Yield of woody biomass from southern Norway and their suitability for combustion and gasification purposes depending on the harvest frequency

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1 Introduction

The intention of the project is to analyse the influence of the harvest frequency on the yield of the woody biomass and their suitability for gasification and combustion purposes.

In 2002 an area of 1,250 m² has been cultivated with three different clones of willow ('Christina' *Salix viminalis*, 'Aage' and 'Steffan' *Salix schwerinii x Salix viminalis*) and three clones of poplar ('Spirit' and 'Muhle Larsen' *Populus trichocarpa* as well as 'O.P.42' *Populus trichocarpa x Populus maximoviczii*). In case of the willow parts of the field were harvested at the beginning of 2003 and 2004. In April 2005 an additional area of 250 m² with three willow clones was established ('Gudrun' *Salix dasyclados*, 'Tordis' *(Salix schwerinii x Salix viminalis) x Salix viminalis* and 'Aage' *Salix schwerinii x Salix viminalis*) with 150 cuttings each. *Table 1* gives an overview of the different woody energy crops established in Grimstad.

Table1: Overview of the different woody energy crops established in Grimstad, stand April 2006

Block number	Clone	Genus	Age of the shoots	Age of the roots
[#]	[-]	[-]	[a]	[a]
1	Gudrun	Willow	1	1
2	Tordis	Willow	1	1
3	Aage	Willow	1	1
4	Christina	Willow	2	4
5	Aage	Willow	2	4
6	Steffan	Willow	2	4
7	Christina	Willow	3	4
8	Aage	Willow	3	4
9	Steffan	Willow	3	4
10	Christina	Willow	4	4
11	Aage	Willow	4	4
12	Steffan	Willow	4	4
13	O.P. 42	Poplar	4	4
14	Muhle Larsen	Poplar	4	4
15	Spirit	Poplar	4	4

2 Materials and Methods

In each willow block two central rows were harvested to measure the yield. To measure the water content samples were dried in laboratory ovens at 105°C until constant weight. The poplar blocks 13 to 15 merely contain 30 trees. Only half of them were harvested in order to follow the production after two more (six in all) years. Bow saw, lopper and hand pruner were used for harvesting the mentioned trees. The remaining border plants were harvested by a chain saw.

The combustion experiments were carried out at the University of Applied Sciences in Stralsund with the boiler "thermi^{nator}" (Solarfocus, Austria). Different four year old samples from Norway were burned as wood chips and as wood logs. The CO content in the exhaust gas was measured with a portable exhaust gas analyser "IM 2800" (IM Environmental Equipment Germany GmbH).

The gasification experiments were performed at the University of Applied Sciences in Offenburg with a downdraft gasification unit. The produced gas was burned in an old Renault 4 Otto engine which is connected to an asynchronous machine. The amount of generated electricity was measured with an electrical counter. The composition of the produced synthesis gas was determined continuously with an ABB "Advance Optima" gas analysis system.

3 Results and Discussion

3.1 Yield

Based on the harvest in late winter 2006 alone you could evaluate the growth as *Figure 1* shows. Here you see that 'Aage' and 'Steffan' reach their maximum annual yield after a growing time of only two years. In 'Aage' up to 16 t_{DM}/(ha a) could be harvested. The yield in 'Christina' is rather poor. The maximum value is obtained after the third growing year with 14.2 t_{DM}/(ha a).

The standardised yields of the old willow seam to decrease with an increasing growing time. Especially in 'Steffan' it is clearly visible that a high harvest frequency leads to optimal yields.

The breeders of the newer willow clones also recommend to harvest after a growing time of two to three years. [1]

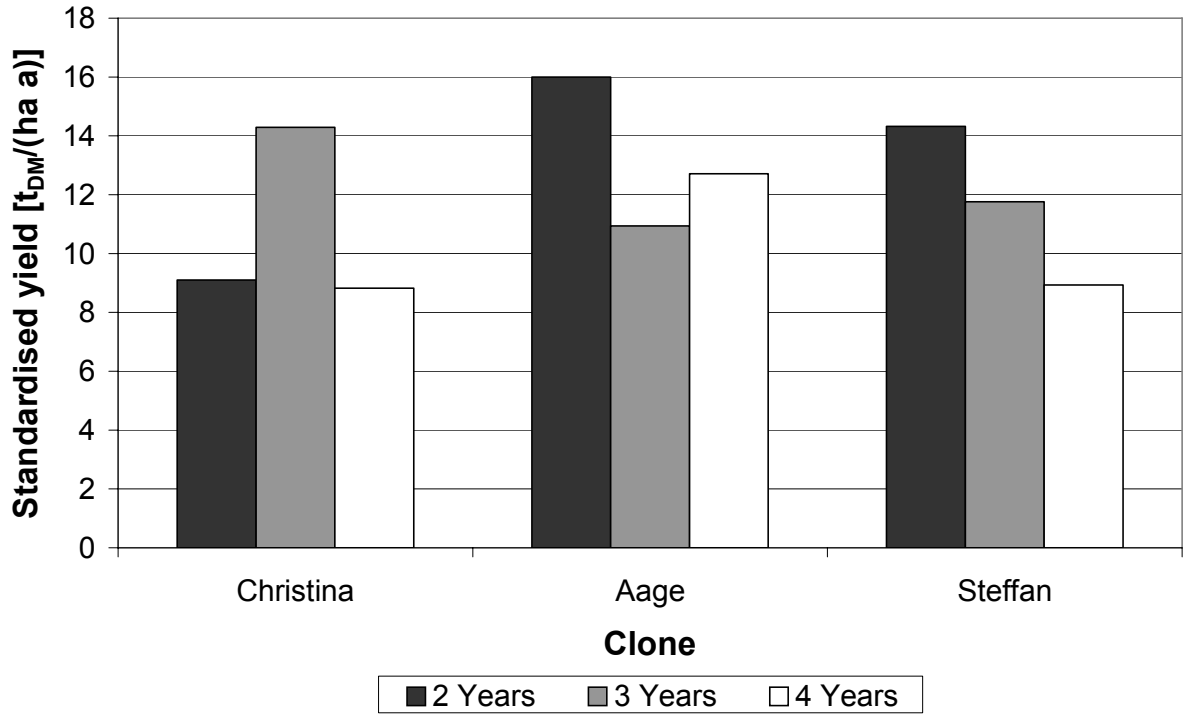

Figure 1: Comparison of the standardised yields of the different clones in the old willow depending on the harvest frequency

With the results of the harvests in 2003 and 2004 it is possible to follow the development of the yield of the different willow clones since the establishment in 2002. This correlation is demonstrated in *Table 2* and *Figure 2*.

Table 2: Absolute measured yields during the harvests in 2003, 2004 and 2006 in the old willow

Block	Clone	Harvest frequency	2002 - 2004	2004 - 2006	Sum	Sum
[#]	[-]	[-]	[t_{DM}/ha]	[t_{DM}/ha]	[t_{DM}/ha]	[t_{DM}/(ha a)]
4	Christina	2+2	7,90	18,20	26,10	6,53
5	Aage		13,90	32,00	45,90	11,48
6	Steffan		18,00	28,64	46,64	11,66
-			2002 - 2003	2003 - 2006	-	-
7	Christina	1+3	4,22	42,86	47,08	11,77
8	Aage		3,10	32,82	35,92	8,98
9	Steffan		1,34	35,28	36,62	9,16
-			2002 - 2006		-	-
10	Christina	4	35,29		35,29	8,82
11	Aage		50,85		50,85	12,71
12	Steffan		35,74		35,74	8,94

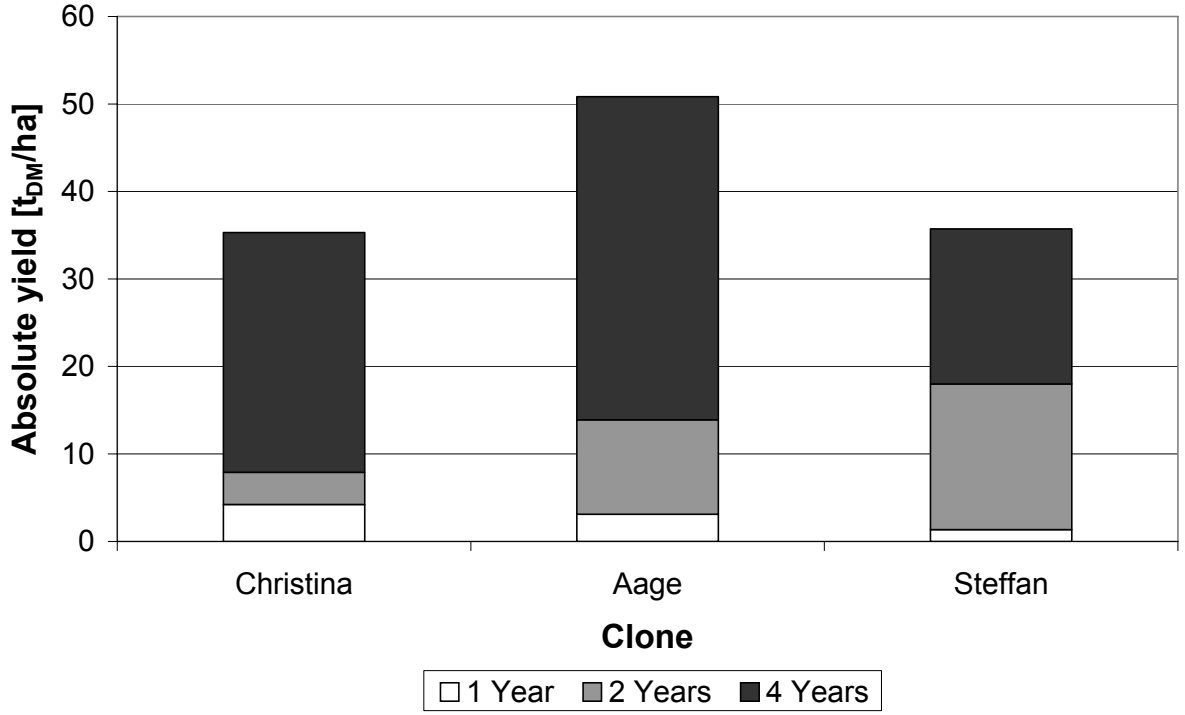

Figure 2: Accumulated absolute yields of the different clones in the old willow measured in 2003, 2004 and 2006. The yield after four years undisturbed growth divided into measured yield after the first and second year.

The yield of the one year old shoots from the field established in 2005 ranges from 1.2 t_{DM}/(ha a) in 'Aage' and 2.9 t_{DM}/(ha a) in 'Tordis'. Compared to the field of 2002 this area has not been fertilised before establishment. So the yields are rather poor according to the yields measured in 2003 in the old willow. 'Tordis' and 'Gudrun' are the most promising clones in the new willow field as they nearly reach the yield of 'Aage' measured in 2003 without fertilizer. This agrees with the findings of the company delivering the cuttings “Ny Vraa”/Denmark. [2]

Regarding the four year old poplar the yield varies from 7.1 t_{DM}/(ha a) in 'O.P. 42' to 10.29 t_{DM}/(ha a) in 'Spirit'. This is based on a single row free from competition on one side. The harvest of the remaining trees in the beginning of 2008 will show how the annual yield will develop perhaps with a more ideal growing time of six years for poplar.

3.2 Combustion experiments

The combustion experiments were performed with the "thermi[nator]" boiler at University of Applied Sciences in Stralsund. This boiler has a nominal thermal power of 50 kW and is suitable for wood logs, wood chips and pellets. It is designed as a shaft furnace. The experiments were done with samples of the four year old willow clones 'Christina', 'Aage' and 'Steffan' as well as a mix of the poplar clones 'Spirit' and 'Muhle Larsen' (both *Populus trichocarpa*). The four different wood types were combusted as wood logs and as wood chips i.e. eight experiments in all.

It was found that the power of the boiler is generally higher when it is operated in the wood log mode. In average the difference is 14.9 %. This fact is illustrated in *Figure 3*.

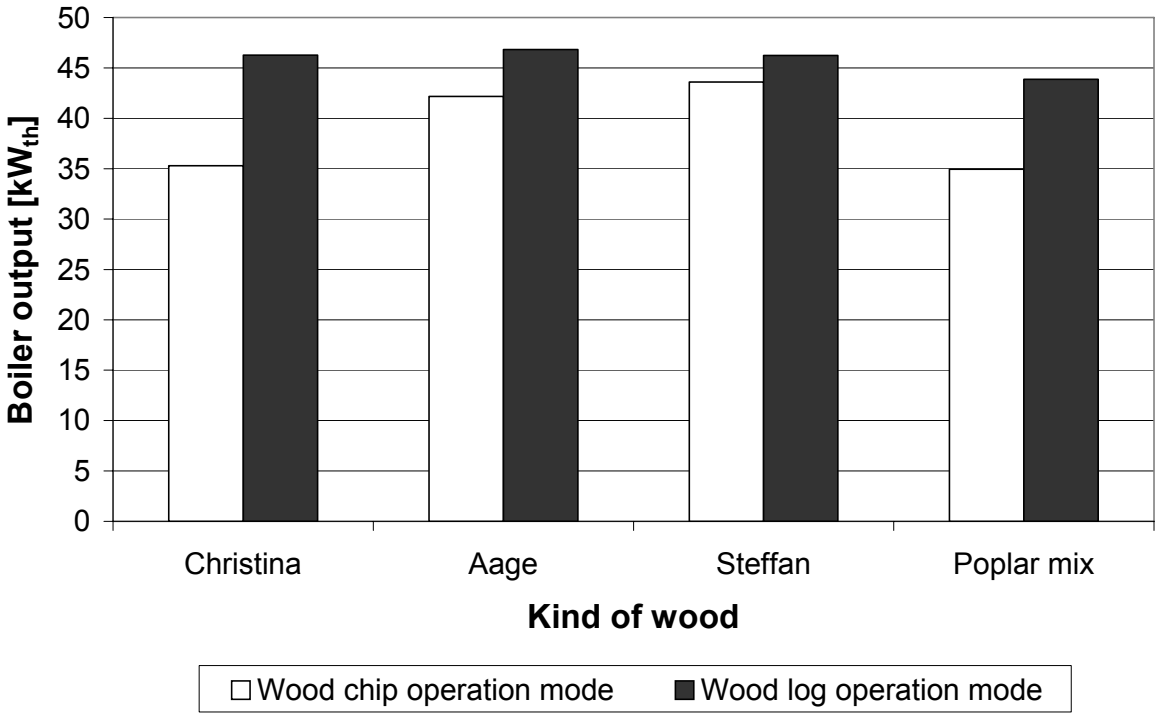

Figure 3: Average output of the boiler in kW_{th} depending on the kind of wood and the operation mode of the boiler in a stationary operation point

The average thermal power in the wood chip operation mode in case of 'Christina' and the Poplar mix is rather poor. This is due to a bad wood chip quality particularly with regard to excess lengths and higher impurities of the fuel. The highest thermal power reached 'Aage' and 'Steffan' in the wood chip operation mode with 46.8 kW_{th} and 46.2 kW_{th} respectively. Furthermore it was found that the released power of the boiler was more constant during the wood log operation mode. Independently of the kind of wood the thermal power always

varied a lot more in the wood chip operation mode. A reason for this phenomenon is the batch wise fuel feed during the wood chip operation mode. In the wood log operation mode the whole fuel had been added before the combustion was started. Normally stoker augers give a more continuous feeding compared batch stoking. The boiler originally was designed for wood logs. So this is why a more constant power release was achieved with wood logs. *Figure 4* demonstrates this fact for the willow clone 'Steffan'.

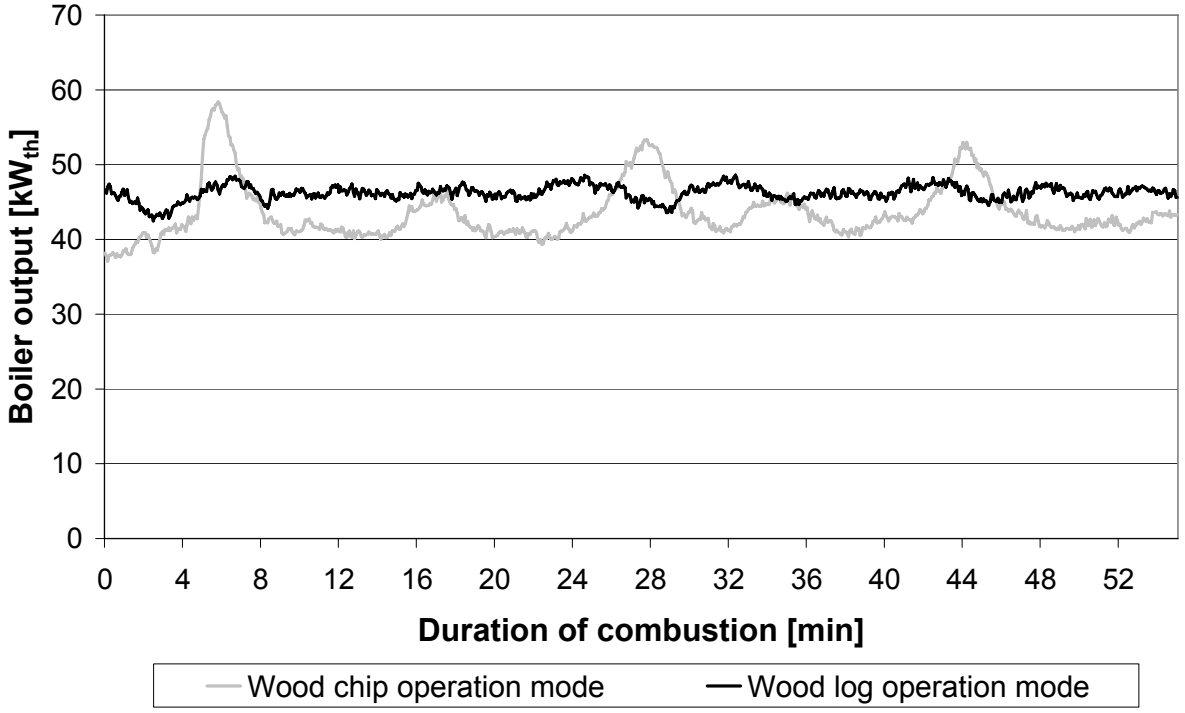

Figure 4: Variation of the thermal power of the boiler in wood chip and wood log operation mode during the combustion at a “stationary operation point”

The CO content in the exhaust gas is a measure for the quality of the combustion. Low CO contents describe an almost complete combustion. The German legislation allows a CO content of 4,000 ppm at a thermal power of 50 kW. [3] The measuring range of the instrument is between 0 and 2,000 ppm. The CO content in the wood chip operation mode is always higher than in the wood log operation mode as it can be seen in *Table 3*. In case of the Poplar mix the CO content reached values higher than 2,000 ppm which were no more measurable with the equipment available.

Table 3: CO content in the exhaust gas in ppm depending on the kind of wood and on the operation mode of the boiler in a stationary working point

Clone	Wood chip operation mode	Wood log operation mode
[-]	[ppm]	[ppm]
Christina	651	82
Aage	431	124
Steffan	309	230
Poplar Mix	>2000	234

3.3 Gasification experiments

The gasification unit at University of Applied Sciences in Offenburg is designed as a downdraft gasifier. It was filled with approximately 20 kg of wood pieces with a maximum length of six centimetres. So it could be ensured that the material slips down the shaft. In the first experiment the water content of the material which was harvested three months before was 24.6 %. This was too high and caused many problems, especially with condensate and tar in the system. The temperature in the reaction zone was not high enough so that the synthesis gas producing reaction didn't start. The quality of the gas was so poor that the engine didn't start. Hereupon the remaining samples were dried at 65°C for two days to a water content of five to nine percent. With this water contents the experiments ran satisfactorily.

The measured data during the gasification experiments are listed in *Table 4* and *Table 5*. There are no data for block five because of the aborted experiment with the high water content mentioned above. In block one and three there was not enough material available for gasification experiments. All experiments were carried out with material harvested between March and April 2006.

Table 4: Determination of the wood consumption during the gasification experiments

Block	Duration of the experiment	Wet material	Water content	Dry material	Wood consumption
[#]	[h]	[kg]	[%]	[kg_{DM}]	[kg_{DM}/h]
2	1.83	14.0	7.02	13.02	7.10
4	1.50	12.4	7.89	11.42	7.61
6	0.33	2.8	7.79	2.58	7.75
7	1.50	12.6	7.96	11.60	7.73
8	1.50	12.4	7.52	11.47	7.65
9	1.50	13.4	6.01	12.59	8.40
10	1.50	12.6	8.79	11.49	7.66
11	1.50	13.6	8.13	12.49	8.33
12	1.50	13.0	9.08	11.82	7.88
13	1.50	11.4	6.75	10.63	7.09
14	1.33	11.0	5.76	10.37	7.77
15	1.50	13.0	6.82	12.11	8.08

Table 5: Determination of the specific produced electric power per block

Block	Produced electric power	Specific produced electric power
[#]	[kWh]	[kWh/kg_{DM}]
2	9.06	0.70
4	6.81	0.60
6	1.65	0.64
7	7.45	0.64
8	7.20	0.63
9	6.45	0.51
10	7.26	0.63
11	6.20	0.50
12	6.55	0.55
13	6.18	0.58
14	5.20	0.50
15	6.36	0.53

In *Figure 5* the results of the old willow are illustrated. The value for 'Aage' – 2 years is missing due to the abortive experiment.

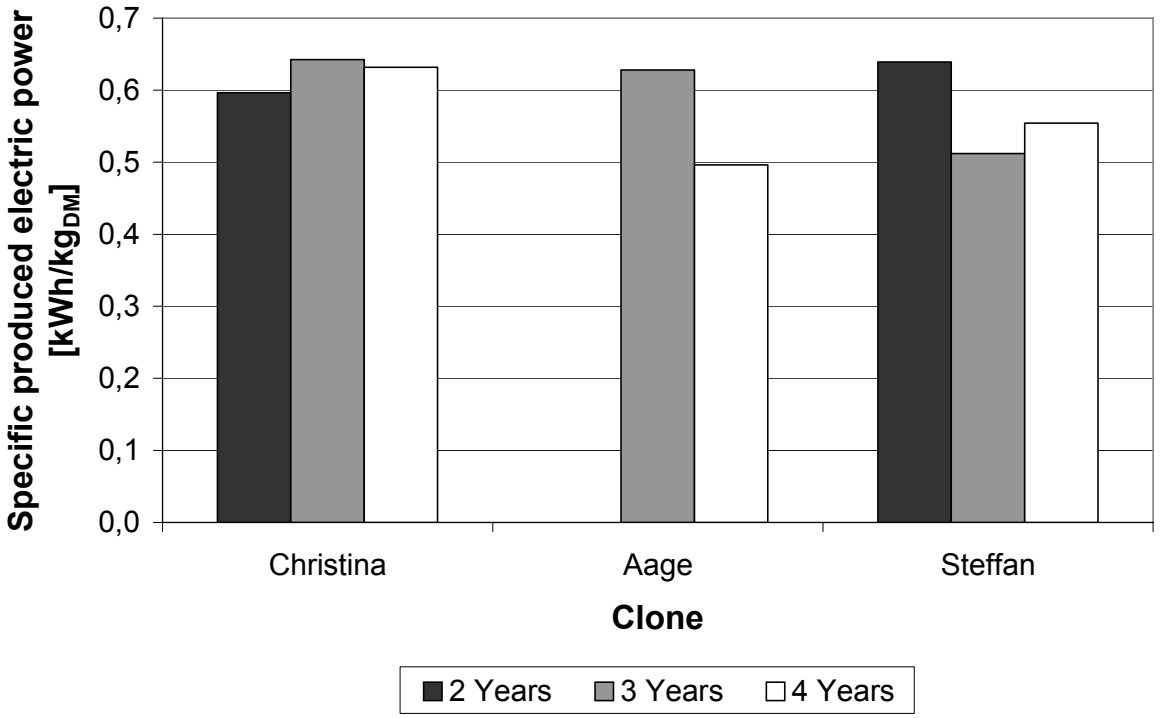

Figure 5: Comparison of the specific produced electric power of the different clones in the old willow depending on the harvest frequency

Interestingly the highest specific produced electric power was generated with the one year old shoots of 'Tordis'. There is no correlation between the age/kind of wood and the specific produced electric power observable. In fact the specific produced electric power seams to be more depending on the way the system is operated (volume flow of the gasification air, pressure in the system). Within the system it is not possible to keep these parameters constant during every experiment.

Figure 6 shows the composition of the produced synthesis gas during a stationary operation point depending on the water content of the gasification material. It is obvious with a low methane content in the producer gas, that a high content of carbon monoxide always goes along with a low content of carbon dioxide and the other way around because the amount of carbon in the fuel is limited. The values of methane and hydrogen seam to be stable over the water contents tested. With slightly higher water contents more hydrogen could be generated.

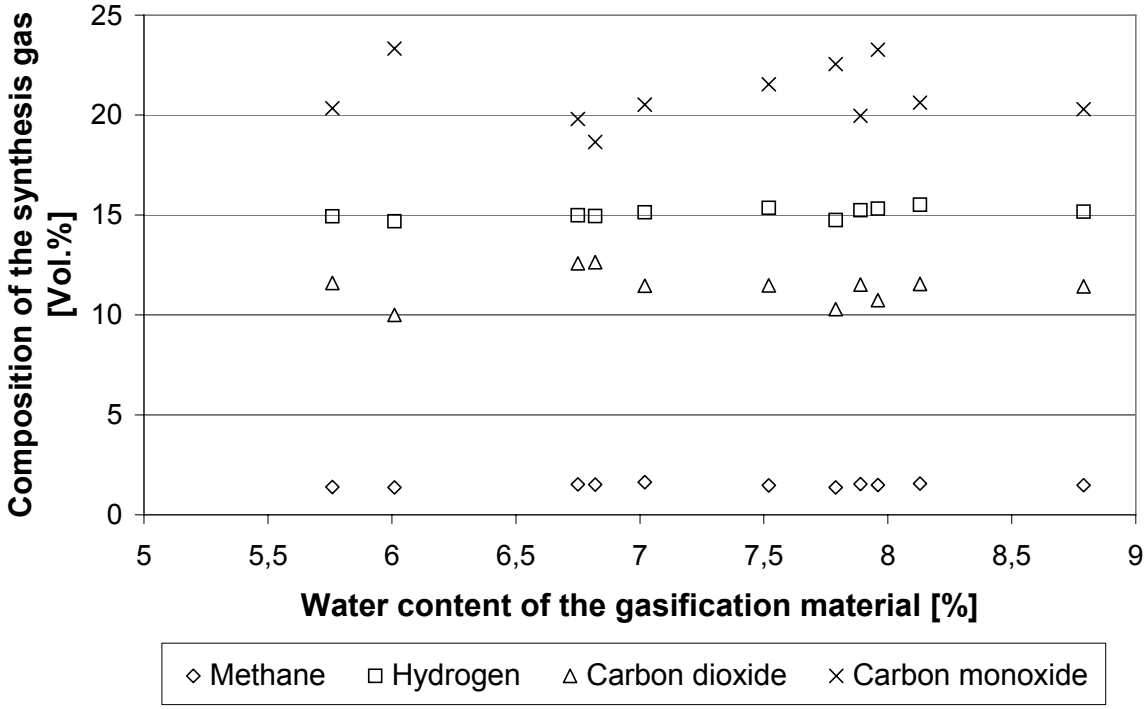

Figure 6: Composition of the produced synthesis gas during a stationary operation point depending on the water content of the gasification material

Compared to literature the values of carbon monoxide are rather low, the values of carbon dioxide in this case are quite high. The values of methane and hydrogen on the other side agree with other findings. [4]

4 Conclusions

The highest yield of 16 t_{DM}/(ha a) could be found for the willow clone 'Aage' with a growing time of just two years. 'Steffan' also reaches its highest yield after two years while 'Christina' achieves the maximum standardised yield after three years of growing. The new willow clones 'Tordis' and 'Gudrun' are most promising and should reach even higher yields in future. The yields measured in the poplar are lower than the maximum yields of the different willow clones.

Based on the few experiments in Stralsund, for combustion purposes it's recommended to use wood logs. They deliver a higher thermal power than wood chips. The released thermal power in the wood log operation mode is much more even than in the wood chip operation mode due to the batch-wise fuel addition. Wood logs are stoked in a single batch though wood chips are stoked in many batches Using wood logs the CO content in the exhaust gas is lower which is an indicator for a higher combustion quality.

For gasification purposes low water contents are required. There is no correlation between the specific produced electric power and the age/kind of the wood. In fact the way of operating the system seams to influence the amount of generated electricity. The synthesis gas consists in average of 21 % carbon monoxide, 15 % hydrogen, 11 % carbon monoxide and 1,4 % methane.

References

[1] Agrobränsle AB, 70117 Örebro, Sweden. www.agrobraensle.se

[2] Ny Vraa Bioenergi I/S, 9382 Tylstrup, Denmark. www.nyvraa.dk

[3] 1. BImSchV § 6

[4] Hans Hartmann, Arno Strehler: Die Stellung der Biomasse im Vergleich zu anderen erneuerbaren Energieträgern aus ökologischer, ökonomischer und technischer Sicht. Münster: Landwirtschaftsverlag, pp 61 – 65, 1995