ECONOMIC ASSESSMENT OF POWER PRODUCTION FROM WOOD IN IGCC PLANTS AND IN NATURAL GAS FIRED COMBINED CYCLE PLANTS

T. Nussbaumer
Hochschule für Technik + Architektur (HTA) Luzern, CH-6048 Horw, (Switzerland), www.hta.fhz.ch
Verenum, Langmauerstrasse 109, CH-8006 Zurich (Switzerland), www.verenum.ch

ABSTRACT: Combined cycle (CC) power plants for natural gas (NG) achieve up to 60% efficiency for plant sizes of around 500 MWe. For biomass, integrated gasification combined cycle (IGCC) has been demonstrated in plants of two order of magnitudes smaller size and promise efficiencies of up to 45% at commercial scale. The study presents an assessment of electricity production for dedicated wood IGCC and co-firing of wood gas to a NGCC plant thus promising advantages due to the economy of scale. Based on cost estimations and experiences from literature, efficiencies and power production cost are calculated for plant sizes from 10 MWe to 1000 MWe. Since plant efficiency and transport expenses increase with plant size, a net efficiency is calculated by taking into account the fuel transport. For the wood potential in Germany, plant sizes of app. 200 MWe based on wood result in maximum net efficiencies and minimum electricity production cost of app. 9 Ct./kWh in wood IGCC for wood available at 2 Ct./kWh without transport. By co-firing wood gas to a NGCC plant, the electricity production cost can be reduced to app. 8 Ct./kWh. Hence, wood IGCC is regarded as a promising technology enabling high CO_2 reduction at economically interesting conditions. Furthermore, co-firing of wood gas to NGCC plants is regarded as even more interesting thanks to scale effects and is regarded as an interesting option as long as NGCC plants are in use for power production.

Keywords: Electricity generation, integrated gasification combined cycle (IGCC), co-combustion.

1 INTRODUCTION

Electricity production contributes to more than one third to the total greenhouse gas emissions and is even more important than the transport sector. Due to an increasing electricity demand worldwide, many countries are currently in the phase of planning or erecting large numbers of fossil power stations, which are mainly coal based and in some cases based on natural gas (NG). The share of coal will even increase in the future, since the coal reserves will last much longer than the reserves on natural gas and oil. Due to the high specific CO_2 emissions of coal, this trend will significantly accelerate the increase of CO_2 in the atmosphere, unless sequestration is applied worldwide.

While biomass is mainly used for heat production nowadays, there are strong efforts to convert biomass into transportation fuels and to replace fossil fuels in traffic. However, the substitution of fossil fuels in the electricity sector promises a higher CO_2 reduction potential than in road transport (e.g. [1–3]). Hence the utilisation of biomass for efficient power production is an interesting option. Beside co-firing in coal fired power stations, dedicated biomass power production is of interest as well. To achieve maximum efficiency, combined cycle (CC) processes are most favourable, as they enable a significantly higher electricity yield than nowadays small and medium scale biomass plants based on Rankine cycles. Today, CC with gas turbine and steam turbine is state-of-the art for the utilisation of natural gas in typical plant sizes of 400 MWe to 600 MWe enabling electric efficiencies of up to 60%. If fuel cells become commercially available in future, combined cycles e.g. by utilisation of pressurized high temperature fuel cells followed by a gas turbine for the flue gas expansion and a steam turbine for the heat recovery promises efficiencies of more than 70% in large scale applications or similar efficiencies as nowadays CC plants based on natural gas in much smaller size ranges (e.g. 10 MWe).

For biomass, the technology of integrated gasification combined cycle (IGCC) has been demonstrated in research and development projects. From experiences from the demonstration plant in Värnamö (Sweden) [4], IGCC is regarded as a promising technology for power production with expected efficiencies of up to 45% in commercial scale applications resulting from app. 75% gasification efficiency and up to 60% efficiency of the CC.

The aim of the present study is to evaluate the economy and the potential of the electricity production from wood in IGCC plants and to compare the power production cost with natural gas. In addition, the co-firing of wood gas in a NGCC power station is evaluated as an interesting option to increase the efficiency and reduce the cost for wood thanks to the economy of scale. Hence the following three cases are evaluated in the present study:

1. Natural gas combined cycle plant as reference case (NGCC),
2. Dedicated power production from wood by integrated gasification combined cycle (wood IGCC),
3. Co-firing of wood gas into a combined cycle natural gas fired power plant (wood in NG plant).

For this purpose, the power production cost and the potential for power production are evaluated in the study for the current prices and potential for wood fuel in Germany. Results for Switzerland are described in a separate report [5].

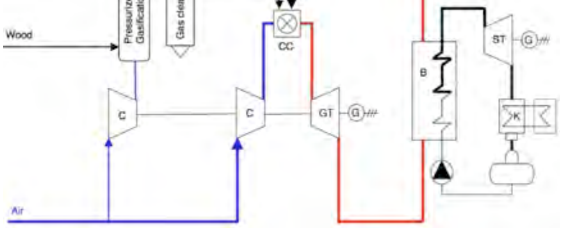

Figure 1: Concept of combined cycle power plant
1. for natural gas (NG) if applied without wood,
2. for dedicated wood integrated gasification combined cycle (wood IGCC),
3. for wood IGCC used for co-firing the wood gas into the natural gas plant (wood in NG plant).

2 TECHNICAL CONCEPT

The technical concept consists of an IGCC plant with pressurized gasification and hot gas clean-up coupled to a commercial gas turbine adopted to wood gas (Fig. 1). In case of co-firing to a NGCC plant, 80% of the power production is based on natural gas and 20% on wood. The co-firing offers several advantages:

- For the utilisation of wood, the economy of scale enables higher efficiencies and lower power production cost based on wood.
- The share of biomass can continuously be increased to establish a reliable wood supply and to finally utilise the available potential within a certain region.
- For the utilisation of natural gas, the co-firing of wood gas enables an attractive possibility to reduce the fossil fuel consumption and the fossil CO_2 emissions.

Without the wood part, Fig. 1 refers to a conventional NGCC plant.

3 ECONOMIC ASSESSMENT

3.1 Method and basic assumptions

The economic assessment is performed according to the method of annuity by taking into account capital cost, fuel cost, and additional operation cost as described in detail in [5] with the following basic assumptions:

Capital cost:

An annuity of 0.06505 is assumed which corresponds e.g. to an interest rate of 5.0% p.a. at a payback time of 30 a. The investment cost are summarized in Fig. 3.

Operation cost and power production potential:

The power production depends on the plant size and plant efficiency as shown in Fig. 2.

Operation of power plant:	6000 h/a
Operation cost for natural gas:	1% of investment
for wood:	2.5%
for urban waste wood:	5%
Fuel price for forestry wood chips:	2 Ct./kWh
Fuel price for wood residues:	1 Ct./kWh
Fuel price for urban waste wood:	0.5 Ct./kWh
Fuel price for natural gas:	5 Ct./kWh

The prices for wood fuels are given without transport. The transport cost are calculated as function of the plant size and the resulting transport distance with fix cost of € 100.- per truck load plus € 2.5 per km and accounting for an empty return drive.

In Germany, the price for commercially available wood chips with a water content of app. 35% in 2006 varied between Euro 35.– and Euro 90.– per ton delivered to the gate [6], which corresponds to approximately 1.2 to 3.0 Ct./kWh. Hence the price for forestry wood chips of 2 Ct./kWh without transport is currently realistic while it might increase in future. However, the influence of varying fuel prices can easily be estimated by taking into account the efficiency as shown in Fig. 2.

In 2006, natural gas was available for private consumers for app. 5 Ct./kWh. Although it might currently be cheaper for power plants, 5 Ct./kWh are assumed as reference price for natural gas in the present study, since natural gas exhibits a higher value than wood fuel due to lower investment cost and higher efficiencies. Furthermore, the price for natural gas might increase due to CO_2 taxes. Hence the investigated scenario is shown as an example and the comparison between natural gas and wood is of indicative value only, as prices for both fuels are related to significant variations.

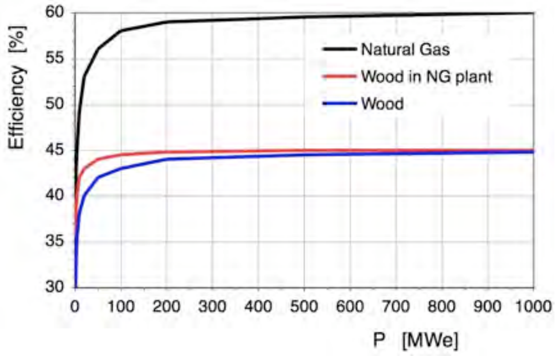

Figure 2: Electric efficiency as function of electric power output. From top to bottom:
1 Natural gas fired combined cycle power plant (NGCC),
2 Wood used for co-firing wood gas in a natural gas plant
3 Wood used in a dedicated IGCC plant (wood IGCC).
For case 2 (and 3), the x-axis corresponds to the power output from wood only, hence 100 MWe corresponds to 100 MWe from wood + 400 MWe from natural gas = 500 MWe in total.

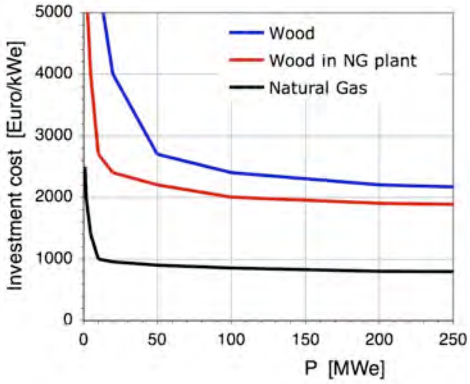

Figure 3: Specific investment cost of the three different power plant types. As in Fig. 2, the x-axis corresponds to the power output from wood only for case 2.

3.2 Efficiency and investment cost

Basic information on cost and efficiencies are available for commercial natural gas fired power plants and for biomass IGCC demonstration plants such as in Värnamö and as expected from other R&D programmes. For large scale IGCC, experiences are also available from coal. From these informations reported in literature [4, 7–13], the expected efficiencies and investment cost are derived for the present study for the NGCC plant and the wood IGCC plant as shown in Fig. 2.

For the combination of natural gas and wood gas, additional assumptions are needed. For the efficiency, the effect of scale of the CC part of the NG plant is assumed to be valid for the wood gas as well, hence for wood an additional gasification efficiency of up to 75% (being constant for large plant sizes) is assumed, while a possible variation in the CC efficiency due to the differences in the heating value of the gas mixture is neglected.

For the investment cost (Fig. 3) of the co-firing part of wood gas, the specific cost are assumed as if the NG part and the wood part were realised independently, but at specific investment cost as for the total plant size in both cases. This assumption does not refer to the real plant design and it overestimates the cost of the CC part (as virtually two independent CC parts are accounted for) on the one hand, while it underestimates the cost of the gasification part on the other hand. However, the assumption does qualitatively respect the economy of scale and it refers to relatively pessimistic synergies by combining a NGCC plant and a wood IGCC plant instead of building two independent plants: In the case of a 250 MWe plant with 200 MWe based on natural gas and 50 MWe based on wood, the savings for one combined plant instead of two independent plants are assumed to be less than 10%, which is probably underestimating the potential synergies. For a plant of 1 GW, the cost savings are assumed to be less than 5%, while for small plants, the savings become more important, i.e., app. 30% in case of a plant with 25 MWe in total or 5 MWe for wood.

Hence, the effect of combining natural gas and wood gas is probably underestimated for a wood output > 50 MWe or for a total plant output in case of co-firing of > 200 MWe. On the other hand, results on much smaller plants are related to high uncertainties due to two reasons: CC plants are unusual for small applications and thus the calculations are related to higher uncertainties in general. In addition, the effect of combining natural gas and wood gas becomes more important (due to increasing effect of scale) but at the same time more uncertain. Hence the present calculations are valuable to estimate qualitative effects of the combination of natural gas and wood, while for small plant sizes (wood < 50 MWe), the results are related to higher uncertainties.

4 RESULTS

4.1 Transport distance and power production potential

Based on the described assumptions, the electricity production cost are calculated for different fuel prices as function of the plant size. Since plant efficiency and transport expenses increase with increasing plant size, a net overall efficiency is calculated by taking into account the energy consumption for the fuel transport. This enables the evaluation of an optimum plant size, which – among other parameters – depends on the density of wood fuel available in a certain area. The calculations were performed for two examples, i.e., Switzerland as reported in [5] and Germany. For Germany, the total wood fuel potential is assumed to 348 PJ/a of which 192 PJ/a are currently used [14]. For the present study, only the remaining nowadays unused potential of 156 PJ/a is respected. For both countries, a homogeneous distribution of the today's unused wood fuel is assumed. Fig. 4 shows the average transport distance as function of the plant size for Germany. Fig 5 indicates the net efficiency including the transport in two different types of trucks used. The evaluation shows, that plant sizes of app. 200 MWe are favourable for Germany thus resulting in maximum overall efficiencies and minimum electricity production cost. With the unused wood potential, 16 such plants could be operated in Germany enabling a power production of app. 19 TWh/a corresponding to app. 3.6% of the nowadays electricity consumption. In Switzerland, the optimization results in 4 plants of app. 150 MWe with a total power production of app. 3.5 TWh/a.

4.2 Power production cost

For plant size of 100 MWe based on wood, electricity production cost of app. 9 Ct./kWh are expected for dedicated wood IGCC (Fig. 6), while app. 8 Ct./kWh are achieved by co-firing of wood gas in a NGCC plant (Fig. 7). Hence the integration of wood co-firing in a NGCC plant enables app. 10% savings thanks to increased efficiency and reduced specific cost.

4.3 Energy yield and air pollution

The total energy yield of power production from wood in IGCC or NGCC applications can be compared to heat production from wood by assuming to drive electric heat pumps by power produced from wood as described in [15]. This comparison shows, that power production at efficiencies greater than 40% is advantageous in comparison to heat production already at a coefficience of performance (COP) of the heat pumps of > 2. Nowadays heat pump applications allow COP of > 3 (up to > 5) thus showing, that dedicated power production from wood is favourable if applied in highly efficient CC power plants. Furthermore, the total pollutant emissions, especially of particulate matter PM10 (which are very low from IGCC plants [16], can be significantly reduced in comparison to residential wood heating even if Diesel trucks are considered for the transport [15].

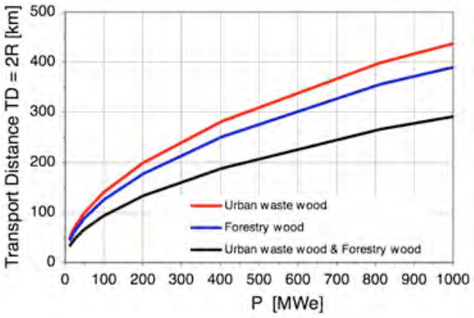

Figure 4: Average transport distance for wood as function of the power plant output based on wood and for 6000 hours of operation annually.

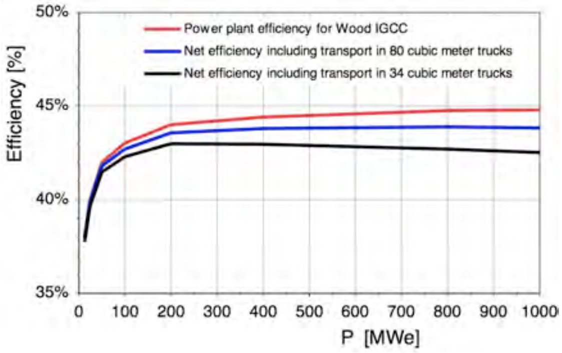

Figure 5: Efficiency of IGCC plants as function of plant size (top). Calculated net efficiency by considering the energy consumption for road transport of the wood fuel in 80 m^3 trucks (middle) and 34 m^3 trucks (bottom).

5 CONCLUSIONS

Power production from biomass by IGCC plants promises efficiencies of up to 45% and enables economically interesting electricity production cost. The evaluation shows, that plant sizes of app. 150 MWe are favourable for Switzerland and of app. 200 MWe for Germany thus

§resulting in maximum overall efficiencies and minimum electricity production cost. With the unused wood potential as reported in recent studies, 4 such plants could be operated in Switzerland and 16 plants in Germany enabling power production cost of app. 10 Ct./kWh in Switzerland (for wood fuel at 3.5 Ct./kWh) and 9 Ct./kWh in Germany (for wood at 2 Ct./kWh) in case of wood based IGCC plants. The combination of wood gasification and utilisation of the wood gas in a natural gas fired combined cycle power stations enables higher energy yield from the wood and reduced power production cost from wood. The savings are expected to be in the order of 0.5 to 1 Ct./kWh. For the fuel supply, all available unused wood within an area of in average app. 60 to 90 km distance around the power plants would be needed for the plant operation.

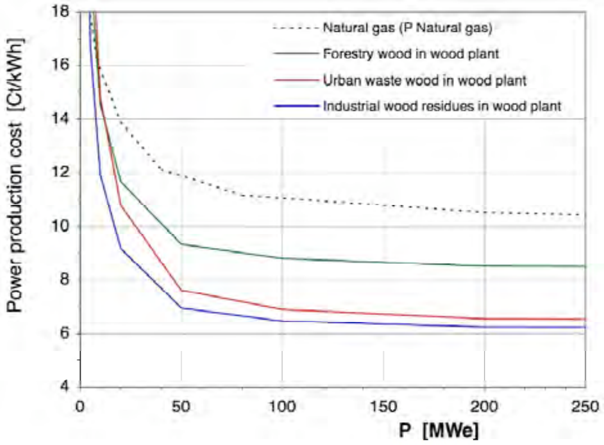

Figure 6: Power production cost from natural gas and from a dedicated wood IGCC plant as function of power output. Fuel prices: natural gas 5 Ct/kWh, forestry wood 2 Ct/kWh, industrial wood residues 1 Ct/kWh, and urban waste wood 0.5 Ct/kWh.

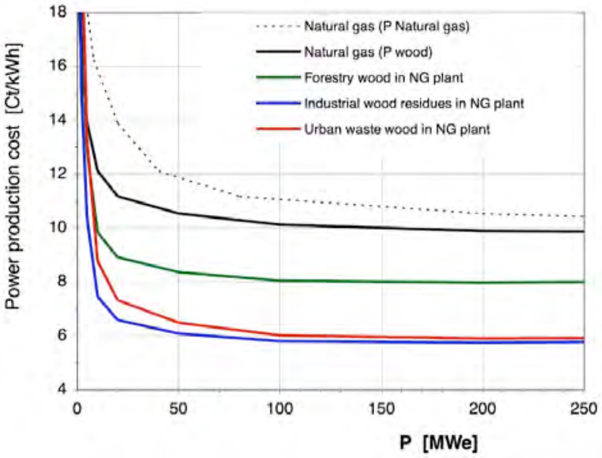

Figure 7: Power production cost from natural gas and for wood used for co-firing in a natural gas combined cycle power station and fuel prices as shown in Fig. 6.
In this figure, 100 MWe from wood corresponds to 400 MWe from natural gas and 500 MWe total power output, as 80% are based on natural gas and 20% are based on wood. The data for wood refer to the power output generated from wood, while the data for natural gas are indicated once as function of the wood power (line below) and once as function of the natural gas power (line above and as in Fig. 6).

6 LITERATURE

[1] Jungmeier, G., Canella, L.: Greenhouse Gas Emissions of Energy Systems with Bio-oil, Science in Thermal and Chemical Biomass Conversion, CPL Press, UK, ISBN 1-872691-97-8, 1700–1713

[2] Edwards, R.: Well-to-wheels analysis of biofuels, 2nd World Conference on Biomass for Energy, Industry and Climate Protection, 10-14 May 2004, Rome, PD 2.4

[3] Arnold, K., Ramesohl, S., Grube, T., Menzer, R., Peters, R.: Strategische Bewertung der Perspektiven für synthetische Kraftstoffe auf Biomasse-Basis in NRW, 10. Fachk. Zukunftsenergien, Essen 14.2.06

[4] Stahl, K., Waldheim, L., Morris, M., Johnsson, U, Gardmark, L.: Biomass IGCC at Värnamo, Sweden – Past and Future, GCEP Energy Workshop, 27.4.04, Stanford University, CA, USA, 2004.

[5] Nussbaumer, Th.: Holzgas/Erdgas-Kombikraftwerk für die Schweiz: Potenzial und Wirtschaftlichkeitsabschätzung, Bundesamt für Energie, Publikation 250049, Zürich 2005, Download www.verenum.ch

[6] Centrales Agrar-Rohstoff-Marketing und Entwicklungs-Netzwerk e.V.: Preisentwicklung bei Waldhackschnitzeln, www.carmen-ev.de, 2006

[7] Abboud, J.: Statement to the United States Senate Appropriations Committee regarding the Department of Energy Turbine R&D Programs, submitted by the Gas Turbine Association (GTA), 2005.

[8] Bridgwater, T.: Biomass for power and heat, Bio-Energy Research Group, Aston University, Birmingham, 2004.

[9] Cameron, J., Kumar, A., Flynn, P.: Power from biomass: The economics of gasification vs. direct combustion, Second World Biomass Conference, 10–14 May 2004, Eta Florence & WIP Munich 2004, 867–870.

[10] Craig, K., Mann, M.: Cost and Performance Analysis of Biomass-Based Integrated Gasification Combined-Cycle (BIGCC) Power Systems, NREL/TP-430-21657, Golden, Colorado 80401-3393, U.S. Department of Energy 1996.

[11] ECG 2004 (Energy Consulting Group Ltd.): Fossilthermische Kraftwerke, BFE-Tagung „Zukunft des Elektrizitätsangebots", 2. Juli 2004, Bern.

[12] Rensfelt, E.: Gasification Survey Report Sweden. In: K. Kwant, H. Knoef (Eds.): Status of Gasification, IEA Bioenergy and Gasnet, 2002.

[13] Tiangco, V., Sethi, P., Zhang, Z.: Biomass – Strategic value analysis, IEPR Workshop, 1.7.05, California Energy Commission, 2005.

[14] Kaltschmitt, M.: Einleitung und Zielsetzung, in: Energie aus Biomass, Springer, Berlin 2001, ISBN 3-540-64853-42001, 1–32

[15] Nussbaumer, Th.: Potenzial und Wirtschaftlichkeit der Holzenergie für Wärme, Wärmekraftkopplung, sowie Stromerzeugung, 9. Holzenergie-Symposium, 20. Oktober 2006, ETH Zürich, 2006, ISBN 3-908705-14-2, 123–159. Download www.holzenergie-symposium.ch

[16] Stahl, K.: Värnamo Demonstration Plant, Berlings Skogs, Trelleborg (S) 2001.

Acknowledgments
Swiss Federal Office of Energy