ECONOMY OF SCALE FOR CHP PLANTS BASED ON AUTOTHERMAL FLUIDIZED BED GASIFICATION

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ABSTRACT: A complete plant concept for the conversion of solid biomass to electricity and heat with an autothermal fluidized bed gasification and dry synthesis gas cleaning is developed. Plants with four distinct fuel capacities of 0.1, 1, 5 and 10 MW are further analyzed: firstly the investment cost are estimated based on commercial offers for main machinery and secondly economic evaluation is performed. Results show that at least a plant with fuel capacity of 10 MW is cost competitive with actual commercial processes. Economic evaluation results in a break-even point of 3.3 MW fuel input, above which such plant is economically feasible. A high degree of heat sold to costumers is another prerequisite to obtain plant profitability.
Keywords: combined heat and power generation (CHP), cost analysis, economics, fluidized bed, gasification

1 INTRODUCTION

Biomass gasification plants for electrical power production based on wooden fuels reveal a high potential for climate protection as they reduce the emissions of green house gases of at least 0.55 g CO_2-equivalent per kWh electrical energy [1] compared to the German electricity mix. If the power plant is operated in CHP-mode, an additional reduction of GHG-emissions of 0.23 g CO_2-equivalent/kWh_{el} is achieved. Therefore, CHP plants based on wood gasification can reach a large share in the reduction of GHG emissions, which the German federal government will reduce by 40 % until 2020 compared to the year 1990.

In Germany, the market for gasification power plants is dominated by downdraft fixed bed gasifiers in the range of 30 to 250 kW electrical power output, although first plants with fluidized bed gasifiers are in the evaluation or even in the commissioning phase. Many of these small commercial plants do not achieve the designed number of full load hours, mostly caused by tar condensation in and especially behind the wet synthesis gas cleaning (water quench and electrical precipitator or RME-scrubber) [2]. Another drawback of fixed bed gasifiers is their need for high quality wood chips, as only a narrow particle size distribution without any fines enables good gasification air distribution inside the fixed bed. At last, fixed bed downdraft gasifiers, especially if they are of throated type, cannot be scaled up beyond 1 MW fuel input because of increasing maldistribution of gasification air [3]. To reach the ambitious goal of GHG emissions reduction of the German federal government, a large number of fixed bed gasification CHP plants have to be build. By this approach no economy of scale can be realized, as cost are linearly linked with either fuel input or electrical power output.

All these problems in operability, fuel quality needs and low profitability provoked Fraunhofer UMSICHT to develop another still gasification based process with clear focus on combined heat and power production, which is more flexible in fuel input and plant capacity. As gasifier fluidized bed with ambient air as gasifying agent was chosen. Intense work was performed in developing a dry hot synthesis gas cleaning. The gas leaving the gasifier contains tar and dust as unwanted components. As dust is removed from a cold gas stream more easily than from a hot gas stream, it is convenient to remove the tar components first. As tar is composed of hydrocarbons and by that it contributes to the heating value of synthesis gas, it is better in view of overall conversion efficiency to convert tar to small gaseous molecules instead of removing it from the gas stream. Standard steam reforming catalysts based on Ni can do such conversion in the temperature range of 850 to 950 °C. As the high dust load of the gas will block a fixed bed of catalyst pellets in a short time, catalytic monoliths of honeycomb type are the best choice. Figure 1 shows a single monolith and the design of the tar reformer, which is to be placed directly behind the gasifier exit. After the tar conversion the synthesis gas can be cooled down in an indirect heat exchanger without danger of tar condensation. A state-of-the-art baghouse filter then is used to remove the dust load at a temperature around 120 °C. Afterwards, the synthesis gas is cooled down to engine inlet temperature with condensation of some water.

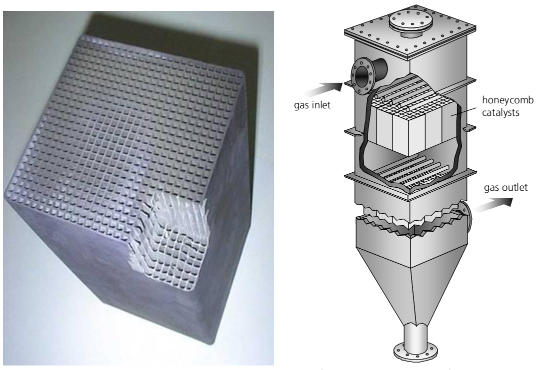

Figure 1: Catalytic monolith (left) and tar reformer with two layers of monoliths (right)

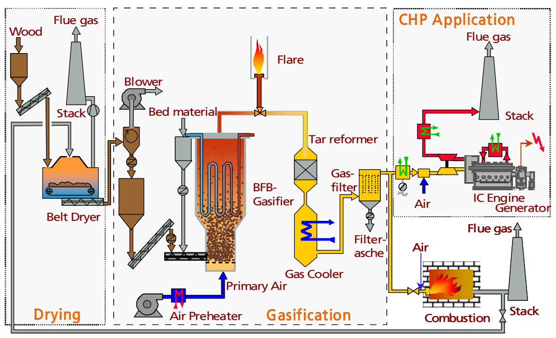

Figure 2: Power plant concept based on bubbling fluidized bed gasification and dry gas cleaning

The good results of such gas cleaning system are given in [4]. The resulting overall process is shown in Figure 2. Meanwhile, the process consisting of bubbling fluidized bed gasification with subsequent tar reforming reactor, cooling, dedusting and gas utilization in an IC engine for combined heat and power production is patented [5]. The overall process is made round by adding a fuel handling section with fuel receiving, storage, drying and dosing.

2 INVESTMENT COST

As a first step towards economic evaluation of the developed concept for CHP plants based on biomass gasification the investment cost for 4 different plant capacities, in particular 0.1, 1, 5 and 10 MW fuel input, have been estimated. Basic design has been performed for all 4 capacities to gain characteristic values for the main equipment. For this equipment quotations have been solicited. The equipment consists of:

- wood storage, drying,
- wood transport and dosing,
- fluidized bed reactor and refractory lining,
- cyclone,
- catalytic tar reformer,
- primary synthesis gas cooler (air preheater),
- primary air blower,
- baghouse filter,
- secondary synthesis gas cooler,
- IC engine,
- stack,
- cooling air blower,
- cooling water system and
- assembly crane.

The values have been added to give the investment cost for main machinery. For the estimation of total investment cost common costing supplement factors for buildings, erection, piping, insulation, electrics, process measuring and control technology and engineering have been used, which are published in [6]. The results of the investment cost estimation are given in Figure 3 as red diamonds. The red dashed trendline shows, that the investment cost do not increase linearly with fuel input, which would be the case, if capacity increase would be realized by numbering up of identical, independent lines. This economy of scale becomes even more evident, if the specific investment cost are looked at.

Assuming an overall electrical efficiency of 29 % independent of plant capacity enables the calculation of the specific investment cost per kW installed electrical power, which is given in Figure 2 as blue bullets. For the smallest plant capacity of 0.1 MW fuel input the specific investment cost are 34,000 €/kW$_{el}$, and for 10 MW fuel input at the other end of plant capacity the specific investment cost drop to 4,400 €/kW$_{el}$.

For comparison, 4 different values are given as green triangles in Figure 2, all representing real offers for CHP plants with an electrical output of 3 MW. Suppliers A, B and C offer different gasification systems with IC engines (steam gasification in fluidized bed, air gasification in fluidized bed and downdraft fixed bed, the latter one by numbering up to reach 3 MW electrical power; the sequence in this list does not correlate with A, B and C) and the last supplier offers a grate firing with boiler and steam turbine. As can be seen from Figure 3, the CHP plant based on autothermal wood gasification in bubbling fluidized bed with dry gas cleaning has the potential to be competitive with other systems offered at present for an electrical capacity of 3 MW, as the estimated cost for the complete plant (building included) are estimated to be less than the cost for plants from other suppliers.

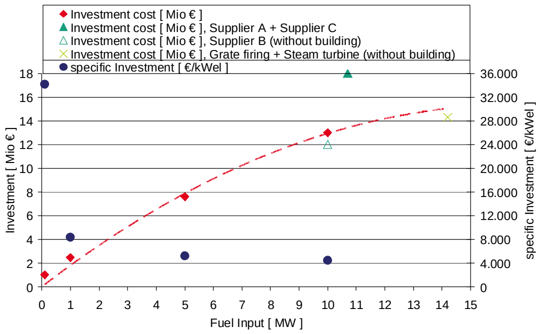

Figure 3: (specific) investment cost vs. fuel input

3 ECONOMIC EVALUATION

3.1 Method and boundary conditions

The economic evaluation of power plants of different scales are based on the VDI guideline 6025 [7], using the annuity method. Starting point is the estimation of investment cost (see Section 2 of this paper). The assumptions for the cost calculations are taken from [8] and are summarized in Table I. All cost and revenues are calculated for the price basis of the year 2010 and no increase over time is considered (as is suggested in [8]).

Table I: Assumptions for cost calculations [8]

Parameter	Value
Full load hours (power production)	7,500 h/a
Full load hours (heat sales)	7,500 h/a
Investment amount	I_0
Interest rate	8 %
Factor for Repairs	(2.5 % · I_0)/a
Assessment period	20years
Fuel (wood chips, 40 % water content)	75 €/t_{db}
Disposal fly ash	150 €/t
Specific personnel cost	50,000 €/(a employee)
Inspection and cleaning	(3 % · I_0)/a
Management	(0.5 % · I_0)/a
Insurance	(1 % · I_0)/a
Unforeseen	(0.75 % · I_0)/a
Electricity rate for own needs	120 €/MWh
Revenues for electricity	German feed-in tariff (EEG)
Revenues for heat	30 €/MWh

The assumed number of personnel is higher than the value from [8], where 0.5 employees are suggested per MW fuel input. As the technology is not suitable for unattended operation – at least for the first plants – there need to be at least one employee on site every time, which results in minimum number of employees of 5. For the smaller plants with fuel input of 0.1 and 1 MW this value is chosen. For the plant with 5 MW fuel input the number of employees is set to 8 and for 10 MW fuel input 10 employees were calculated. Additionally, the cost for catalytic monoliths is set to 227 €/piece.

3.2 Results

The annual cost and revenues calculated according to the annuity method of VDI guideline 6025 [7] are given in Figure 4 to 6 for plant capacities of 1, 5 and 10 MW fuel input, respectively. In these Figures the respective structure of cost and revenues are shown. As can be seen, the capital-linked cost (light blue block on top) is the largest constituent in the cost structure for all capacities and accounts for roughly 38 % of the annual cost. The influence of personnel cost (block in the middle) is decreasing from approximately 30 % for the plant with 1 MW fuel input to only a share of 12 % for the plant with 10 MW fuel input. On the other hand, the share of fuel cost (dark blue block on the bottom) increases from 13 % to 27 %.

The relative share of the components of the revenues is constant over fuel input as they are linearly linked with the electrical and thermal energy exported to the respective grid.

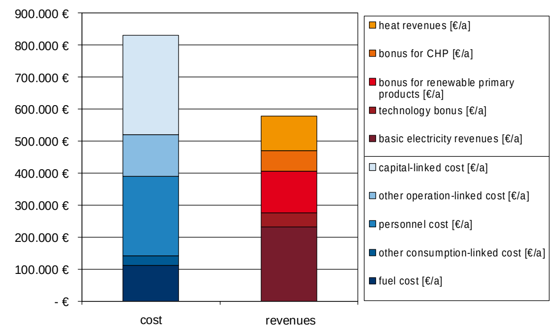

Figure 4: Cost and revenues for 1 MW fuel input

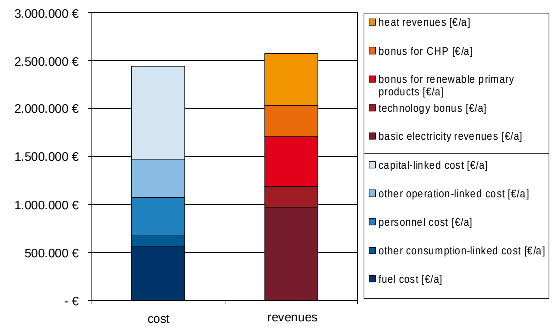

Figure 5: Cost and revenues for 5 MW fuel input

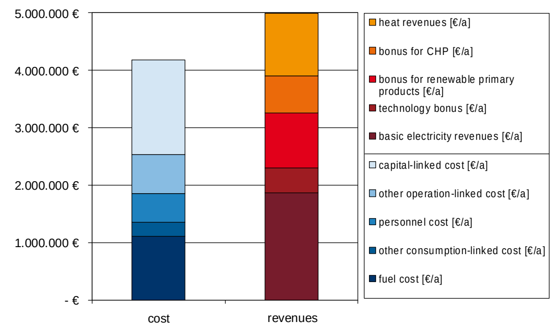

Figure 6: Cost and revenues for 10 MW fuel input

For a fuel input of 1 MW the cost are greater than the revenues. Such a plant would have a negative annuity (revenues – cost), and **isn't** economically feasible. For the larger plants, the revenues are greater than cost and therefore the annuity is positive, which means the plants **are** economically feasible. The annuity is shown in Figure 7 as a function of fuel input. For the base scenario with assumptions following Table I the break-even point (annuity equals zero) for a CHP plant based on fluidized bed gasification and dry gas cleaning is reached at a fuel input of approximately 3.3 MW fuel input, which is equal to an electrical power output of 1 MW.

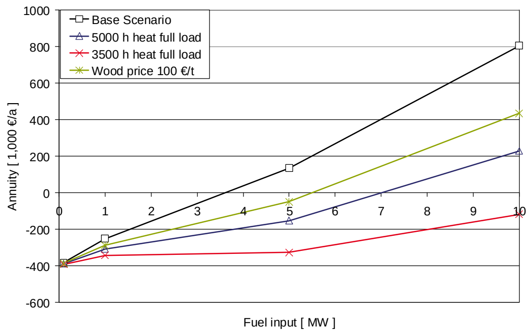

Figure 7: Annuity vs. fuel input of different assumptions

3.3 Sensitivity analysis

To demonstrate the influence of different assumptions from Table I on profitability economic calculations have been repeated with all assumptions kept constant bar one. The first assumption changed is the fuel price. If the fuel price increases from 75 €/t_{db} to 100 €/t_{db}, the cost increases while revenues are the same and therefore the break-even point is shifted to 5.5 MW fuel input, as can be seen from Figure 7. A reduction in heat full load hours has an even more severe impact on profitability of CHP plants based on fluidized bed gasification. If the electricity export to the grid is kept at 7,500 full load hours and only the heat sales are reduced to 5,000 full load hours, the break-even is already shifted to 7 MW fuel input. And if the heat sales are reduced further to only 3,500 full load hours per year, none of the analyzed plant capacities can be operated economically.

4 CONCLUSION

The estimation of investment cost presented here clearly indicate that an autothermal biomass gasification plant with dry gas cleaning and an IC engine for combined heat and power production is competitive with actual commercial biomass to power processes at least at higher plant capacities. Above fuel capacity of approximately 3.3 MW such a plant could be operated economically under certain boundary conditions. Furthermore, the economic evaluation showed that under German economic conditions such a CHP plant can **not** be operated economically even at high fuel capacities if the heat produced together with the electricity is not sold to a high degree.

To come to a marketable product the next step of development has to be the erection of a demonstration plant with a fuel capacity of around 1 MW. Such an installation will cost around 2.5 Mio € and will not be profitable. But such a plant has to demonstrate the ability of continuous operation while the revenues will be sufficient to cover all running cost except return of investment.

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