	6–7	o	+	(70–110 %)
Start-stop-behavior:					
–– impossible or very hard					
– many hours					
o few hours					
+ <1 h					
++ minutes					
Ramping ability:					
–– no ramping					
– <10 % per hour					
o 20 % per hour					
+ 1 % per minute					
++ 10 % per minute					

[a] According to EU definitions in Horizon2020, Work Programme 2014–2015, Annex G

fuels) or sensible heat (e.g. in flue gas). In Table 4.2, different intermediate energy carriers for power production from solid biomass and their respective storage technologies are listed. Classification of storage efficiency is based on the comparison to electric power storage (e.g. in batteries), while loading and unloading access is evaluated in consideration of heat and mass transfer as well as available technology.

In Table 4.3, different power generation technologies are compared in terms of Technology Readiness Level (TRL), start-stop-behavior, ramping behavior (see Table 4.1) and electrical efficiency for typical units.

4.3.1 Technologies Based on Steam Cycles

In steam cycles, the energy used for phase changes is the main driver for the process. There are different technologies based on steam cycles. They can be different in terms of the medium (usually water or an organic liquid) and the power conversion technology (usually turbine or engine).

In **steam turbines**, water is used as medium within a Rankine cycle. Water is boiled and superheated to temperatures above 500 °C [6]. The superheated steam, typically with a pressure of 20–250 bar, drives an often multi-staged steam turbine [6, 7].

Table 4.2 Intermediate energy carriers from solid biomass for power production technologies

Intermediate energy carrier	Energy density	Storage technology	Technology Readiness Level (TRL) of storage technology	Storage efficiency	Loading and unloading access
Flue gas	<90 kWh/m^3	Heat storage (hot water, phase change material)	9 (for T < 100 °C), 7 (for T > 100 °C)	–/o	Good
Water steam	<100 kWh/m^3	Steam storage	9	–	Very good
Organic steam	Unclear	Steam storage	1–2	(–/o)	Unclear
Synthesis gas	f(p)	Syngas storage	3–5	(+)	Good
Synthetic natural gas (SNG)	f(p)	Natural gas grid	9	+/++	Very good
Liquid synthetic fuels	>1,000 kWh/m^3	Tank storage	9	++	Very good
Storage efficiency:					
–– <30 %					
– <50 %					
o <70 %					
+ <85 %					
++ >85 %					

Table 4.3 Flexibility of different power generation technologies

Power generation technology	Typical electrical power range	Technology Readiness Level (TRL)	Startstop-behavior	Ramping (load change) ability	Electrical efficiency η_{el}
Steam turbine	>1 MW	9	o	++	25–35 %
Organic Rankine Cycle (ORC)	100 kW … 5 MW	9	o	+	15–25 %
Steam engine	<1 MW	9	+	++	10–20 %
Gas turbine	>30 kW	9	++	++	30–40 %
Gas engine	<500 kW	9	++	++	35–45 %
Integrated Gasification Combined Cycle (IGCC)	>10 MW	7	o/+	+/++	40–50 %
Fuel cell	1 kW … 5 MW	7–8	–	+	35–65 %
Stirling	<500 kW	7–8	+	o/+	10–18 %
Externally Fired Gas Turbine (EFGT)	10–500 kW	6–7	+	+	18–25 %
Thermo-electric Generators (TEG)	<1 kW	5–7	++	+	<4 %

In condensing steam turbines, the pressure at the turbine outlet is very low. Usually it is already a vacuum below 0.1 bar or 46 °C, making it impossible to use the heat behind the turbine [7].

In non-condensing or back-pressure turbines, pressure at the turbine outlet is typically above 1 bar or 100 °C, which allows heat utilization [7].

For both types, the turbine can be built as an extraction turbine allowing for changes in heat output and the power-to-heat-ratio. A controllable amount of steam is extracted from the turbine at an intermediate pressure and temperature [7].

Back-pressure turbines are commonly used for plants in the range of 0.5–5 MW_{el}. While extraction turbines are suitable for plants above 5 MW_{el}, condensing type turbines are commonly used for larger plants with significantly more than 25 MW_{el}.

Large coal fired power plants with condensing type turbines have reached overall electrical efficiencies of 46 %, which is close to the theoretical maximum [6]. For biomass fired plants, lower electrical efficiencies of 25–35 % are common (depending on size and turbine technology).

In general, steam turbines have to be considered as a fairly flexible technology for power production. The availability of steam is usually the limiting factor.

Organic Rankine Cycle (ORC) systems are based on the same thermodynamic principle as steam turbines. The working medium is an organic fluid. Heat is usually transferred to the working medium via a thermal oil to prevent cracking of the fluid.

As there is no water vapor in the system, it can run in stand-alone mode without continuous observation by humans. This reduces working costs significantly. However, at the same time, the electrical efficiency is, due to lower temperatures, much lower (maximum of about 25 %; in a general work cycle approx. 15 %).

Although ORC systems show some flexibility due to the possibility of changing the ratio of electrical power to heat output, it is estimated to be not as good as extraction steam turbines. However, they still function relatively well in part load operation [8].

In **steam engines**, just as in steam turbines, water is used the medium. Instead of a turbine, an engine is used for power conversion. The engine shaft is linked to a generator which produces electricity. Steam engines are typical for rather low electrical outputs of few kW to larger outputs ranging in the hundreds. The electrical efficiency of the overall system is approx. 10–15 %. The most common types of steam engines are piston engines and screw engines.

In comparison to steam turbines, steam engines are very flexible in power output, limited mostly by the availability of steam. In part load operation they perform at an acceptable level but can also perform extremely well [9].

4.3.2 Technologies Based on Chemical Conversion

The main driver in chemical conversion based technologies is the reaction enthalpy of the energy carrier, which can be used in thermodynamic cycles or by electrochemical conversion.

Gas turbines are usually based on the Brayton cycle (also: Joule or Joule-Thomson cycle). In the compressor-stage, the air needed is compressed. The gaseous fuel from biogas or gasification of solid fuels is then injected and combusted in a combustion chamber. Temperature and pressure resultingly increase significantly. Expanding gas can drive a turbine conducted by an electrical generator. The efficiency of gas turbines depends on their size. Their efficiency can reach values of up to 35 %. The remaining flue gases have relatively high temperatures. So the remaining hot gases can be used for additional electricity production. Gas turbines can be considered as being very flexible, they are currently in use for flexible power production and can supply full power within minutes or even seconds even to extremely large turbines. The flexibility of gas turbines can be used for solid biomass, in particular in combination with the production of synthetic natural gas (SNG) or biomethane. The use of synthesis gas (high contents of hydrogen and carbon monoxide) can often require storage of the synthesis gas or a gasification process which is as flexible as the gas turbine. For externally fired gas turbines.

The basic principle of **gas engines** is the Otto cycle. For solid biomass, gas engines are often used in conjunction with small or medium scaled gasification systems. The product gas from the gasification process is cleaned and cooled. Gas engines show high flexibility and an acceptable electrical efficiency rate of between 35–45 %, according to the fuel input to the engine [10].

Integrated Gasification Combined Cycle (IGCC) is a system of gasification, gas turbine and steam turbine. It has the potential to achieve high electrical efficiency of up to 50 % (based on the higher heating value) [11]. Due to the combination of gas turbine and steam turbine, there is some flexibility in power-to-heat ratio. Today, cost-efficient IGCCs demand at least 10 MW_{el} due to the complexity of the system.

In general, **fuel cells** make it possible to generate electrical power from chemical power through an electrochemical reaction within a cell [12]. In the context of solid biomass, fuel cells can be used to produce electricity from synthesis gas or hydrogen.

Solid oxide fuel cells (SOFCs), which can use synthesis gas without further shifting, are operated at high temperatures. Thus, their start-up and shut-down behavior is not optimal, because the fuel cell stacks are easily damaged by large temperature differences. Still, they behave well in part load operation and have good flexibility [12]. There are new developments in the field of SOFC, e.g. the use of metallic cathodes, allows for a higher number of thermal cycles.

The rate of efficiency from gas to electricity is in the range of 35–65 % depending on size and system [12].

4.3.3 Technologies Based on Sensible Heat Conversion

In some conversion technologies, only the sensible heat e.g. of flue gas, is used as a driver.

Stirling engines are based on thermodynamic cycles with a gaseous working medium [13], which could be air, helium, hydrogen or others [14]. Stirling engines are classified as Alpha, Beta and Gamma engines depending on the following variables: compression space, expansion space, cooler, heater, regenerator and, if required, displacer piston [15]. Usually, stirling engines provide a relatively constant power output [14]. Thus, they are not suited for a rather flexible power generation as needed for primary control. The use of stirling engines is still possible to provide daily or seasonal flexibility. For gaseous fuels, a theoretical electrical efficiency rate above 40 % is possible, with ar mere realistic rate in the range of 20–25 % [13]. With solid fuels in the small scale up to a few hundred kW, the typical annual efficiency is currently in the range of 10–18 % [10].

Difficult fuels (as e.g. straw) can be used in **externally fired gas turbines (EFGT)** by introducing external combustion with a heat exchanger, which heats the working gas (e.g. air). Due to the additional heat transfer and the material characteristics of the heat exchanger, the electrical efficiency is significantly lower, it has been described to be in the range of 25 % with the potential to reach 30–35 % [10]. Externally fired gas turbines for the use of biomass have been discussed in literature [10, 16].

In **thermo-electric generators (TEGs)**, the so-called Seebeck effect is used to produce electricity [17]. While electrical efficiency is very low (usually <4 %), TEGs have the advantage of having no moving parts and are thus expected to be a robust technology. TEGs have the potential to supply auxiliary devices, such as control systems or measurement equipment, with power as well as to provide black start capability.

4.4 Concepts for Power Generation from Solid Biomass

In general, concepts for power generation from solid biomass are based on one or several thermo-chemical conversion processes combined and one or more power generation technologies. An overview on possible combinations is given in Fig. 4.1. It should be noted that some possible additional intermediates (like thermo-chemically treated solid biofuels or biobased synthetic natural gas – bio-SNG) or processes (like torrefaction) are left out since they are dealt with in separate Chap. 8. In a small number of cases, the conversion process is integrated into the power generation technology, e.g. for turbines for sawdust [10, 18]. Since there are no available processes on the market, this possibility will not be discussed further.

These possible combinations can be classified into state-of-the-art-concepts (e.g. combustion + steam turbine, combustion + ORC turbine, combustion + Stirling engine, gasification + gas engine), technologically available concepts (e.g. combustion + externally fired gas turbine, gasification + gas turbine) and future concepts (e.g. gasification + fuel cell, combustion + thermo-electric generator). An overview of the estimated TRLs for different concepts is given in Fig. 4.2, including typical power ranges for these concepts.

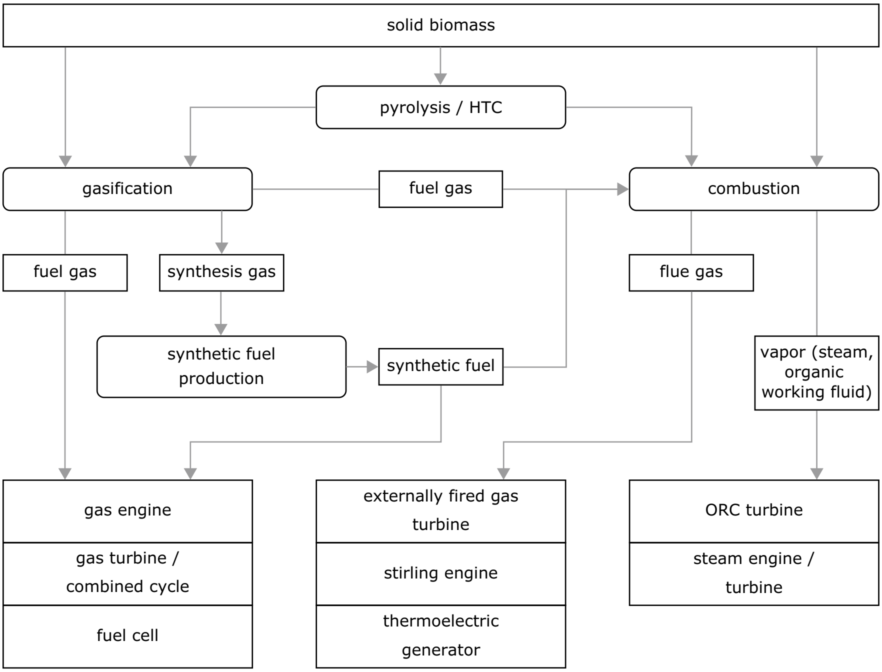

Fig. 4.1 Possible combinations of thermo-chemical conversion processes and power generation technologies, extended from [19] (*HTC* Hydrothermal carbonization, *ORC* Organic Rankine Cycle)

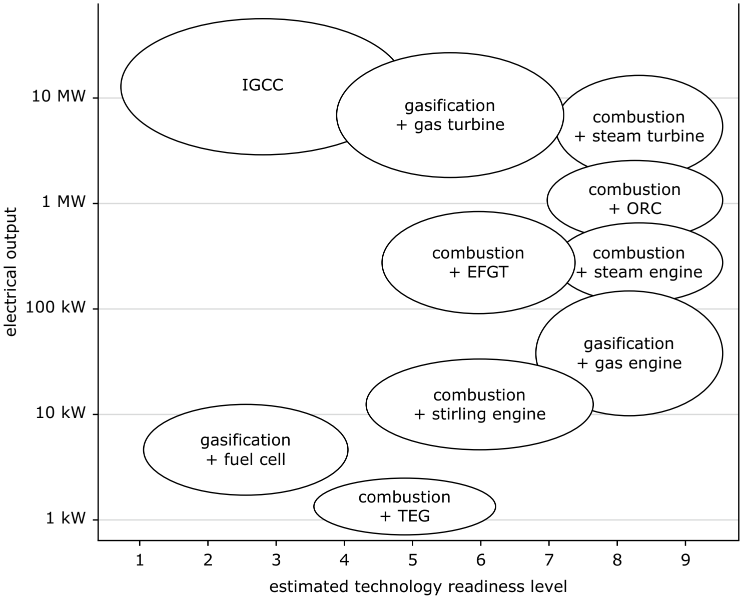

Fig. 4.2 Overview of TRLs for different concepts (*IGCC* Integrated Gasification Combined Cycle, *EFGT* Externally Fired Gas Turbine, *ORC* Organic Rankine Cycle, *TEG* Thermo-electric Generator)

Co-firing concepts, where further technologies could be counted as state-of-the-art, are not considered here since the scope of this work is focusing on renewable energy.

4.5 State of the Art

The most common power plants using solid biomass that are steam based systems, ORC plants and gasification plants with a gas engine (see Fig. 4.3), are to this day usually operated for base load power production due to economical reasons. Some steam based systems are already delivering heat (e.g. process steam) on demand. Furthermore, some of these power plants in Germany are offering tertiary control.[1] Some micro-CHP systems are able to change the power-to-heat ratio [13].

At the moment the number of new installations of steam turbines and ORC turbines has decreased to almost zero. This is caused by increasing biomass prices and decreasing feed-in tariffs. Only the installation of gasifiers together with gas engines has increased rapidly. Due to their low specific electrical nominal power, the total installed electrical power of these gasification units is currently not very high (around 60 MW_{el}).

Some existing plants are already able to provide some flexibility for power production. To achieve further flexibility in existing plants, repowering is necessary.

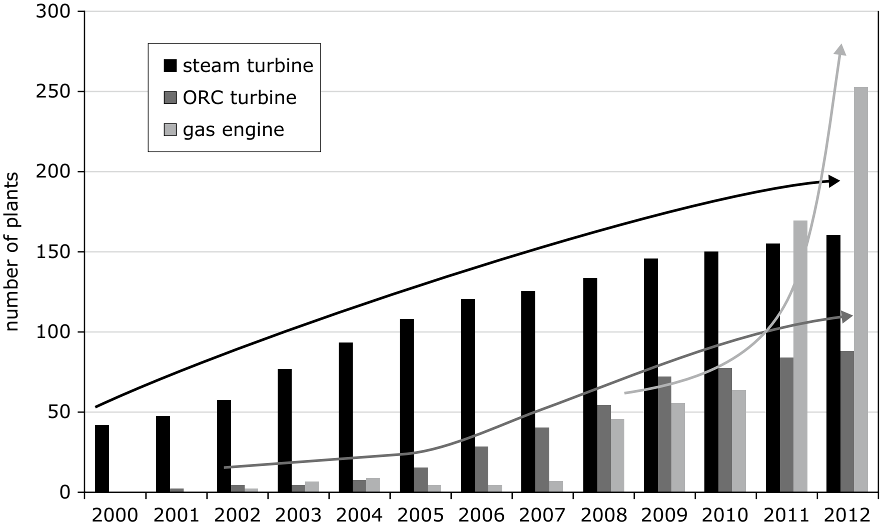

Fig. 4.3 Quantity of steam based systems, ORC plants and gasification plants (According to [24])

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[1] Tertiary control is used to stabilize the grid for deviations lasting longer than 15 min.

Furthermore, the feed-in-tariff according to the Renewable Energy Resource Act is currently not offering financial incentives for flexible operation of plants powered by solid biofuels.

4.6 Options for Flexible Power Generation in Existing Plants

Increasing the flexibility of power provision of existing plants powered by solid biofuels can be realized in two main ways. On the one hand, existing equipment within the operation units can be exchanged or improved to increase their flexibility. On the other hand, introducing additional storage options for intermediate energy carriers may provide higher flexibility.

Figure 4.4 shows the basic process schemes for the most relevant technologies for combined heat and power production from solid biomass in Germany. For each

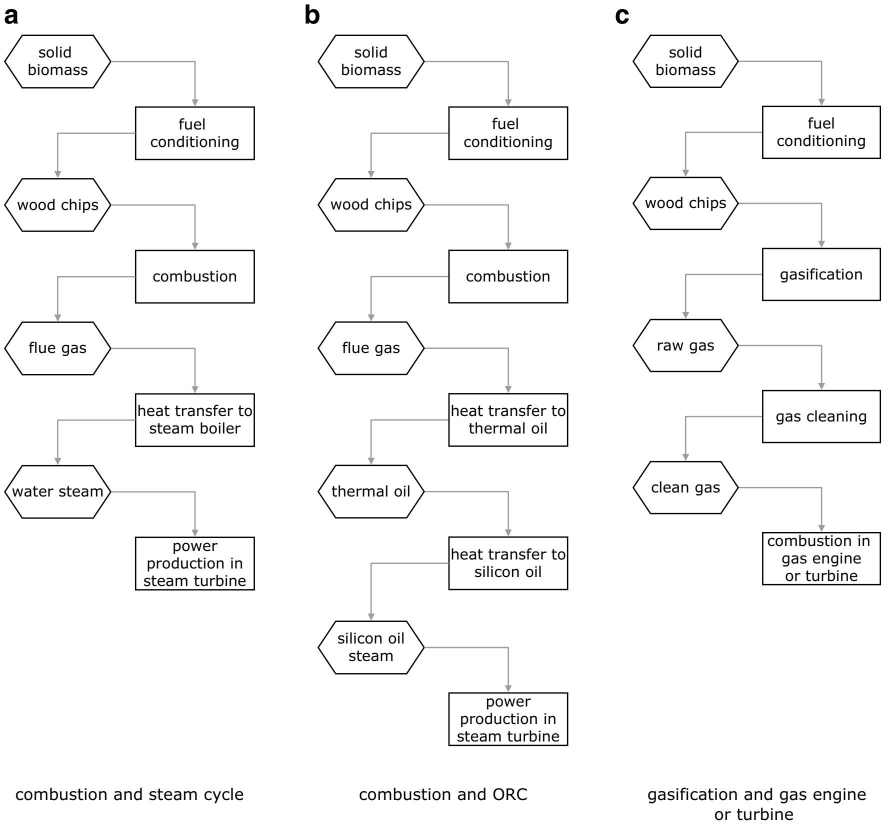

Fig. 4.4 Basic process schemes for the most relevant technologies for combined heat and power production from solid biomass in Germany

technology, the different material streams are listed on the left side due to their importance for storage based solutions. On the right side, the different process units are given that need to be considered for equipment improvement. To increase flexibility the whole chain has to be considered, starting from the last storage option which must offer a high enough capacity to have an effect on flexibility.

4.6.1 Increasing Flexibility of Plant Equipment

Flexibility in existing power plants for solid biomass is strongly dependant on the fuel input and the technology used. For example, some combustion technology is designed for moisture rich fuels (moisture content >40 %). The combustion chamber for such fuels sometimes has very strong brick walls to stabilize combustion. The heat capacity of such walls can limit the flexibility of the combustion process.

Traditionally, ramp rates of steam turbines are below 10 % per minute [20]. Overall flexibility of steam based power plants is much lower. For larger plants, steam bypasses can provide some flexibility within a small modulation range. There are steam cycle based biomass power plants in Germany that are qualified to provide negative tertiary control and that are actively offering control power at the respective markets.

ORC turbines can provide some flexibility by lowering heat transfer from the thermal oil cycle to the silicon oil cycle. The degree of flexibility depends on the heat demands of the overall system.

Gasification systems with gas engines are often already designed to run less than 5,000 h per year due to limited heat demand. If there is already a heat storage, the overall system can provide flexibility.

Steam turbines are offered with a ramp rate of up to 25 % per minute and a minimum turndown rate of 14 % (in certain combined cycle configurations) [21]. If heat provision has to be guaranteed, heat or even steam storage must be installed. Steam storage systems are available but induce losses in efficiency [22]. The overall system, including the combustion unit, can be expected to go down to 30 %. The most common options for increasing flexibility in an existing plant, according to solid biomass power plant operators, are improved control technologies (e.g. software, telecontrol options, enhanced boiler and turbine control).

4.6.2 Storage of Intermediate Energy Carriers

For all existing concepts based on fuel gas, synthesis gas or synthetic fuels as intermediate energy carriers, storage of these intermediates is a general option. Synthetic natural gas can be stored within an existing natural gas grid or in additional natural gas tanks, while even liquefaction is possible. Gases consisting of carbon monoxide and hydrogen and further gaseous components (fuel and synthesis gases) may be stored to improve short-term flexibility, i.e. to provide control power (see Table 4.4).

Table 4.4 Types and time frames of increasing flexible power supply based on solid biofuels

Flexibility time frame	Flexibility type (market)	To balance	Examples for necessary technical adaptations
<15 min	Secondary + tertiary control	Net frequency	Steam bypass or storage (for Steam Cycle Power Plants); gas storage (for gasification + gas engine)
15 min – 12 h	Intraday	Grid schedule optimisation	Advanced control strategies, heat storage
12–24 h	Day ahead	Weather forecast (PV, wind)	Advanced control strategies, heat storage
1–7 days	Day ahead	Macro weather situation (PV, wind)	Long-term heat storage with high capacity
7–90 days	Day ahead	Macro weather situation (wind, PV)	Long-term heat storage with high capacity
90–365 days	Day ahead	Seasonal fluctuations	Increasing efficiency in part load operation e.g. due to constructive changes in combustion chamber

4.7 New Concepts for Flexible Power Generation from Solid Biofuels

4.7.1 General Aspects

For 2050, the European platform on renewable heating and cooling for biomass expects a market potential in the range of 10 GW_{el} for biobased micro-CHP [23]. The technologies already described in Sect. 4.3 are, therefore, expected to be improved and to enter the market within the next 5–20 years. Flexible power production from solid biomass can be achieved through several technologies and varying production plant sizes.

For small scale systems, like micro-CHP, the main concepts for flexible power generation will be

- stabilization of local supply grids,
- minimization of local peaks in power demand or supply ("peak shaving"),
- and stable energy provision for micro grids, e.g. for isolated areas or buildings.

Depending on the concept, control systems for such micro-CHP plants will have to consider grid frequency and voltage as well as smart home aspects or even security of supply. Optimization strategies will focus on economic aspects or on grid stability, depending on the concept. Plant design will strongly depend on local heat demand, including the integration of heat storage and its respective control systems. Typically, the electrical output is expected to be in the range of 1–2 kW_{el} with electrical efficiency of 30–40 %, along with a thermal output of the whole system in the range of 2 kW_{th}. Depending on the integration concept, there will be increased communication between local systems and other entities, e.g. grid control systems, virtual power plants, or alike.

For large buildings and small industry, medium scaled units in the range of 15 up to 250 kW_{el} can play a major role in supplying demand based power and heat. These systems will have to be included in the HVAC (heating, ventilation and air conditioning) as well as in the electrical power control for the building with additional info from the grid. Heat storage and control are also an important aspect for these systems. Electrical efficiency should at least be in the range of 50 %.

New designed fuels (see Chap. 8) can possibly help to improve the technical flexibility of the systems.

4.7.2 Improvement of Technologically Available Concepts

Technologically available concepts, that are not state of the art, are usually characterized by a small number of installations and only a few providers. Usually, this leads to a lack of available data concerning economic, environmental and sometimes even technical aspects. From a conceptual approach, the different technologies provide different options of improving flexible power provision:

Combustion and EFGT

Externally fired gas turbines in combination with combustion is a promising option for flexible power generation especially in terms of fuel flexibility. The limiting factor in power production flexibility is the combustion process itself, since there is no steam cycle or the like. Usually, hot exhaust air from the turbine is used as combustion air. By bringing higher flexibility to the combustion process, system and combustion control becomes more challenging.

Gasification and Gas Turbine

Today, most gasification processes are installed in combination with gas engines. The combination of gasification with gas turbines has the potential to achieve a higher rate of electrical efficiency and high flexibility. Depending on the requirements, additional flexibility can be gained by changing the load of the gasification process or by storing syngas as an intermediate energy carrier.

4.7.3 New Concepts

In general, gasification is most promising for new concepts for flexible energy production from solid biomass. The product of gasification is a syngas which will give the highest possible amount of flexibility in electrical power production, if properly treated. Since such syngas or (by methanisation) synthetic natural gas can be mixed with biomethane and natural gas, additional degrees of freedom can be reached.

Gasification and Fuel Cells

Although there is already some research on the combination of gasification and fuel cells, the concept has not yet been introduced to the market due to high production costs and strict requirements in gas cleaning. A combined system of gasification and fuel cells, if including syngas and heat storage and an advanced control system, could provide flexibility in several time scales. Further developments indicate, that the reverse usage of fuel cells as electrolysis units is possible. Such a combined biomass-to-gas-to-power-to-gas system could provide control power in the range of −100 % to +100 %.

Hybrid IGCC

In regions with larger potentials of biomass for energy, IGCC can be an option for higher flexibility at high efficiency and nominal power. Since gasification and gas cleaning is the most limiting factor for the flexibility of such an IGCC, hybrid systems using biomethane from the grid and synthesis gas from gasification are promising. If lower electrical power is required within short time frames, reducing biomethane combustion will give a quick response in the gas turbine part, and vice versa.

Synthetic Fuel Production

Flexible production of synthetic fuels via the gasification path has the potential to provide electrical energy on demand by lowering the fuel production (see Chap. 7 – liquid and gaseous biofuels).

By using this approach, gasification and gas cleaning can run on constant power, which might be preferable for some fuels or gasification processes.

4.8 Conclusions

Flexible and demand-based production of electricity and heat from solid biomass is very interesting in the context of a renewable energy system since the used fuel shows excellent storability, including an existing infrastructure for logistics and pretreatment (e.g. pelletizing). However, conversion and power generation technology still restrain higher flexibility for different reasons. For example, some small scale CHP units based on combustion have high requirements on flue gas purity due to the heat exchanger materials and the like, which may limit load change rates. Larger plants may show less flexibility due to their thermal inertness (which sometimes has been part of the design, e.g. to stabilize combustion of fuels with low heating value).

For flexible power generation from solid biomass, there are several options. While some of them are based on already existing and installed technology, there are advanced concepts that will give even higher flexibility. An overview of such concepts is given in Table 4.5. It should be noted, that all estimates of efficiency, load change rates and potential electrical output ranges are strongly dependant on the actual size of the power generation system. For example, the combination of combustion and a steam engine in general is expected to show lower flexibility compared to an IGCC. Nevertheless, a small scale combustion system with a very small steam cycle might have higher load change rates than a large scale IGCC system.

Altogether, future power generation concepts for flexible energy production from solid biomass are required to have high electrical and overall efficiency, high load change rates and a high output range. Together with heat and fast (e.g. electrochemical) power storage, such systems can provide a wide range of flexibility for several applications from primary power control to seasonal variability.

In Table 4.5, the discussed concepts are compared in terms of current status, expected load change rate (see Table 4.1), electrical output range and electrical efficiency. The respective evaluations are a blend of those for thermo-chemical conversion technology, intermediate carrier and power conversion technology. As can be seen in this table, concepts with very high flexibility and efficiency can be expected to rely on gasification as a thermo-chemical conversion process due to the flexible handling of the gaseous intermediate energy carriers.

Table 4.5 Comparison of different concepts for flexible power generation from solid biomass

Power generation concept	Status	Load change rate	Potential electrical output range	Electrical efficiency
Combustion + steam turbine or steam engine	State-of-the-art	o/+	30–110 % (0–110 % with steam storage)	o
Combustion + ORC	State-of-the-art	o/+	0–100 %	–
Combustion + EFGT	Available technology	+	30–110 %	o
Gasification + gas turbine	Available technology	o/+	50–110 % (0–110 % with syngas storage)	+
Gasification + gas engine	State-of-the-art	+	50–110 % (0–110 % with syngas storage)	+
Hybrid IGCC	New concept	++	50–110 % (0–110 % for the gas turbine part)	++
Gasification + fuel cell	New concept	++	−100 % – +100 %	++

While the basic units of these future systems are already available, their complexity requires some further research work. Larger plants can be expected to be installed until 2025 under helpful conditions.

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