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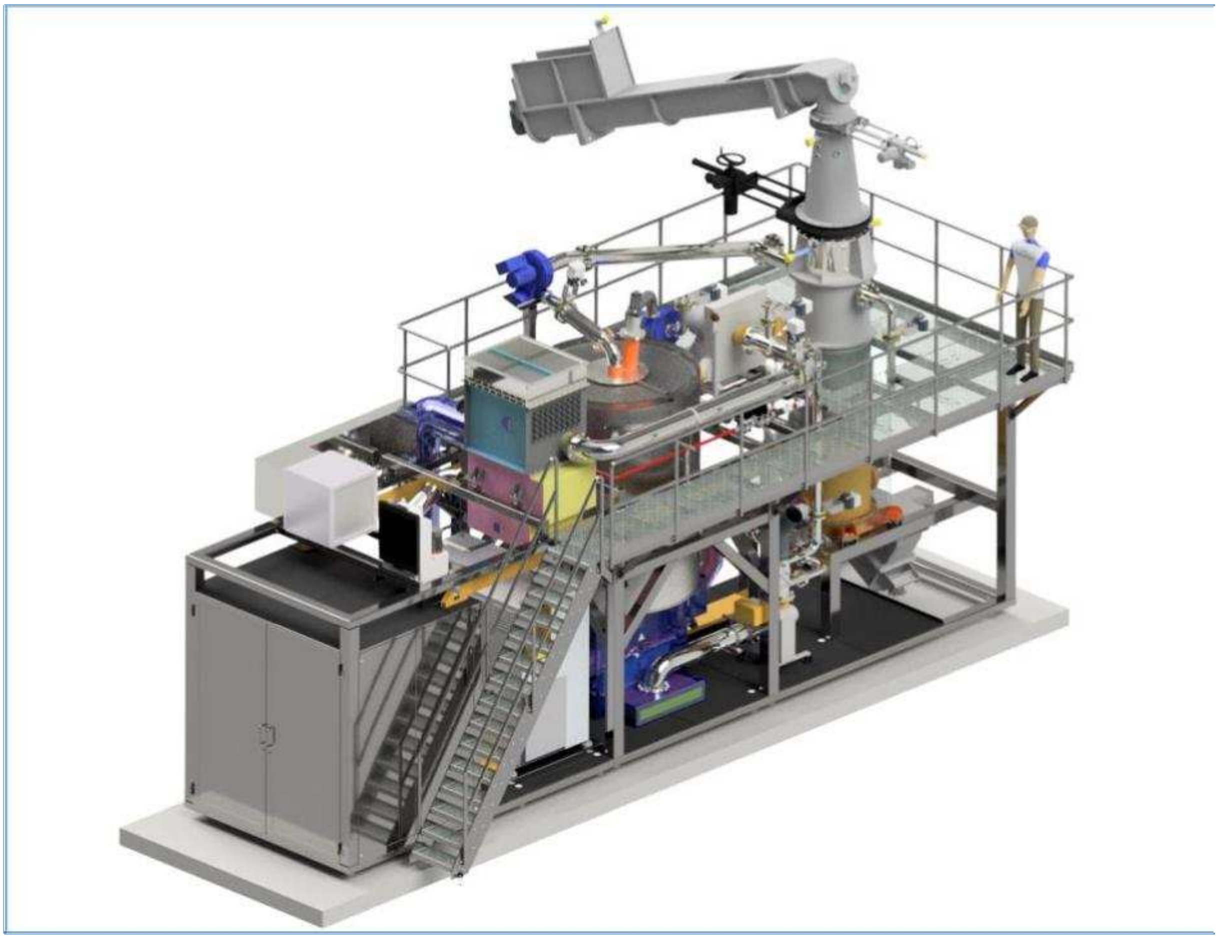
Interim Report of **12 December 2019**

PyroPowerPlant

COMPAG - Residues for electricity, heat and Pflanzenkohle



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Summary

The production of electricity and heat from residual biomass is an important pillar for achieving the objectives of the Energy Strategy 2050. Various technologies are available today for the combustion and thermal use of forest wood. The heat-crackcoupling with guts-free, low-ash wood from sawmills is also well advanced in development. However, a technology for the energy use of residual biomass for the production of electricity and heat is still scarcely availableand would greatly increase the potential of biomass as an energy supplier for Switzerland. The technology developed in this project aims to unlock this difficult-to-use potential.

In addition to energy production, the production of plant charcoal is alsoan important aspect of the project. Research is increasingly recognizing the value of charcoal for a wide range of agricultural purposes. Plant charcoal shows positive effects in soil improvement and humus rise,helping to maintain soil fertility inthe long term. In addition, the use of plant coal in agriculture is a long-termCO_2sink. Therefore, the approach of coupled electricity, heat and plant charcoal production inthe text of climate protection and agriculture consistently showspositive effects and it can also improve the economic efficiency of biomass energy systems.

In the present project, heat, electricity and vegetable coal are produced from bark, wood chips or sifted wood from composting plantsin a novel pyrolysis process. The gases produced during pyrolysis are burned in a low-gas burner. The exhaust gases are used for heating heat and converted into electricity with a hot air turbine. The exhaust gases are largely odourless and very low in particulate, i.e. the limit value of the LRV for wood firings of the corresponding power is significantly lower.

The extracted charcoal meets the strict requirements of the European Biochar Protocol and can be used for a wide range of purposes. If, as in the present case, the charcoal is used as a soil improver in agriculture or in thegarden, the carbon remains stable for several hundred to several thousand years and thus represents a CO_2sink. For every kilowatt hour of useful energy generated (electricity and heat), 400 to 500 g co2 are permanently removed from the atmosphere with this procedure. The plant with the stand area of a container (10 x 2.4 m) can process 2,400 tof moist biomass residues peryear. This will produce about 400 tonnes of plant coal with 340 tonnes of C content, 400 MWh of electricity (50 kWe) and up to 2,760 MWh of heat (345 kWth). In addition to this energy production, approx. 1250 t of CO_2 are extracted from the atmospheric waste run in theform of biochar each year and"sequestered" in the soil.

The heat and electricity produced are used entirely at the plant site, on the site of the vegetable producer Gerber Bio Greens AG in Fehraltorf. The company also operates a green-cutting collection and a composting plant, where the above-mentioned biomass residue is produced. The resulting charcoal is partly used in the greenhouses for soil improvement, and partly also sold.

The installation of the Fehraltorf plant has been completed. Various elements were optimized during commissioning with natural gas. Sensors were better placed, leaks in the system were fixed and a wider temperaturecontrol window in the combustion chamber was achieved by converting the hot gas lines to theturbine. During the test operation with biomass, two evaporations were carried out, each of which was carried out during the start-up from a safety stop. The various causes of the evaporations have been corrected. In the previous Betrieb, an electrical feed-in power of up to 50 kWe and a hot water output of up to 270 kWth could be measured.

Summary

The production of electricity and heat from biomass residues is an important pillar for achievingthe implementationofs of the 2050 energy strategy. Various technologies are currently available for the combustion and thermal use of forest wood. In addition, heat-force coupling with wood without ash, without livestock, from sawmillsis already well advanced. However, a technology for the energy use of residual biomass for electricity and heat generation is still not widely available and would significantly increase the potential of biomass asan energy source forSwitzerland. The technology developed in this project aims to unlock this potential that is difficult to use.

In addition to energy production, biocoal production is an important aspect of the project. Research is increasingly recognisingthe value of biochar for a variety of agricultural uses. Biochar has positive effects on soil improvement and humus formation, thus contributing to long-term soil fertility. In addition, the use of biochar in agriculture represents a long-term CO_2 sink, so the approach to the coupling of electricity, heat and biochar production in the context of climate protection and agriculture always has positive effects. And italso improves the economy of biomass energy systems.

As part of this project, heat, electricity and biochar are produced from bark, wood chips or sifted wood from composting facilities using a new pyrolysis process. Gases resulting from pyrolysis areburned in a low gas burner. The exhaust gases are used for heating and converted into electricity with a hot air turbine. Exhaust gases are largely odourless and very low in particulate matter: the corresponding output is significantly lower than the OPair limit for wood heating.

The resulting biochar meets the strict requirements of the European protocol on EBC biochar and can be used for a variety of purposes. If the biochar used - as in thepresent ca s - as a soil conditioner in agriculture or horticulture, the carbon remains stable for several hundred to several thousand years and therefore represents a CO_2 well. For every kilowatt hour of useful energy (electricity and chaleur), Atmosphere with this private procedure continuously 400 to 500 g of CO_2.

The plant with the footprint of a container (10 x 2.4 m) can process 2,400 t of wet biomass residues per year. This will produce about 400 tonnes of biochar with a c arbone contentof 340 tonnes, 400 MWh of electricity (50 kWe) and up to 2,760 MWh of heat (345 kWth). In addition to this energy production, about 1250 t of CO_2 is extracted from the atmospheric cycle as biocoal each year and "sequestered" in the soil.

The heat and electricity generated are used entirely at the plant site at vegetable producer Gerber Bio Greens AG in Fehraltorf. The company also operates an eco-friendly collection and composting plant where the aforementioned amount of biomass wasteis produced. The resulting biochar is used in greenhouses for soil improvement, sometimes sold.

The plant in Fehraltorf is complete. During the commissioning of natural gas, variouselements were optimized. Sensors were better placed, system leaks eliminated and conversions on hot gas lines to the turbine allowed for a wider temperature operating window in the combustion chamber. During the biomass test operation, two explosions occurred, each of which occurred during the start-up from a safety stop. The various causes of the explosions have been eliminated. During a previous operation,a power supply of up to 50 kWe and a production of hot water
up to 270 kWth could be measured.

Summary

The production of electricity and heat from biomass residues is an important pillar for achieving the objectives of the Energy Strategy 2050. Various technologies are currently available for the combustion and thermal utilization of forest wood. Also the Co-generation with bark-free, ash-free wood from sawmills is already well advanced. However, a technology for the energetic utilization of residual biomass for the production of electricity and heat is still hardly available and would enormously increase the potential of biomass as an energy supplier for Switzerland. The technology developed in this project aims to unlock this difficult-to-use potential.
In addition to energy production, the production of biochar is an important aspect of the project. Research increasingly recognizes the value of biochar for a variety of agricultural purposes. Biochar has positive effects on soil improvement and humus build-up, helping to maintain soil fertility in the long term. In addition, the use of biochar in agriculture represents a long-term CO2 sink. Therefore, the approach of coupled electricity, heat and biochar production in the context of climate protection and agriculture has consistently positive effects - and it can also improve the economics of biomass energy systems.

In this project, heat, electricity and biochar are produced from bark, wood chips or screened wood from composting plants using a novel pyrolysis process. The resulting gases in the pyrolysis are burned in a lean-gas burner. The exhaust gases are used for heating and being converted into electricity with a hot-air turbine. The exhaust gases are largely odorless and very low in particles. The of the corresponding output is significantly lower as the limit value of the Ordinance on Air Pollution Control (OAPC) for wood firing.

The biochar obtained meets the strict requirements of the European Biochar Certificate EBC and can be used for a variety of purposes. If the biochar used - as in the present case - as a soil conditioner in agriculture or horticulture, the carbon remains stable for several hundred to several thousand years and thus represents a CO2 sink. For each kilowatt hour of useful energy (electricity and heat) are the Atmosphere with this procedure permanently deprived of 400 to 500 g CO2.

The plant with the footprint of a container (10 x 2.4 m) can process 2'400 t of moist biomass residues per year. This will yield about 400 tonnes of biochar with 340 tonnes of C-content and 400 MWh of electricity (50 kWe) and up to 2,760 MWh of heat (345 kWth). In addition to this energy production, about 1250 t of CO2 are extracted from the atmospheric cycle in the form of biochar every year and "sequestered" in the soil.

The produced heat and electricity are used in their entirety at the site of the plant, on the premises of the vegetable producer Gerber Bio Greens AG in Fehraltorf. The company also operates a green collection and composting plant where the above-mentioned amount of biomass residue is produced. The resulting biochar is partly used in the greenhouses for soil improvement, partly sold.

The installation of the plant in Fehraltorf has been completed. Various elements were optimized during commissioning with natural gas. Sensors were better placed, leakages in the system eliminated, and conversions on the hot gas lines to the turbine allowed for a wider temperature operating window in the combustion chamber. During the test operation with biomass, two deflagrations took place, each of which took place during startup from a safety stop. The different causes of the deflagrations have been eliminated. In the previous operation, an electrical feed-in power of up to 50 kWe and a hot water output of up to 270 kWth could be measured.

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List of abbreviations

AGR	exhaust gas recirculation / exhaust recirculation
AP	Arbeitspaket
BECCS	Bio-Energy and Carbon Capture and Sequestration
BHKW	Block Heizkrafwerk
CIFOR	Center for International Forestry Research
CFD	Computer Fluid Dynamics
CDR	Carbon Dioxide Removal
CO	carbon monoxide
CO_2	carbon dioxide
EBC	European Bio Char Certificate (Europäische Pflanzenkohle Zertifikat)
FLOX®	Flameless Oxidation (registered trademark and patented principle)
FHNW	University of Applied Sciences Northwest Switzerland
FMEA	Failure Mode Effects Analysis (Fehlermöglichkeits- und –einflussanalyse)
FU	Frequency inverter
HT-WT	High Temperature Heat Exchanger
KVA	Sweeping incineration Plant
kWh_e	kilowatt hour electric
LRV	Air Recontent Ordinance
MWh/a	megawatt hour per year
NR	National Council
NO_x	nitrogen oxides, the sum of NO and NO_2, standardized to NO_2
PAK	Polycyclic Aromatic Hydrocarbons
REPIC	interdepartmental platform of the federal offices SECO, SDC, FOEN and SFOE
SDR	Solar Radiation Management
SVGW	Swiss Association of Gas and Water
SVUT	Swiss Association for Environmental Technology
GHG	greenhouse gases
TS	Dry substance
UNFCC	United Nations Framework Convention on Climate Change
CHP	Wärmekraftkopplung

1 Introduction

1.1 Starting position and background

The package of measures of the Energy Strategy 2050 and the Climate Strategy 2050 call for more renewable energies and also consider technologies that are
permanently remove greenhouse gases and store them. Both strategies require technological developments in order to exploit the potential in the best possible way.

The increased energy use of biomass is particularly relevant for the production of heat andstrom in the winter months or in process applications. The focus of energy production from biomass is on the expansion of possible fuels. Waldholz is already easy and economically versatile to use. Biogenic substanceswith a high proportion of mineral components (e.g. bark) or with contamination by stones and soil (root pieces, floating wood) still have a great potential untapped potential. For these difficult-to-use biomass fractions, processes mustbe established which enable energy and economically advantageoususe.

The technical possibilities for removing greenhouse gases from the atmosphere are still limited today. On behalf of the FOEN, the Risk Dialog Foundation has calculated potentials for Switzerland in 2018 and 2019[1]. The greatest potentials were seen in humus-building regenerative agriculture, with the introduction of plant coal into the humus soil, as well as Direct Air Capture and BECCS (combination of biomass heating power plantswithCO_2 sequestration technology). BECCS can also be combined with pyrolysis or the present PPP method.

The most comprehensive way to extract greenhouse gases from the atmosphere is the "4-Promille Initiative" of the French Ministry of Agriculture and was presented at the UNFCC's international conference in Paris (COP21) [2]. Thousands of studies on this subject have already been carried out and published worldwide. Forexample, the datenbank of the CIFOR – Center for International Forestry Research has been running 4,565 articles and publications since 1995 under the keyword "Biochar".

Since the pyrolysis process generates plant coal, this technology can also contribute tothe implementation of the 2050 climate strategy. In the event that the produced charcoal is incorporated into the soil, carbon is removed from the atmosphere and stored permanently.

This project can energically utilise a wide range of biomassand produces plant coal. As a result, the planned plant will contribute to the Energy strategy and the 2050 climate strategy.

Currently, there are no plants on the market with thermal power <1MW that can use difficult-to-use biomass energetically in the form of heat *and electricity* and materially in the form of plant charcoal. Plants for the production of heat and coal through the pyrolysis process have only been available on the market for a few years (in Central Europe from the companies: BioMaCon, Pyreg, Polytechnik and Degussa).

1.2 Motivation of the project

In the present project, charcoal, electricity and heat are produced from bark, wood chips or sifted wood from composting plants using a novel pyrolysis process. The gases produced during pyrolysis are burned in a low-gasburner. The exhaust gases are used for heating heat and converted into electricity with a hot air turbine. The exhaust gases are largely odourless and very low in particulate, i.e. the limit value of the LRV for wood firings of the corresponding power is significantlylowered.

The charcoal thus obtained meets the strict requirements of the European Biochar Protocol and can be used for a wide range of purposes. If the charcoal is used as a soil improver in agriculture or horticulture, the carbon remains stable for several hundred to several thousand years and thus represents a CO_2sink. For every kilowatt hour of useful energy generated (electricity and heat), 400 to 500 g co2 are permanently removed from the atmosphere with this procedure. Theplant planned herewith the stand area of a container (10 x 2.4 m) can process 2,400 t of moist biomass residues per year. It is expected that about 340 t of plant coal, 400 MWh/a of electricity (50 kWe) and up to 2,760 MWh/a of heat (345 kWth)will beused. In addition to this energy production, approximately 1250 t of CO2 are removed from the atmospheric cycle in the form of biochar each year and "sequestered" in the soil.

The heat and electricity produced are used entirely at the plant site, on the site of the vegetable producer Gerber Bio Greens AG in Fehraltorf. The company operates a green cutting collection and a composting plant, where the above-mentioned biomass residue is produced. The resulting charcoal isused in the greenhouses forboden improvement, partly also sold.

The plant can use biomass fractions energetically (heat and electricity) and material (plant coal) that could not be used economically until now. In particular, sand-containing woods (root sticks, floating wood) which lead to slagging in a conventionalfire. With chemical aid (minimum lime) this material can already be burned today. For pyrolysis, on the other hand, impurities are not a problem, since the mineralsdo not melt or evaporate due to the lack of oxygen and the lowlevels. The simultaneous production of plant coal increases the overall economic efficiency of the biomass-energy system.

The potential study of the WSL [4] shows a currently usable potential for forest and land wood of 11.5 PJ and for reclaimed wood and green ery of 2.5 or 3.3 PJ. According to the study, this potential results after deduction of various restrictions of a technical or economic nature. The pyrolysis plant maylift some of theserestrictions. However, the extent of the potential expansion is very difficult to quantify.

Different biomass fractions can be classified as input material based on feedback from interested parties – but without detailed figures on thepotential. Green cutting (flurwood) is the main input material for the pilot plant in Fehraltorf. According to various members of CharNet, rhizomes and floating wood are relatively expensive to dispose of. Wood chip-rich horse manilag is a regularly mentioned possible input material (approx. 10 PJ – current use unclear). Grain residues (spelt, chaff) also have great potential with 2.6 PJ.

Not all of the above-mentioned biomass fractions can be used as plant coal EBC in agriculture according to fertiliserregulation, as this requires "natural wood" as a substrate. On the other hand, the charcoal from all the above-mentioned substrates can already be used today as a filter coal for water and waste water according to EN12907.

1.3 Project objectives

The aim of this project is to develop, build and operate a pilot plant with a novel pyrolysis system for the production of electricity, heat and charcoal from wood and wood-like residues. The WKK plant with ahot air microgas turbine and FLOX combustion is to generate 400MWh of electricity, 2760 MWh of heat and 340 t of vegetable coal (EBC-certified [1]) from approx. 2,400 t/a of wood.

The following sub-objectives are to be achieved:

Input substrate[1]: Material according to EN ISO 17225-1 of size class P63 must be processed can be used. The following parameters must be adhered to:

- Feingutanteil ≤10%
- Water content -40%
- Aschegehalt ≤ 4%[2]
- Caloric value Q x 2.67 kWh/kg in the delivery state
- largest dimension of foreigntoffen e.g. stones (according to size class P63)
- largest dimension of wooden pieces (max. 20mm thickness)

Note:
Standardised wood chips (P31S according to EN ISO 17225-1) are used for success control.

Electrical energy: 50 kWe (+/- 5KWe) should be achieved at 15°C outside temperature.

Thermal power: 345 kW of heat is to be generated.

Coal: 42.5 kg/h of EBC-quality charcoal is to be achieved.

Operating hours The plant is to be completedafter the completion of the trial operation and after handover to the customer, an availability of > 8000 operating hours per year.

Air pollution limit The emission limits for gas firings in accordance with Annex 3 number 61 LRV must be complied with in accordance with the additional provisions of Annex 3 Section 62 LRV
With regard to nitrogen oxide levels, paragraph 61 should be sought in accordance with Annex 3(411)(see Annex 3 for more).

2 Anlagenbeschrieb

The plant consists of the main components pyrolysis reactor and combustion chamber. In the pyrolysis reactor, the fuel is heated and the resulting fuel gases are burned in the combustion chamber. The hot exhaust gases from the combustion chamber are used for heatingthe pyrolysis reactor, for electricity production and for heating purposes.

The pyrolysis reactor (Figure 1 on the left) is filled from above with moist or dry biomass fuel (hack material). In the start-up phase, external fuel (e.g. natural gas) is burned in the combustion chamber (image 1 on the right) and the resulting hot exhaust gases arefed into the reactor. As soon as these hot exhaust gases hit the biomass fuel, pyrolysegas are created.

[1] Für die CH sind verschiedene Biomasse-Fraktionen möglich. So können unter andereme Grüngut, Baum- oder Strauchschnitt, Wurzelstöcke, Ernterrückstände wie Spelzen, Altstroh, Getreidestaub,Holzreste, Sägemehl, Material der Nahrungsmittelproduktion wie Trester, Kerne, Schalen verwendet werden. . (siehe Positivliste EBC):

[2] if certain quality criteria for the sale of charcoal are to be achieved, e.g. for fodder coal >80% C content

The now existing pyrolysis exhaust mixture then flows through the entire biomass fuel in the pyrolysis reactor in the counter-current principle and is fed back into the combustion chamber.

In Figure 1, the biomass not yet oxidized, which is flowing through theice-eissen pyrolysis exhaust mixture, is symbolized by green leaves.

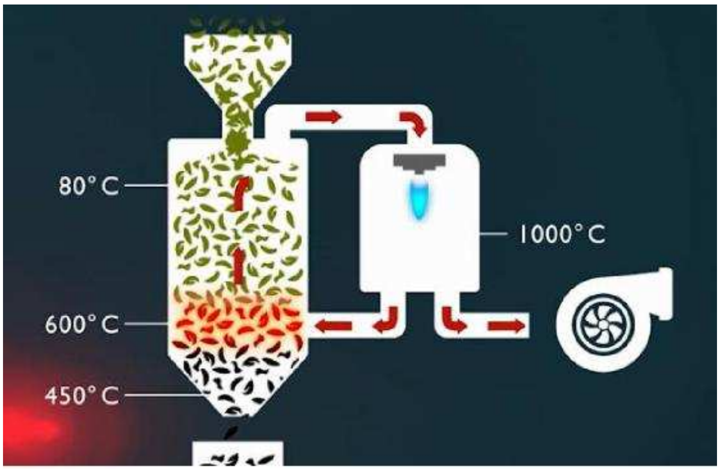


Figure 1 Simple representation of the PPP process, excerpt from the TV report for NANO. The reactor is shown on the left and the combustion chamber on the right.

The pyrolysis increasingly released in the pyrolysereaktor gradually replaces the external fuel until the process runs exclusively with pyrolysegas during the operating phase.
In the operational phase, the pyrolysis generated in the reactor is also heavily diluted by combustion exhaust gases produced in the combustionchamber. Thanks to the use of FLOX® technology in the combustion chamber, it is possible to burn this low-calorie low-calcairous gas with the lowest exhaust emissions.
The hot exhaust gas, which is not required for the heating of thepyrolysis reactor, is generated in a hot air turbine. After the turbine leak, the exhaust gas can still be used for the production of process heat or hot water.

3 Procedure and method

3.1 General approach

In order to meet the project objectives set out in paragraph 1.3, a plant has been developed that works as described in paragraph 2.

The procedure has been divided into the following steps:

- Conception (incl. research anddevelopment of critical components)
- Construction and construction
- Test components and subsystems
- Operation (commissioning, operation without observer, continuous operation)

The diagram in Figure 2 shows in a very simplified form the function diagram with differentprocess parameters as a result of the engineering work for this plant. Figure 2 provides guidance for investment and process understanding.

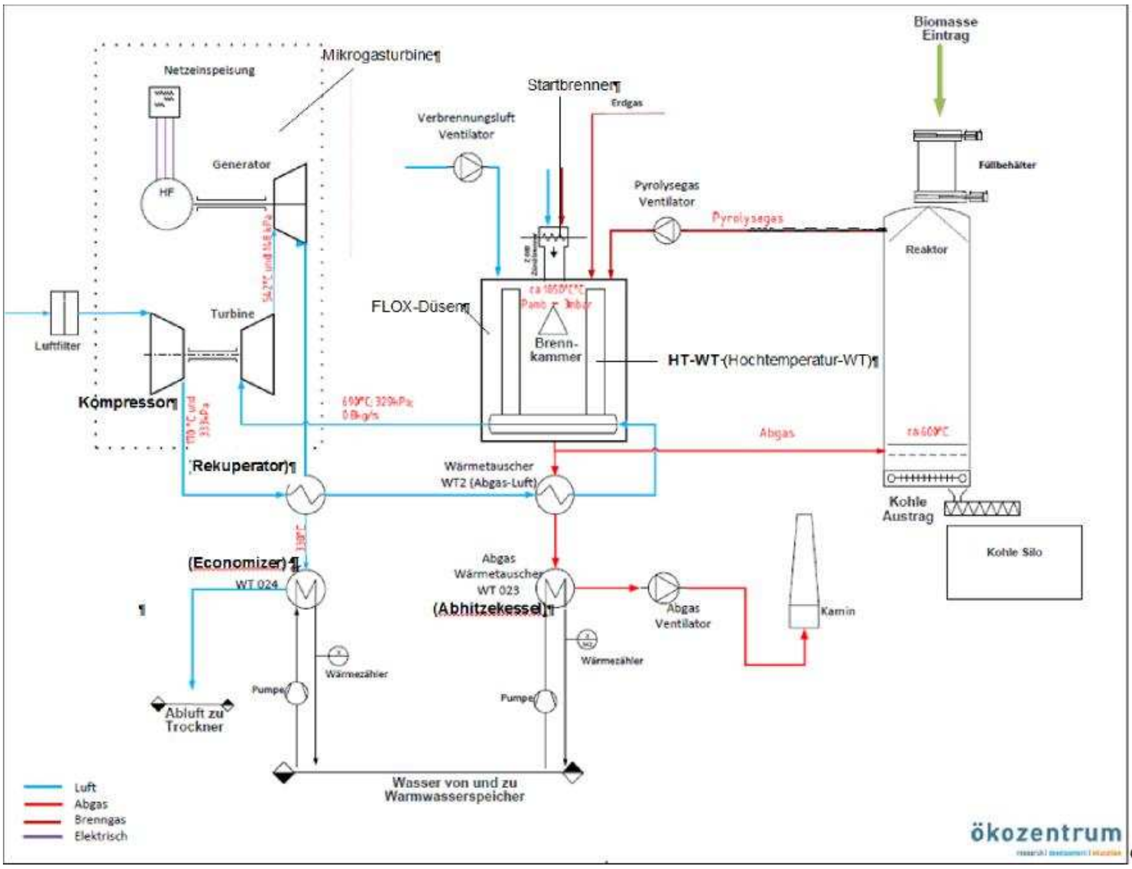


Figure 2 Simplified flow image of the pilot plant. The full P&ID schemes are attached.

3.2 Methodology for success monitoring

3.2.1 Data collection

In order to verify the objectives defined in paragraph 1.3, a comprehensive data collection system has been installed on the installation. This enables the most relevant technical indicators for the project success, such as overall efficiency, electrical efficiency and theclassification of emission limits, to be recorded. To check these parameters, the following sub-chapter describes a detailed procedure. Tests such as unit tests, special operating states (power failure, emergency stop, failureof asingle component) have been carried out, but are not described further.

The control of the pilot plant stores almost 200 values (measurement data, characteristics of actuators, etc.) at regular intervals. If predefined limits are exceeded, additional data is stored. This means that relevant operating parameters for normal operation as well as in exceptional/limit operation are documented in the necessary time resolution.

Throughout the process, the relevant data on temperature, pressureand oxygen / (Lambda sensors), data of the flaps, data of the frequency inverters and the fans and the water circuit are stored. In addition, the messages of the guardians are dropped. Guardians are functions thatmonitorsecurity-relevant parameters. For this purpose, limit values were defined for each guard in which the system is to be operated. Messages are issued in case of overshooting and/or undershooting. If necessary, measures are taken automatically.

Inaddition, the measurement data from external measuring instruments such as the exhaust gas analysis can also be collected if required.

3.3 Measurement and testing concept

3.3.1 Compliance with emission limits

According to the current assessment, only nitrogen oxide (NOx) levels are critical for emissions in the exhaust gas of the plant. The nitrogen oxide values for the present burner type are significantly dependent on the nitrogen content of the fuel.

Based on the already availablemeasurement results from 2019 at the research facility and at the pilot site, it is clear that the NOx limit value of 250 mg/m^3_n x 3% O_2 can be met with qualischnitzel, i.e. low-bar and leaf-poor wood, but not with the typical branch and greensnow t wood assortments at the pilotsite.

It is not yet clear whether the standardisation value for natural gas (3% O_2) has been used for the use of wood gas instead of natural gas as afuel. However, since the limit value of 250 mg/m^3_n x 13 % O_2 in relation to NOx freight is a factor of 2.25 higher than for standardisation to 3% O_2, the choice of reference oxygen is highly relevant to the pilot project and potential follow-up projects. If a reference oxygen of 13% O_2 can be chosen,the limit value would also be applicable to the branch andgreen-cut wood assortments typical of the pilot site. [3]

[3] Der definitiv gültige Grenzwert wird, wie bereits in der Verfügung vom Juli 2018 festgehalten, durch das AWEL nach der Messung und Diskussion der Resultate festgesetzt.

3.3.2 Measurement concept Total efficiency

The efficiency of the plant cannot be measured analogously to a wood combustion, since the additional product plant carbon is produced, for which an energy input is also necessary, but no direct energy output in the form of electricity or heat can be measured. The following describes the steps necessary to determine the efficiency.

1) Wood supply to the reactor:

   Since the reactor does not have a continuous fuel supply (only 4-6 fillings/hour), the fuel supply must be measured over a long period of time and thus amore
   fuel performance. Fuel input should be measured at least over a period of 6 hours.
   Representative samples are taken from the fuel and analysed for water content, ash content, nitrogen content and calorific value.

2) Coal discharge from the reactor:

   The coal bunker and the conveying system are emptied before the measurement day and emptied after the measurement. The coal produced is weighed. Representative samples are also taken from the charcoal produced during the measurement period (approx. 1 BigBag). The coal samples of the produced coal are analysed for water content, ash content and calorific value (as well as other charcoal parameters such as C content, surface BET, etc.), whereby it is calculated that the water content comes entirely from the humidification plant after the pyrolysis zone.
   The C content of the samples and the production quantity can be used to determine the deposited amount of carbon.

3) Thermal performance water:

   Taken directly from the data acquisition of the controller (heatmeter). The total values (energy) can be averaged over the same period as the measurements (1) and (2)

4) Electrical power water: Analog

   thermal power.

5) Thermal power exhaust air to the drying plant.

   The temperature of the exhaust air used for drying is measured at the entrance to the dryer channel. The mass flow is calculated from the measurement data of the turbine. The throttle curve canbe used to calculate the mass flow from the measurement of compression ratio, absolute pressure and temperatureby comparing the data with the turbine's throttle curve. The heat capacity cp of the air is determined from the tables of the specialist literature.

6) Kaminverluste

   The mass flow is generated from the measurement of the residual oxygen in the exhaust gas and the fuel analysis and corresponding quantity. The exhaust gas temperature is
   measurement data acquisition is taken from the controller. The heat capacity cp of the exhaust gas is calculated with the help of the simulation tools of the FHNW.
   With the measurement of the CO_2content in the exhaust gas, the CO_2emissions can also be

calculated whoThe. And the mass flow can be controlled in reverse, because the C content directly related to the fuel input less the quantity of coal produced (excluding its mineral content).

7) Review of gross combustion performance.

With the *hess set,* the firing power can be calculated or checked. The Hessian heat set (also set *of Hess*) is used to calculate changes inenthalpy in chemical reactions.

The enthalpy change of an overall process is the sum of the changes in the energyof the individual process steps. Assuming standard conditions, the standard reaction enthalpy of a substance is the difference from the standard formation enthalpy of the products minus the standard forming enthalpy of the products:

$$\Delta H_R^0 = \underbrace{\sum \Delta H_f^0}_{\text{Produkte}} - \underbrace{\sum \Delta H_f^0}_{\text{Edukte (Reaktanten)}}$$

Reaction enthalpy does not depend on the reaction path, but only on the initial and final state of the system. From fuel power and carbon capture (with well-known the calorific value of the carbon) can therefore be determined by the gross combustion capacity.

3.3.3 Measuring concept for electrical efficiency

The maximum electrical efficiency of the CHP system is determined easiest by firing the FLOX combustion chamber with natural gas and reading out the gas meter. The turbine inlet temperature and natural gas output arevaried and the resulting electrical feed-in power is measured. Each parameter variation must be followed by a constant operation of at least 15 minutes.

This concept assumes that the thermal energy of the reactor is very low and isless than 2%[4] of the fuel power (8 kW). This would affect the result with 15% electrical efficiency by a maximum of 0.35% points.

These measurements and calculations also determine the minimum thermal power for nominal electrical power.

A comparison with measurement data from operation with pyrolysegas should show whether the heat transfer is comparable in the transmissionof natural gas or pyrolysis. Only then is a calculation of the electrical efficiency in natural gas operation permitted.

Measurements should be as close as possible to 15°C at ambient temperatures. 15°C is the standard temperaturefor the design and indication of microgas turbine nominal power and efficiencies.

[4] die Emissivität der lackierten Oberflächen kann mit etwa 6 W/m2/K angenommen werden, die Oberflächentemperatur liegt bei etwa 60°C, d.h. die typische Temperaturdifferenz zur Umgebung ist höchstens 45 K. Die relevante Oberfläche des Systems beträgt weniger als 25 m2.

4 Work carried out and results

4.1 Completion of Installation Work

At the end of January 2019, the plant was delivered to the Fehraltorf site in a pre-assembled condition and incorporated into the buildings created for the plant. Subsequently, various work was carried out in order to equip and connect the plant forcommissioning. The following work has been carried out since February 2019:

- Creation of the water distribution around the waste heat from the exhaust gas strand, from the hot air strand of the gas turbine and the coal discharge.
- Creation of the supplyand exhaust airducts and installation of the fireplace.
- Connection of the plant to the natural gas supply.

Electrical connection of the system

Electrical, hydraulic and pneumatic connection of the conveyor technology.

Subsequently, all sensors and actuators were tested in adetailed functional test.

Before the start of the hot start-up, the entire gas technology was approved by an expert from the SVGW. The safety technology and the layout calculations were checked.

After completion of the installation work, the commissioning phase wascompleted. As a first step, the plant was put into operation with natural gas. After various incidents and optimizations, the entire plant was put into operation.

4.2 Hot gas commissioning with natural gas

At the beginning of April 2019,after the start-up burner operation had been tested, the gas turbine was launched. For this purpose, the combustion chamber was brought into the Flox plant with natural gas. After reaching about 600°C turbine inlet temperature, the gas turbine was powered up electrically. After whichseconds, the stable self-operation was achieved, in which the turbine runs on its own power (thermally driven) and feeds electrical energy into the grid. This test phase was carried out with natural gas because of the better controllability. During this test phase, the relevant operating parameters of the gas turbine were determined. The following diagram (Figure 3) shows the temperatures of the combustion chamber and turbine inlet as well as the most important performance data from the two water heat exchangers and the gasturbine. It was found that the maximum turbine inlet temperature in natural gas operation was reached at 910 to 930°C. Originally, it had been expected that a combustion chamber temperature of about 1000 to 1050°C would be necessary. (See chapters 0 and 4.7 for details)

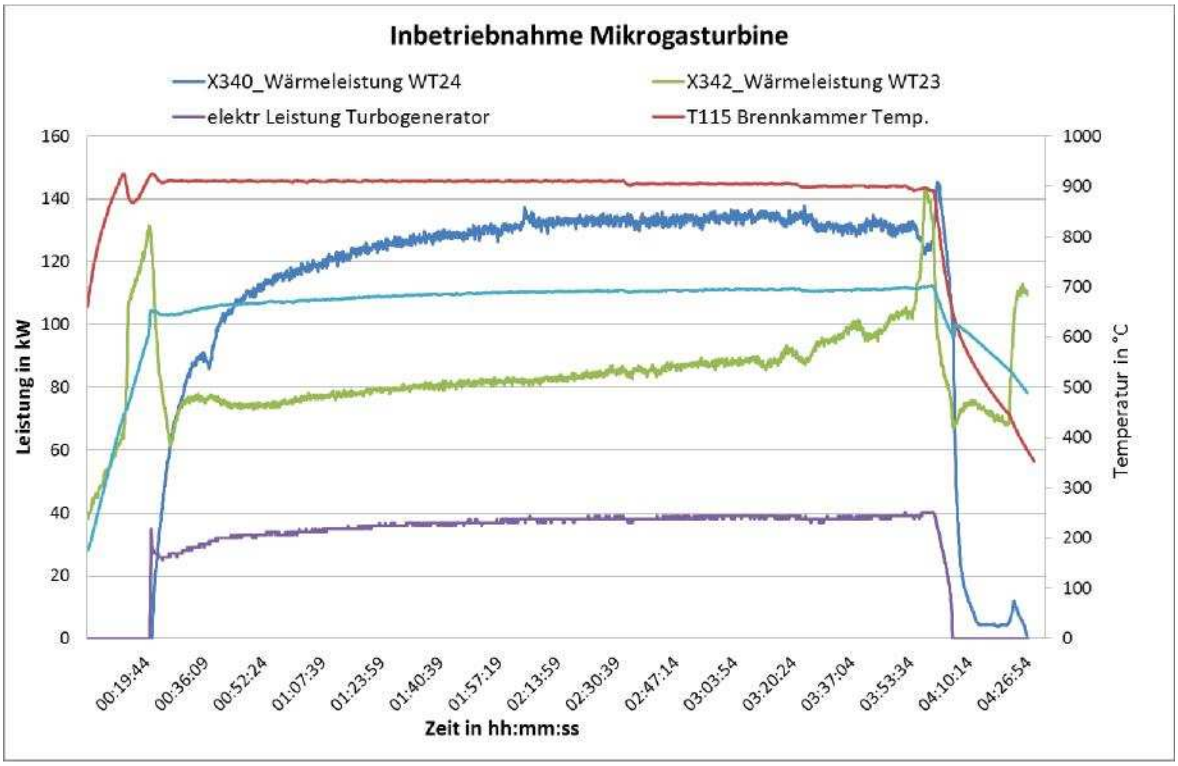


Figure 3 Graphic representation of relevant temperatures and outputs during the commissioning of the gas turbine

4.3 Observations in the test phase

4.3.1 Unfavorable placement of the exhaust gas probe

In tests with natural gas it was observed that the display of the oxygen values in the exhaust gas of the combustion chamber are displayed with a delay of more than 30 s. A delayed oxygen display makes precise combustion control and thus low CO values in the exhaust gas impossible. The probes were therefore positioned more directly in the exhaust duct, so that they are flowed more directly from the exhaust gas. As a startof the changes, the response time of the oxygen measurement has decreased to 1 to 3 seconds, which issufficient for the combustion.

4.3.2 Leaks in the system

In addition, above-average oxygen readings were observed in the exhaust gas. The measuring probes (Lambda probes) are located in the exhaust line between WT2 and the waste heat boiler (WT 23), in addition, exhaust gas is extracted and analyzed after the waste heater seel during testoperation. In the investigation of the causes, leaking connections to pipelines and during the transition of the combustion chamber to the WT2 were detected.

4.3.3 Vibrations in combustion

In test mode, a barely noticeable but mit the oscilloscope on the combustion chamber pressure sensor was observed several times, pressure vibration with about 2 to 4 Hz frequency and up to 20 hPa amplitude. This is an indication of an unstable Flox combustion. Stable FLOX operation requires turbulence, interne exhaust gas recirculation and a corresponding combustion temperature, whereby turbulence and internal exhaust gas recirculation depend on each other and are significantly influenced by the Venturi effect of the air (and gas) injection and combustion chamber geometry. The different recirculation areas in the FLOX burner are explained at the end of this subchapter.

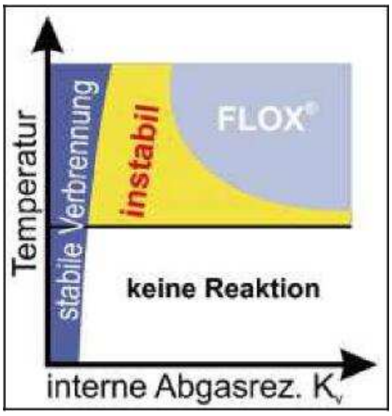


Figure 4 Representation of the conditionof the stable FLOX combustion [5]

For a stable combustion with flame (dark blue deposited area in the graphic) it requires deep flow speeds, precisely adapted to the fuel. After the ignition of the gas, no mini-gas temperatures arerequired. However, FLOX combustion (light grey area in the graph) can only occur above the self-ignition temperature - represented by the horizontal black line in Figure 4 (diagram center). In addition, therates of congestion, internal recirculation rates and turbulence must be so high that the formation of local flames and evaporations is prevented. Hot exhaust gases and newly inflowing air and fuel must be mixed and heated evenly, as well as the partial pressures of all participating products must be reduced in such a way that the formation of flames is also prevented. Only when these conditions are met can we speak of stable FLOX operation. It also expressesabsolute noiselessness and extreme tolerance against condensing value fluctuations.

The following factors may cause the observed vibrations in the combustion chamber:

- Too low temperatures in peripheral regions of the combustion chamber.
- Too low turbulence in the combustion chamber. Due to the large diameter of the combustion chamber at the CPP800, the internal exhaust gas recirculation rate K is always sufficiently high according to calculations of the FHNW, avia the turbulence (shear gradients of the Venturi effect) may already be somewhat reduced. A too low flow speed and turbulence in the mixing of air and exhaust gas is rather unlikely here, or to exclude on the basis of the CFD data of the FHNW. Too low turbulence in the mixing of air/exhaust gas with the fuel gas is more likely, but this cannot be shown in the CFD simulation.
- Incorrect air entry after the combustion chamber. By adjusting the control to a narrowly over-stoichiometric operation, there is a danger that leaks after the combustion chamber, but before the oxygen measurement, could lead to a narrowly substoichiometric operation in the combustion chamber. Dadurch könnten durch lokale Verpuffungseffekte und durch die Flammen an der undichten Stelle Schwingungseffekte in der Verbrennung entstehen.

- Micro-evaporation effects when the shield air of the start-up torch is flowing together (lower Airflow to protect the inactive start torch from radiation from the combustion chamber) with the pyrolysis aces, which are almost combined in the upper center of the combustionchamber.

Corresponding tests in test mode confirmed the first three effects as relevant. The system had to become significantly denser from the combustion chamber to the oxygen measurement, which was achieved in several steps. Due to the conversions now carried outfor a controllable partial bridging of the turbine air heat exchangers, a higher combustion chamber temperature can now be achieved.

Differences in the different exhaust gas recirculation systems and their function
- The *internal exhaust gas recirculation* (AGR):D floX torus vortex, which is created in the combustion chamber by the Venturi effect of the rapid injection of fresh gases (air, natural gas) permanently swirls exhaust gas with air and fuel gas. Since the internal AGR takes place within the insulated combustion chamber, it has no cooling effect. On the contrary, the internal AGR heats the newly inflowing gases. The internal AGR is never "too much": it should be possible to make flame-free oxidation optimal. The internal AGR is not regulated, butdepends on the design of the combustion chamber and nozzles, as well as the mass flows involved.
- The *external exhaust gas recirculation* serves only the independent controllability of the combustion chamber temperature and has a similar role as in a conventional combustion of the excessof thefuse. The external AGR consists of "cold" exhaust gas (exhaust gases from after the energy disconnection, approx. 120°C) and is primarily used for cooling. As a side effect, the external AGR increases the mass flow through the combustion chamber and should therefore alsoincrease the internre recirculation.
- A *third exhaust gas recirculation: To heat the reactor,* hot exhaust gas is fed into the reactor via pyrolysis-gas fan and, together with the pyrolysis, back to the combustion chamber. This circuit is used with the volume regulation(mass flow) to regulate the pyrolysis performance and by mixing different hot exhaust gases also the temperature control of the pyrolysis.

4.3.4 Evaporation I

At the beginning of May, an attempt was made to put the entire plant into operation with pyrolysis. Due to a wiring error on the high-temperature control, there was a evaporation. For commissioning, the system was manually controlled and various safety functions were passively set. The evaporation occurred after an error in the frequency inverter (FU) of the combustion air fan. The combustion chamber vacuum, the pre-pressure on the FLOX nozzles and the combustion chamber temperature are variables for the safety circuit that releases the high-temperature torch control. Due to the failure of the air fan,the safety circuit wastemporarily interrupted because the form on the Flox nozzles was missing.
As a result, a safety shutdown was triggered in accordance with the regulations. After testing all parameters (temperatures had fallen below 850°C, pressures, atmosphere) it was decided that a "reset" of the FU is possible. By restarting the fan, the combustion air pre-pressure was again reached, which closed the safety circuit for the high-temperature control. Due to a wiringswitch,the high-temperature control has then released the gas valve at the electrical output for the low-temperature range (up to 850°C). This allowed natural gas to flow in and when the ignition limit was reached, the mixture ignited. The printing elasticsystem (combustion chamber lid) opened up and prevented major damage (Figure 5). Minor damage was visible to the insulation lining and had to be repaired (Figure 6).

Figure 5 Combustion chamber lid after evaporation from 6 May 2019

Figure 6 Insulation damage after evaporation (recording after removal of the combustion chamber lid)

After the failure, an in-depth check for investment errors was carried out.

Initially, the wiring error on the torch control was eliminated and brake resistors were additionally installed for the air fan and exhaust fan and parameter adjustments were carried out on the FU. This should ensure that FU errors and interruptions do not occur even in fast control operations.

4.3.5 Re-checking system tightness

The topic of increased oxygen values was also further investigated in more detail in the course ofthe examination after the evaporation, by using mass flow measurements of the false air ingress in the combustion circuit as in the reactor and conveying technology circuit. It was found that at about 1 mbar vacuum, counterfeit air is already sucked in at about 1 mbar. This amount of false air already corresponds to more than 3% of the nominal mass flow and could not be accepted. Therefore, the leaks were made visible by means of a fog machine. It was shown that at the entry and exit of the high-temperature heat exchanger (HT WT) at the combustion chamber, at the flue gas-water heat exchanger (WT23) and over the entire length of the discharge conveying technology as well as the slider above the reactor there were major leaks (see Figure 7).

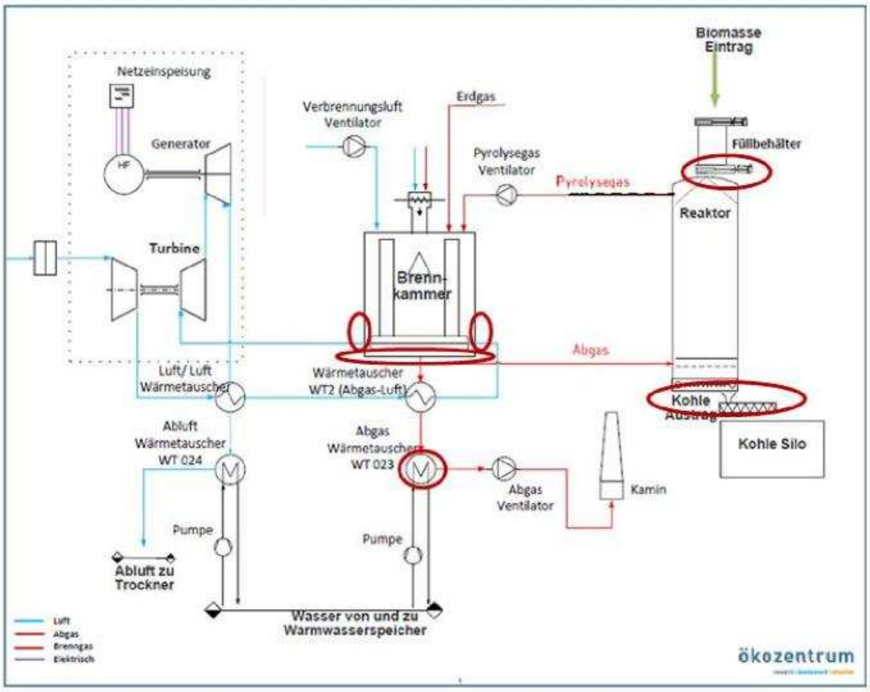
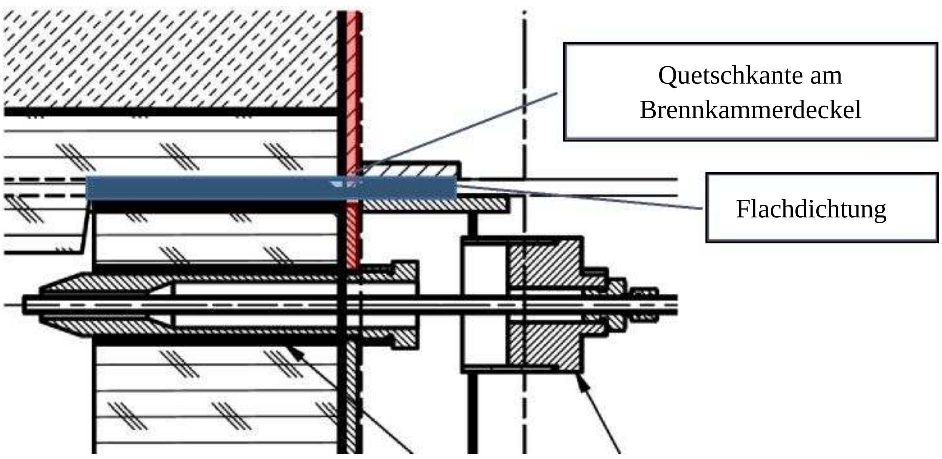


Figure 7 Diagram showing the detected false air leaks (marked in red)

The leaks were then fixed. Insubsequent measurements, 3 mbar vacuum was achieved and false air inputs of about 6 kg/h were measured. This allows the plant to be operated. Furthermore, the support of the combustion chamber lid was improved, as it had been shown that in the original design the flat seal on the crushing edge (Figure 8) is damaged and therefore the tightness cannot be maintained permanently.

Abbildung 8 Brennkammerdeckel mit Quetschkante, die die Flachdichtung durchtrennt



In the new design, a support ring of 10mm height was welded on, which picks up a ceramic sealing cord, which then ensures the tightness (fig.g 9).

Figure 9 Combustion chamber with improved seal and repaired insulation

The connection of the combustion chamber to the exhaust-air heat exchanger (WT2) also did not prove to be sufficiently dense. By the installation of longer expansion screws and an intermediate flange with intermediate sealing cord, a stable dense connection should beachieved. This optimization is currently being implemented.

In addition, the combustion chamber lid was adjusted to improve the flow behavior of the Flox® gas nozzles. This has reduced the vibrations in the combustion process. In subsequent tests, it was possible to drive in natural gas operation witha maximum open external exhaust gas recirculation flap. Only barely perceptible vibrations in the combustion process were detected.

4.4 Modification of exhaust gas heat exchanger WT2

The mentionedto geringitic temperature difference between the combustion chamber and the turbine entrance was met with a first simple modification. Sheet metal inserts in the tube bundle in WT2 should reduce the transmission power and thus cause the air to enter the high-temperature WT colder (see Figure 10). This modification has been tested and maintained until and with the test at the end of August. However, the increase in the combustion chamber temperature of 20 K to 30 K achieved with this measure is lower thanexpected.

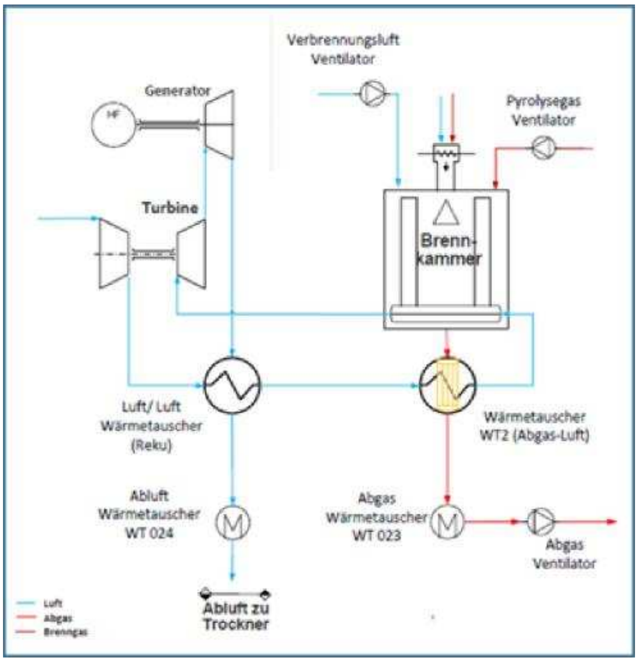


Figure 10 Measure to increase the combustion chamber temperature by reducing the transmission power on the WT2

4.5 Commissioning of the entire plant

After the improvement steps were carried out, the plant test was continued. Gradually, the pyrolysis system was powered up. Due to the optimizations carried out, some parameters of the combustion control had to be adjusted first. The sensor settings and parameters of the conveying technology also had to be adjusted.

At the end of July, the plant was then driven over 24 hours in pyrolysis operation. Estimated from the number of fillings of the reactor, about 16 m^3 wood chips were processed and about 4 m^3 plant coal was generated. The thermal power output ranged from 200 to 270 kW, the electricaloutput between 30 and 44 kW. The power fluctuations were primarily caused by errors in the material supply and discharge. These errors or resulting non-optimal operating parameters resulted, among other things, a fluctuating reactor performance, which was reflected in fluctuating fire chamber performance.

The influence of the outside temperature is relevant for turbine power. During the night with lower outside temperatures, the electrical output is significantly higher than during the day. This is to be seen in the increased performance in the middle part of the trial period.Know. In addition, small changes in the turbine inlet temperature also caused significant changes in the turbine's electrical power output (see Figure 11).

In this test, the settings for continuous operation couldbe optimized.

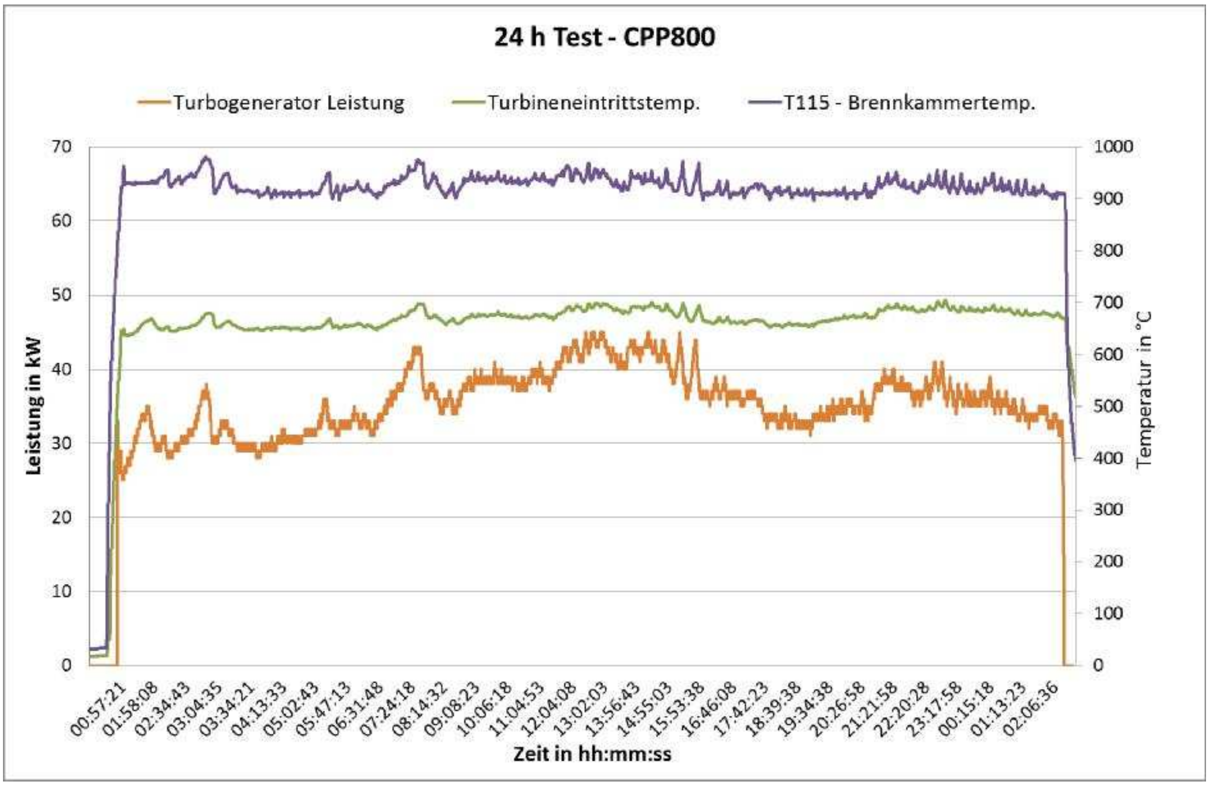


Figure 11 Representation of the combustion chamber and turbine inlet temperature with the electric turbine power in 24 h continuous operation

In another test, a plant with pyrolysegas was driven over 12 hours. The combustion chamber had tobe kept in the lowest (temperature) operating window in order to avoid overheating of the turbine. This resulted in a temperature window in the combustion chamber between minimum temperature for a stable Flox combustion and maximum temperature fortheoverheating of the turbine of about 60 K.

In manual control mode, an automatic safety stop (e.g. due to overtemperature at turbine entrance) could be avoided by control interventions at various locations. In automatic operation, however, it can become valid with such a small operating windowto regulate process fluctuations, e.g. due to minor irregularities in the fuel or in the entry or discharge system. Figure 12 shows individual temperature peaks just above 700°C at the turbine inlet temperature, which required significant interventions.

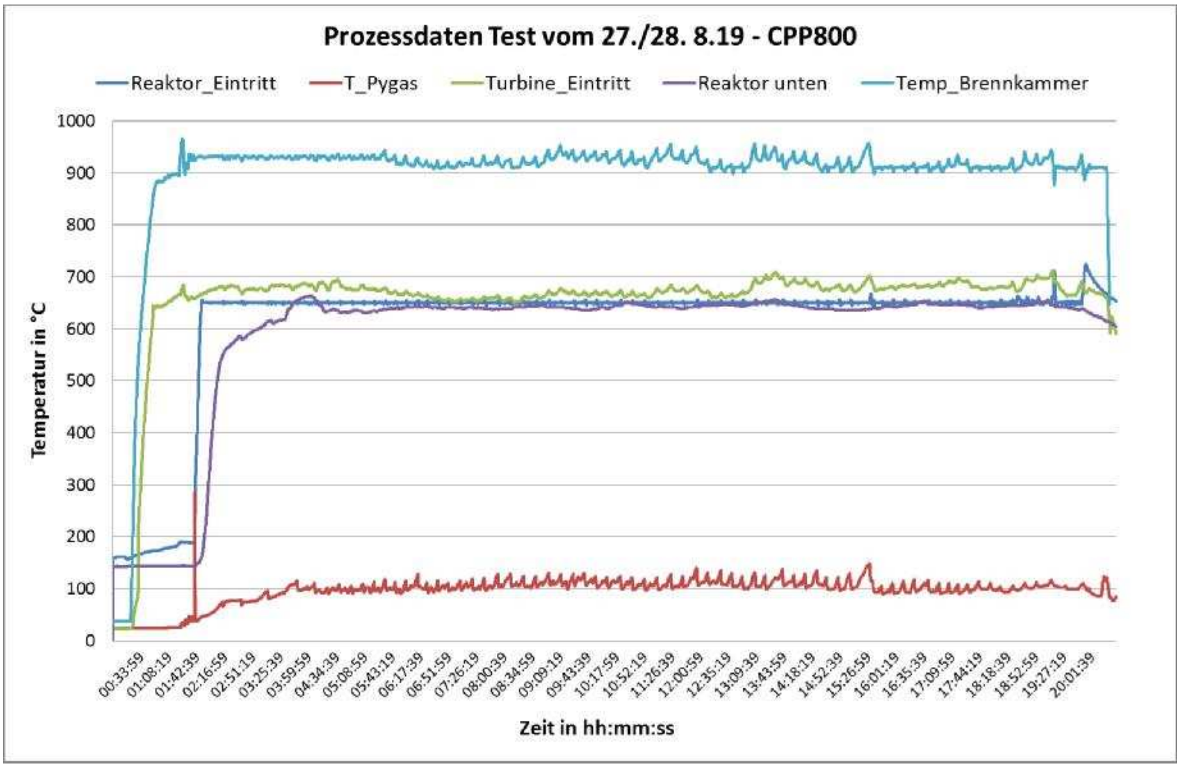


Figure 12 Presentation of important process temperatures from the operating test on 27/28 August

4.6 Previous energy measurements

In previous operation, the electrical feed-in power could be measured with up to zu 50 kWe, as well as the hot water output of up to 270 kWth.

According to the design concept of the CPP800, the thermal hot water performance in a wide range should be independent of the electrical feed-in power. This means that the temperature of the combustion chamber can and should be regulated relatively independently of the thermalperformance. As already pointed out, this is only possible to a limited extent due to the slightly better transmission performance of the two air/exhaust heat exchangers (HT-WT and WT2). Therefore, modifications are still necessary toincrease the operating power of the combustionchamber. The modification already carried out had too little effect. (see 0)

Since the previous operation took place at ambient temperatures well above 15°C, it is expected that the electrical power can reach the nominalen 50 kWe. Therefore, no optimization measures are currently planned for the turbine circuit.

4.7 Modifications to extend the operating window of the burner and to increase the thermal performance of the system.

In the current system design, the maximum combustion chamber temperature (and correspondingly also combustion chamber capacity) is limited by the maximum inlet temperature of the exhaust gases at the turbine. According to the design, the combustion chamber temperature should be well above 1000°C and the temperature at the Eentry of the turbine must not exceed700°C. The heat exchangers were designed in such a way that a temperature difference between the combustion chamber and the turbine inlet of approx. 310°K is achieved. However, since the heat exchangers have a better performance,al s is calculated, and the inlet temperature of the turbine cannot be increased, the combustion chamber temperature must be reduced. However, this has an effect on the operating window of the system and thus on the setting of the controllers.

The combustion chamber temperature is regulated by the following measures (with a constant air surplus of about 3.5% O_2) (see also Figure 13):

1) With the external exhaust gas recirculation, the combustion chamber can be effectively cooled. The effect was measured and confirmed. The control speed is slightly lower than expected—it takes a few minutes for an effect to set in.

2) With the variation of the preheating of the combustion air can also be cooled. For this purpose, the preheating of the combustion air can be lowered from about 300°C to 200°C. The control speed is sufficient here, but the achievable minimum e temperature of the combustion air isnot as low as expected. This can be adjusted by increasing the cold air supply. This measure would be implemented if it were to become apparent in continuous operation that the cooling by means of external exhaust gas recirculationand the existing reduction of the air preheating should not be sufficient.

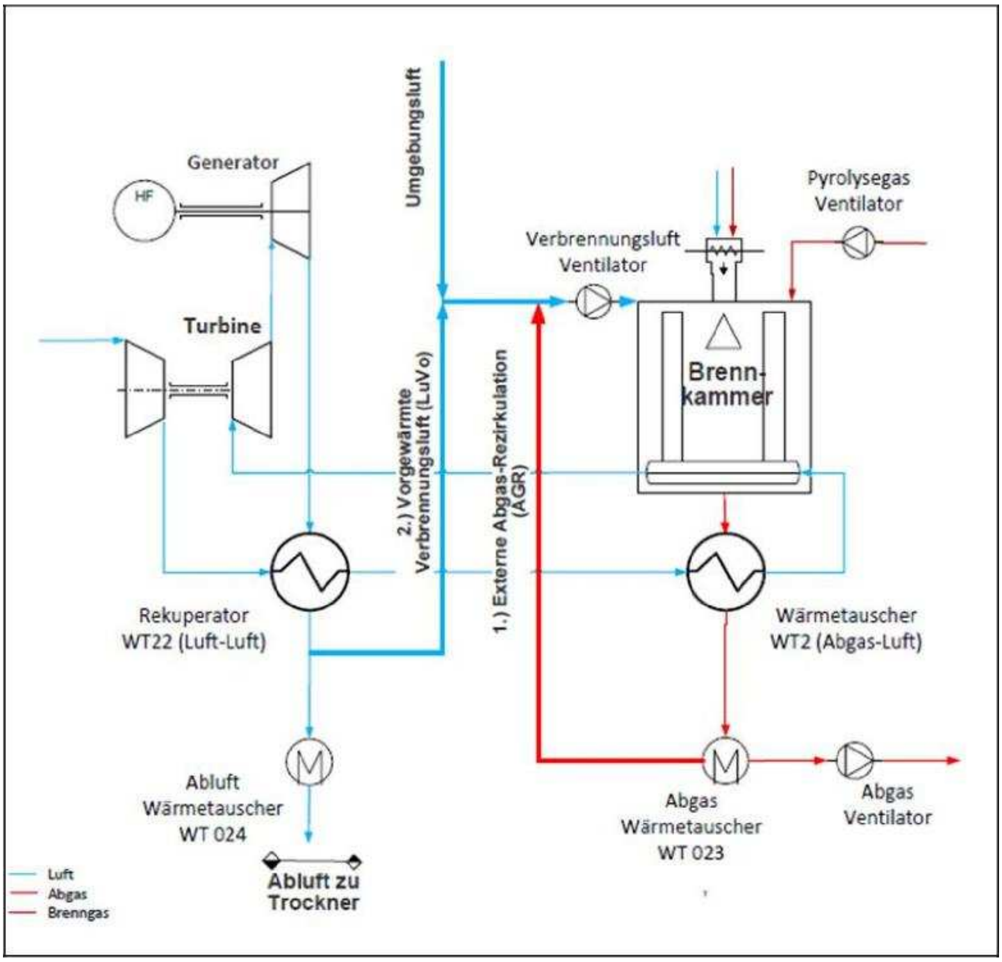


Figure 13 Schematic representation of the control and control components of the CPP800. 1.) External exhaust gas recirculation, (2) preheated combustion air (exhaust air hot airturbine)

The fire chamber performance, which can be increased or reduced by means of the power of the Pyrolysegas fan, also influences the combustion chamber temperature.

All these measures make it possible to regulate the temperature in the combustion chamber, but do not reduce the basic problem of the minimum temperature difference between the turbine entrance and the combustion chamber. This minimum temperature difference was designed "byDesign" at >310 K, i.e. for combustion chamber temperatures of greater than 1,000 °C at 690°C turbine inlet temperature. However, since the HT-WT and the WT2 each have slightly better performance than designed and the recuperator meets the specifications,this temperature decrease currently onlyexceeds 240 K.

Since the inlet temperature of the turbine must not exceed 700°C, the combustion chamber temperature is limited to 930°C accordingly. This is sufficient for safe and clean FLOX burneroperation, but significantly reduces the operating window.

Therefore, the temperature range of the combustion chamber should be increased and made adjustable for safe fully automatic operation. For this purpose, a controllable bypass of therecuperator was realized at the pressureless point of the turbine circuit, at the turbine output (Figure 14).

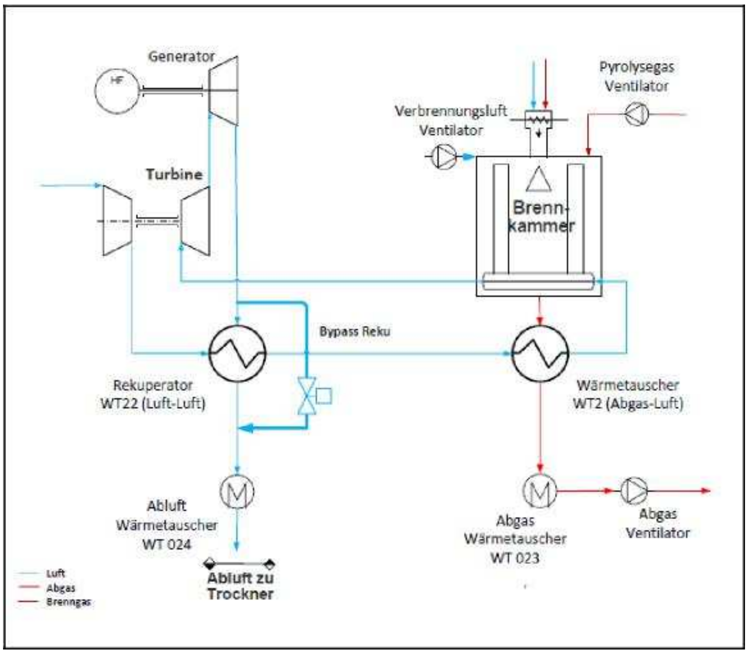


Figure 14 Schematic representation of the bypass via the recuperator "Bypass Reku"

This allows the heat transfer in the recuperator to be regulated and thus also the inlet temperature in WT2 and subsequently the combustion chamber. Thus, the combustion chamber temperature can be increased to keep the turbine inlet temperature in the ideal range (680 to 690°C).

The already mentioned other modification to the exhaust heat exchanger WT2" (see chapter 4.4) was removed after the installation of a controllable bypass of the recuperator. The following illustrations (Figure 15 and Figure 16) show the bypassabove the recuperator.

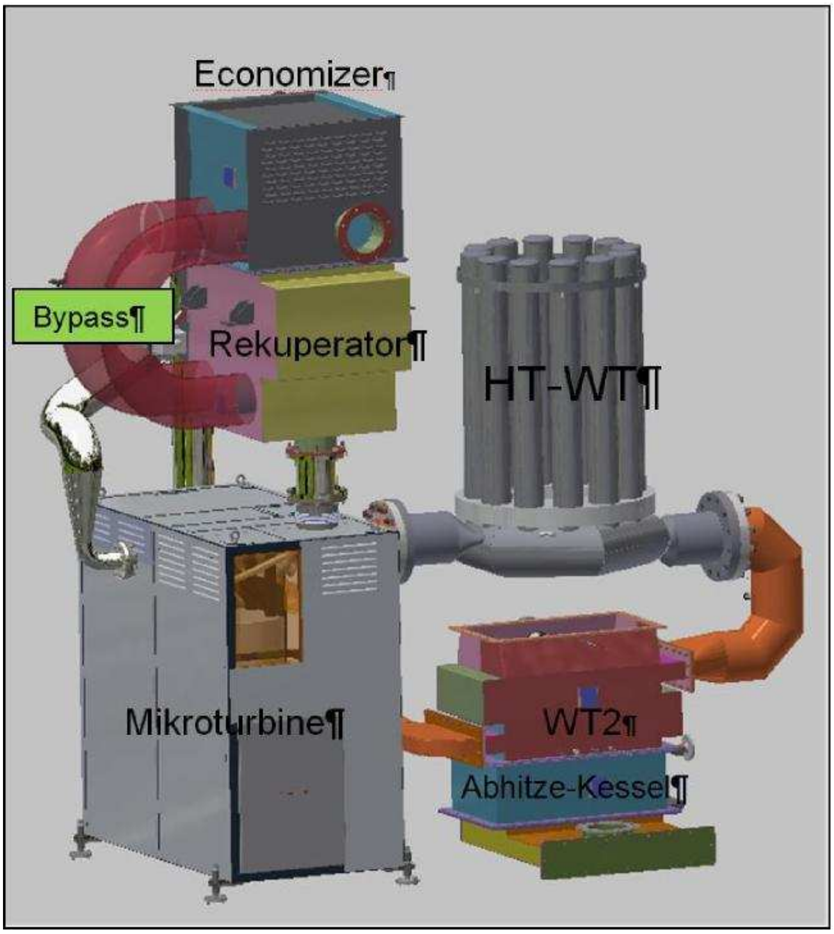


Figure 15 In the CAD representation of the entire turbine circuit, the reku bypass is quite large because the pressure losses via the recuperator are so low that the bypass must have a large cross-section to show an effect.

Figure 16 Bypass recuperator (still without isolation)

4.8 Measuring/determining the effect of the conversions

Measurements of the efficiencies are still pending. Based on the measures (see chapter 4.7), the system was simulated with up-to-date measurement data. It was found that the high-temperature heat exchanger in the combustion chamber is significantly more efficient than calculated. It takes about 210 kW of thermal power from the combustion chamber instead of 170 kW. This is of course partially provoked by the measure itself, in that the inlet temperatures increase lower and thus also the temperature difference to the combustion chamber.

In order to check the effect of the measures described, various tests were carried out. Due to the automation of the system, individual decoupled tests of subcomponents are hardly possible. Therefore, the effects are not always easy to calculate and mustbe explained in connection with various other parameters.

The conversions allow for an enlarged operating window of the combustion chamber temperature. However, the measures show less strong effects than expected. The measured effectsbased on (Figure 17) are discussed below.

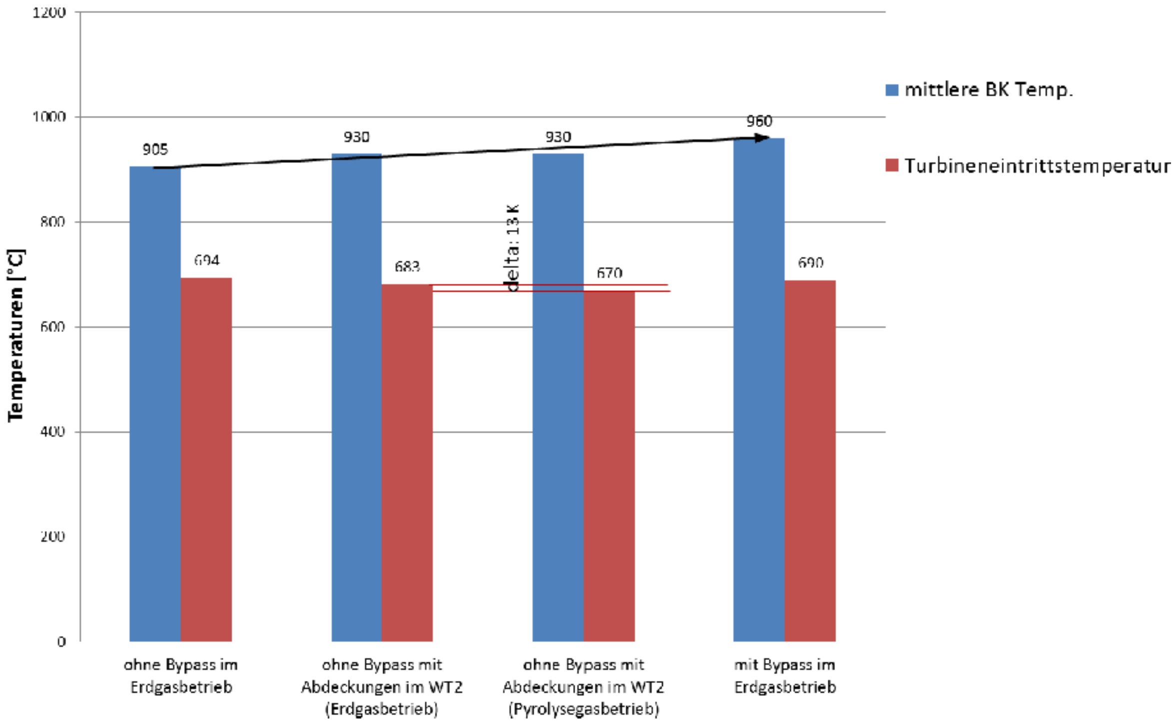


Abbildung 17 Versuche zur Evaluation der Wirkung des Reku-Bypasses

Figure 17 shows the combustion chamber temperature and turbine inlet temperature of four tests on the system. The turbine suppliedabout 40 to 48 kWe to these tests, so that mass flows of about 0.68 to 0.75 kg/s can be assumed.

The system can be operated in natural gas operation (with closed external recirculation and nominal air preheating to 250°C) at 960°C combustion chambertemperature at a turbine temperature of 690°C to 700°C. Although this is still less than by interpretation (1,000°C

/ 690°C) but a sufficiently wide range for safe autonomous operation. In pyrolysis operation, an improvement of about 10 K is expected. This is due to the slightly different (radiation) behaviour of pyrolysis to natural gas (see Figure 17, test without bypass with insert plates in WT2 in natural gas operation versus pyrolysis operation).

In summary, it can be said that the measure "reku-bypass" increases the temperature difference between the control temperature of the combustion chamber and the turbine inlet von 211 to 270 K (see Figure 17), if the additional aid is neglected by the external exhaust gas recirculation. The goal was to increase the spread to 310 K. Thus, only about 60% of the effect of the measure was achieved (increase ofthe temperature difference by59 instead of 100 K). However, the increase in the range is sufficient to ensure fully automatic operation.

4.9 Evaporation II

Following the conversions, the plant was ramped up in pyrolysis mode in order to adapt the control to the bypass conversion in biomass operation. After about 12 hours of operation, the system has automatically shut down due to an oil pressure drop in the turbinesystem. In order to be able to resume the test program as quickly as possible, an attempt was made to restart the system. Due to the high activity of the reactor, pyrolysis asses have flowed into the combustion chamber despite the flaps closed. Dueto the manuelle manipulation of the limit temperature for restarting, the inflowing pyrolysis asses caused a evaporation when the air fans started to start. The lid (provided pressure relief device) has opened. No damagehasbeen caused. After inspection of the combustion chamber, the combustion chamber lid and the pipes, the system was put back up for operation. The gas hose is replaced for safety reasons. In a subsequent test, the functionality of the plant was checked and driven in natural gas operation.
As a consequence, no hasty restarts after shutdowns may be carried out in commissioning mode.

5 Evaluation of the results so far

5.1 Anlagetechnik

The commissioning of the plant was much more demanding than expected. Due to the complexity of the plant technology, errors such as false air inputs, power fluctuations or unexpected efficiency values of heat exchangers cannot usually be assigned simply tothe cause. The search for these plant defects has delayed the project, but has also provided various new insights for the construction of future plants.

In particular, the correct materialization of the system (seals, insulation,v screws) must be paid even more attention to future systems in order to avoid time-consuming repairs.

Although the system has not yet been operated without observers, the various tests have made it possible to prepare a large part of the control circuits for operation without observers.

In the field of engineering, the findings were valuable through the optimizations. The extreme effects of a slightly too high efficiency of heat exchangers were not expected and allows individual components to be resized in future plants and high-temperature processes, which also offers financial advantages.

Due to the various retrofits carried out, the plant has only been in operation for a short time since it was put into operationin August. Accordingly, no significant amounts of energy or any further biochar were produced and continuous operation of the plant could not yet be tested.

5.2 Energy flows and material flows according to design

PyroPowerPlant receives a material flow (low quality wood chips), a small amount of electricity for self-consumption as well as for the heating process additionally natural gas.

This results in a material stream in this WKKK system (plant coal, which also contains the minerals of the wood), as well as three energy streams (electricity, useful heat and losses).

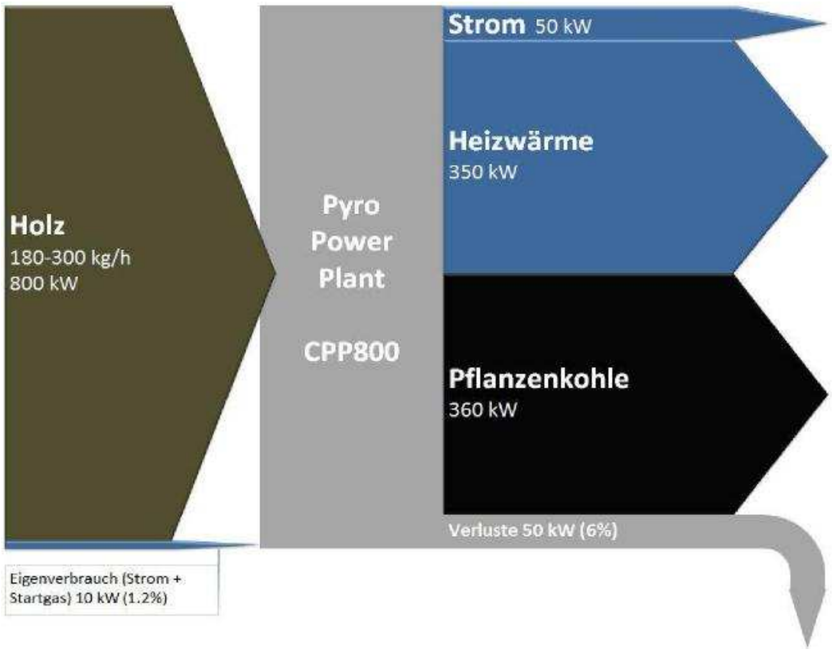


Figure 18 Input and output streams of PyroPowerPlant CPP800. Total efficiency = 93.8%

From this point of view, the overall efficiency is 93.8%. However, if only energy turnover is considered, i.e. only the part of the input, which is converted into energy output streams, the overall efficiency is reduced to 88.9%. This figure is compared to the 2017 application (90.0%) slightly lower, because the self-consumption of natural gas for some take-off operations is also distributed as a power throughout the year,in addition to the own electricity consumption, which was previously taken into account.

Figure 19 Input and output flows minus the amount of plant coal, which remains 'unused' in terms of energy turnover. Total efficiency 88.9%.

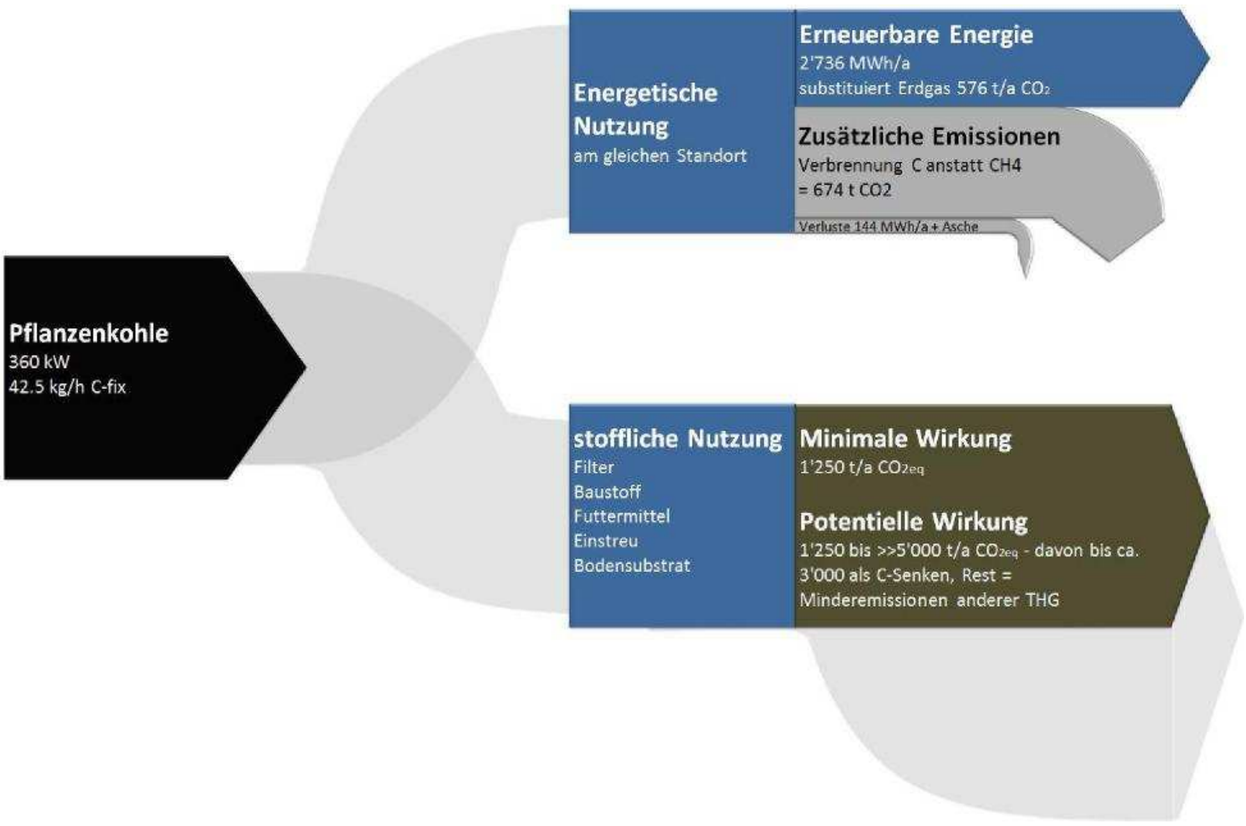


Figure 20 The use of charcoal as fuel or material. The additional effects of material use in agriculture (reduction of nitrous oxide, ammonia and methane emissions, as well as the possible build-up of humus (further determination of carbon) are outside the project and are not elaborated here.

If the material use of the carbon shown in Figure 20 is preferred to energy use with substitution of natural gas, at least 674 t less CO_2 emissions are produced.

Thus, for example, replaces the coal produced from hard coal filter coal in a sewage treatment plant (which is then disposed of at the end of use via incineration in a KVA and also partially energetic is used) – the burning of natural gas instead of plant coal is very worthwhile ecologically. In other applications in agriculture and animal husbandry, according to the literature, the climate benefit is even higher because humus build-up and the reduction of nitrous oxide and meademissions are also possible.

6 Next steps

The next milestone to be met is 7 days of operation without observers. This milestone is expected to be reached in 2019. Before this automatic continuous operation, a fewtests of the safety systems (e.g. in the event of failure of sensors, switches especially in the turbine system) have to be carried out. For continuous operation, the control of the pyrolysis fan and thus the reactions in the reactor must be finely adjusted.

Inoperation, error messages must be evaluated and, if necessary, adjustments made to the controller. The points condensation in the pyrolysis line, tightness at the transition to the WT2 and function of the level sensor must be observed, asfurther optimizations must be made here at all.

The following measures are foreseen to achieve stable continuous operation:

Problem	Cause	Measure	Date	Responsible
Condensate deposits in the pyrolysis line hinder the gas flow	The pyrolysis line is the coldest area despite isolation	Installation of an electric trace heating system on the pyrolysis line and at the upper reactor output	KW 3 2020 (depending on delivery date)	OeZ
Reactor is unevenly filled with biomass. This results in process fluctuations and increased congestionin the reactor	Level sensor reactor works unreliably	Replacement microwave probe with another sensor (e.g. rotary wing level limit switch) In addition, a dust separation at the reactor output or an enlarged outlet cross-section may have to be installed at the reactor in order to provide additional safety againstexcessive lyric isinput of particulate matter into the pyrolysis line and the combustion process.	From WEEK 4 2020 (depending on delivery date) optional KW 5-6 2020	Compag (in Discussion)
Leaks lead to substöchiometric combustion in the combustion chamber and increased air ingress into the pyrolysis process	Tightness Connection from combustion chamber to WT2 is insufficient under high thermal stress	In order to permanently minimize the thermo-mechanicalstresses on the connection, the decoupling of the heat exchangers from the combustion chamber via compensators is necessary	KW 12 to 14 2020 (long delivery times for compensators and approx. 2-3 weeks installationonwan d)	compag/ OeZ (in Discussion)

The HAZOP procedure must be carried out together with the FHNW.

In addition, the documentation and user manuals for the system must be prepared.

In the 1 Q 2020, the own exhaust gas measurements including total dust analysis will also take place, and shortly afterwards the official measurement on behalf of the AWEL Canton of Zurich will take place.

The final scientific task is efficiency measurements.

At the end of the project, although data on the proportion and proceeds of the plant coal sold and used in their own homes are already available, an economic analysis can be carried out.

The project currently has a delay of about 2-3 months againstthe schedule in the application.

7 National and international cooperation

In June 2019, a delegation from Berg+Kiessling (B+K) from Berlin and Cottbus visited the pilot plant. B+K has successfully implemented a project similar to that of MPT in Freiburg, namely to modify a Capstone microturbine in such a way that can be integrated into a hot air turbine system. The resulting product is called ClinX. The performance data also confirm our design and the calculations of the FHNW of 2014/15.ions are available. Integration possibilities in both directions are conceivable – integrate the compact heat exchanger system and the clean burn-out with FLOX combustion chamber into a wood-WKK system from B+K and Partner, or integrate a B+K microturbine into a pyrolysis system CPP800.

UniDO expert activity enabled the optimising in June 2019 of a PPV300 pyrolysis system (Figure 21), which was exported from Vietnam to Cambodia. The plant is operated with rice spelt andthus provides 220 kW of heat for the rice drying and parboiling process, as well as 45 kg/h of vegetable charcoal (with 50% C content). Although the plant was tested with rice furs before delivery, the supplied operating instructions were based on the much more energy-rich and ash-poor coffee bowls of the Robusta process. After a corresponding correction, the performance of the system was increased by 80% to the above-mentioned values. The silicon-containing rice spelt could beworked much better thanexpected. After half a year of operation inside, the reactor is still bare, without adhesion of substrate, ash, slag, glass or the like.

Figure 21 PPV300 from Vietnam in Cambodia - in operation with rice furs.

8 Communication

Presentation of the project with mention of the support of the SFOE

a) On the occasion of the plant manager training at Strickhof ZH in the renewable energy module together with Holzenergie Schweiz (March 2019)

b) In the Demeter Farmer's Training in Rheinau ZH in the Module Energy and Novel

c) At the pyrolysis and plant charcoal, sowie composting training of the Hausverein Nordwest Schweiz in Reinach (April 2019)

d) At 9 meetings with well-known Swiss companies in the field of renewable energy, recycling and food production.

e) On Summer WEFF Davos 2019 on August 24, 2019

f) An the ERFA meeting with Wood Energy Switzerland in Flaach ZH on 4 September 2019

g) In the permaculture designer training in Langenbruck on 19 October 2019

The climate fund of Stadtwerk Winterthur mentioned the project and the commissioning in the newsletter of July 2019

9 Publications

Pyro Power Plant – A greenhouse heating that makes coal! 4-page brochure as a printed matter, all partners with logo mentioned.

Valorizing rice husk > biochar and energy – improvement of service of a Vietnamese Pyrolysis System PPV300 in Cambodia; Mission Report für UNIDO mit Erwähnung des vorliegenden Projektes in Wort und Bild

10 Bibliography

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[2] www.4p1000.org

[3] CIFOR is also part of the CGIAR network headquartered in Par is, with which the eco-centre and its international partner SOFIES have contact in Indonesia and Vietnam as well as in Peru and Colombia. https://www.cifor.org/

[4] Thees, O.; Castle, V.; Erni, M.; Bowman, G.; Lemm, R., 2017: Biomass potentials of the Schweiz for energy use, results of the Swiss Energy Competence Center SCCER BIOSWEET. WSL Ber. 57: 299 p.

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