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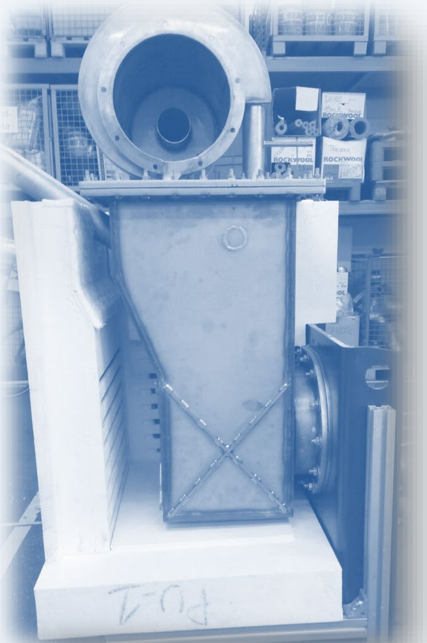
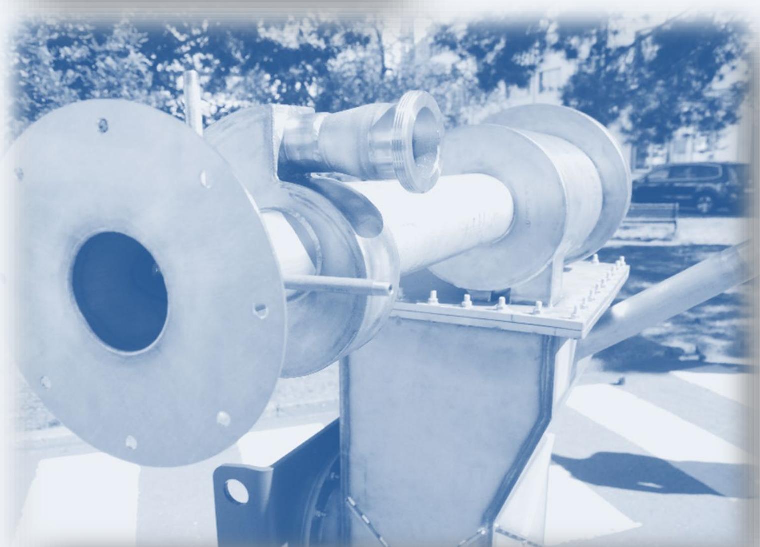


2nd German Doctoral Colloquium Bioenergy, 1st of October 2019

„BioWasteStirling“ – Long-term operation expercience of a fluidized bed-fired Stirling engine for micro-scale CHP



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Agenda

I
II
III
IV

1. Challenge and objective of the project „BioWasteStirling“

2. Characterization tests of the pilot plant concept in lab environment

3. First long-term test in lab environment

4. Setup and commissioning in field test environment

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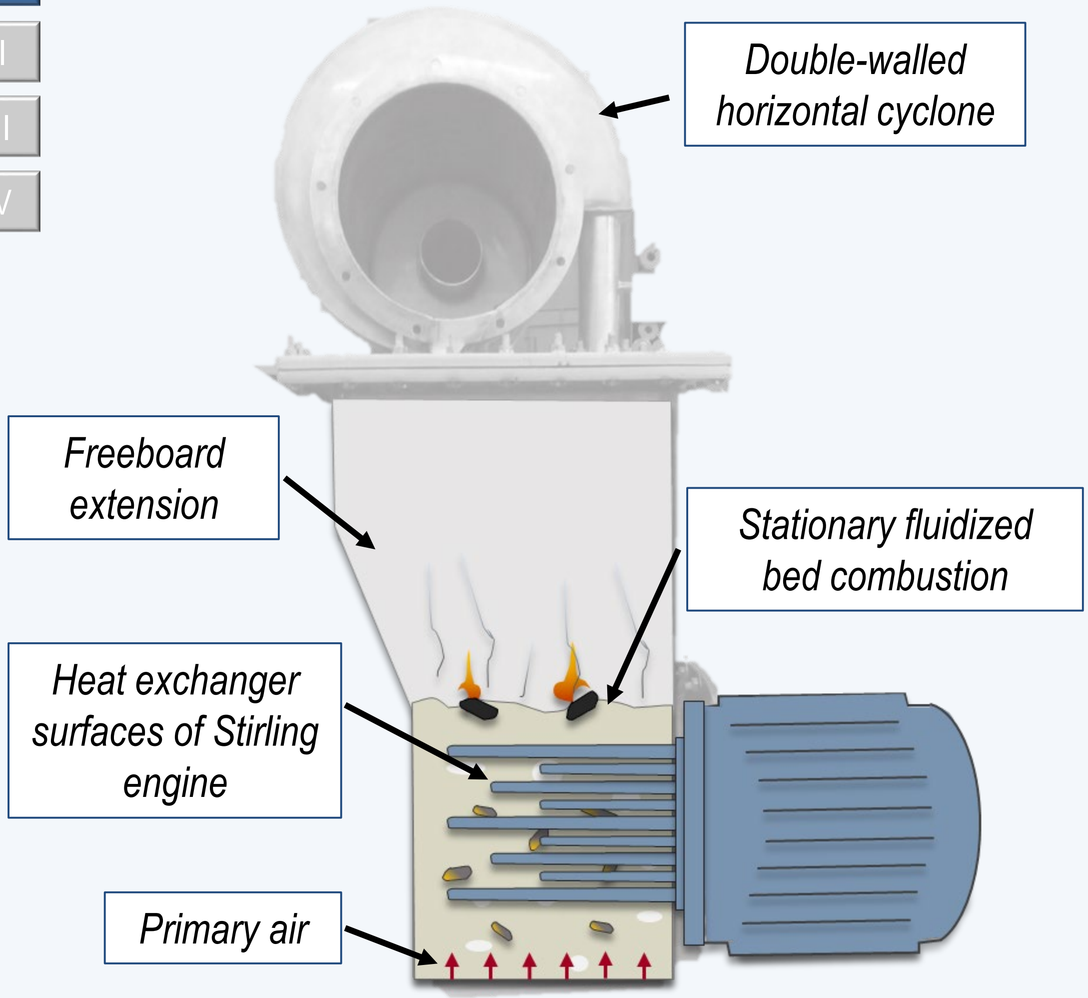
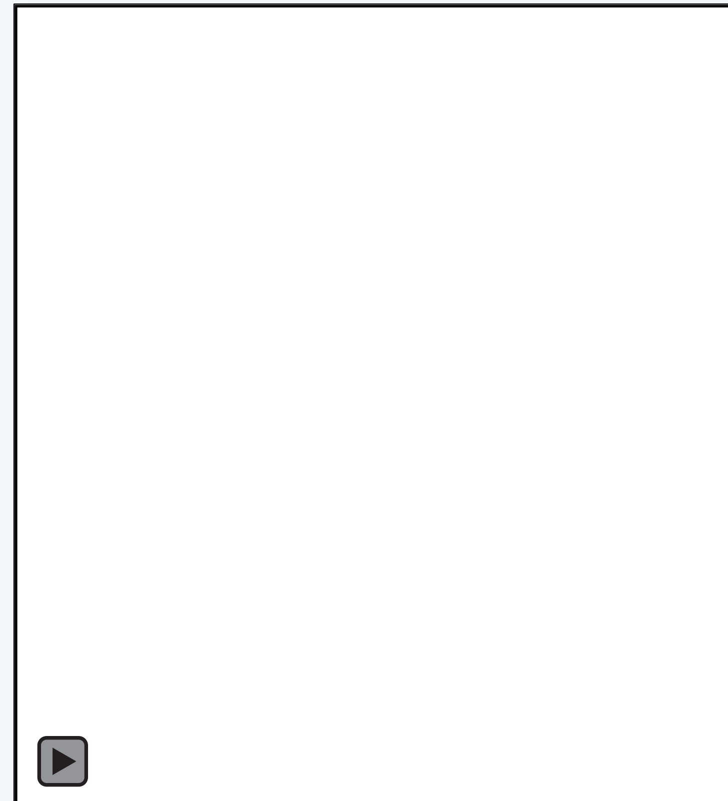
Motivation

- Most of biomass-fired CHP-systems often failed due to declining heating of the heat engine
- High ash contents correlating with low ash melting temperatures result in fouling and slagging on heat exchanger surfaces and finally system failures

Concept

→ Direct placement of heat exchanger surfaces of the Stirling engine into a fluidized bed combustion





Barracuda VR simulation of the particle distribution in a fluidized bed combustion at fluidization = 12

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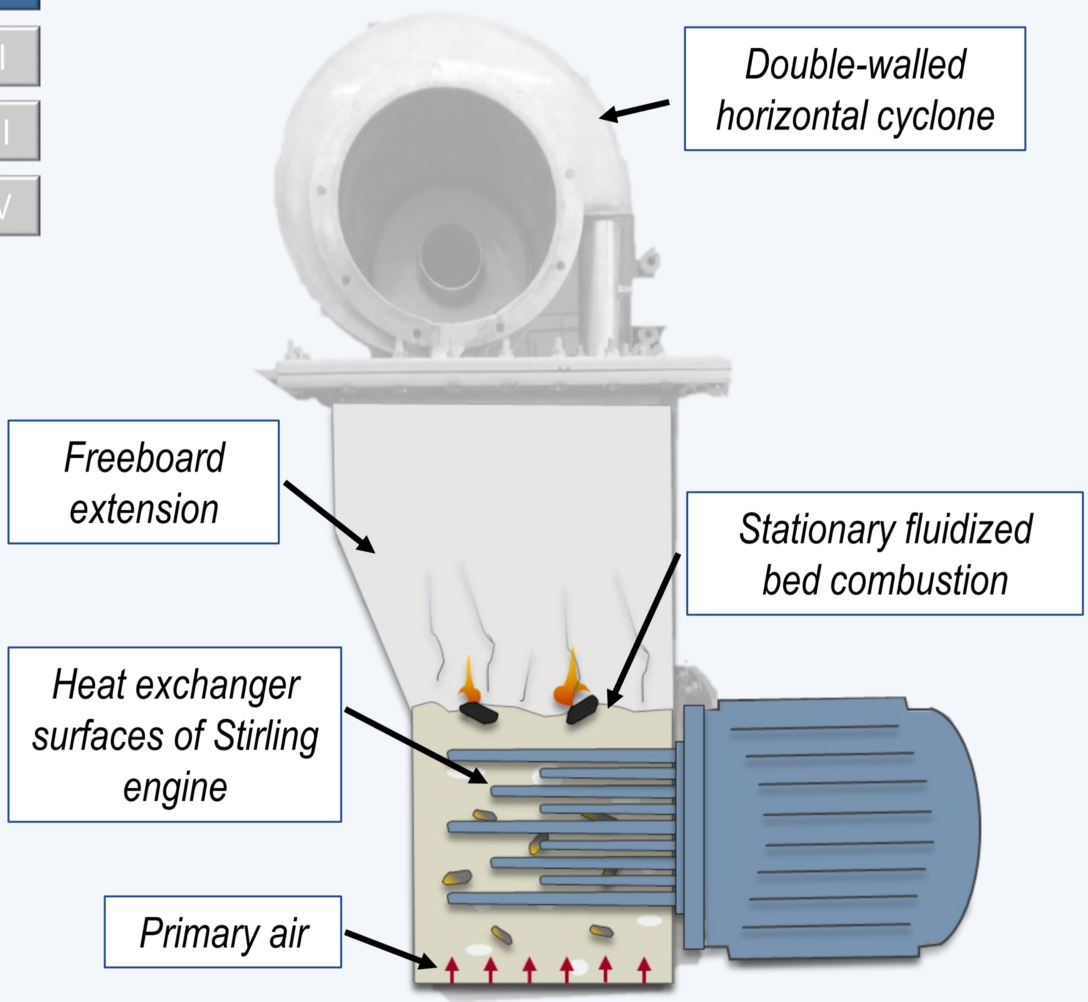
Concept

I
II
III
IV

→ Direct placement of heat exchanger surfaces of the Stirling engine into a fluidized bed combustion



Advantages of the fluidized bed

- Homogenous temperature distribution
- High heat transfer
- Fuel flexible
- Scalable (output range < 100 kW)

Direct coupling of Stirling engine and fluidized bed combustion allows

- Effective prevention of fouling
- High combustion efficiencies
- Exploitation of biogenic residues

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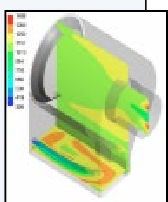
Project content & partner

I
II
III
IV

1st of September 2017 – 31st of August 2020

AP3 Particle separation



AP4 Erosion

2017 → 2018 → 2019 → 2020

AP1 Setup & commissioning

AP2 Field test

AP5 Economic analysis

Project partner

Energetische Biomassenutzung

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

- FAU Erlangen-Nuremberg, EVT
  - Further development of particle separation
  - Market analyses & deployment scenarios
- SWW Wunsiedel
  - Performance of the field test
  - Fuel preparation
- TFZ Straubing
  - Fine dust analytics
  - Legal considerations
- Frauscher Thermal Motors
  - Supply od the Stirling engine
  - Further development of heat exchanger design

SWW wunsiedel wir bewegen

WUN bioenergie.

TFZ

frauscher thermal motors advanced bioenergy

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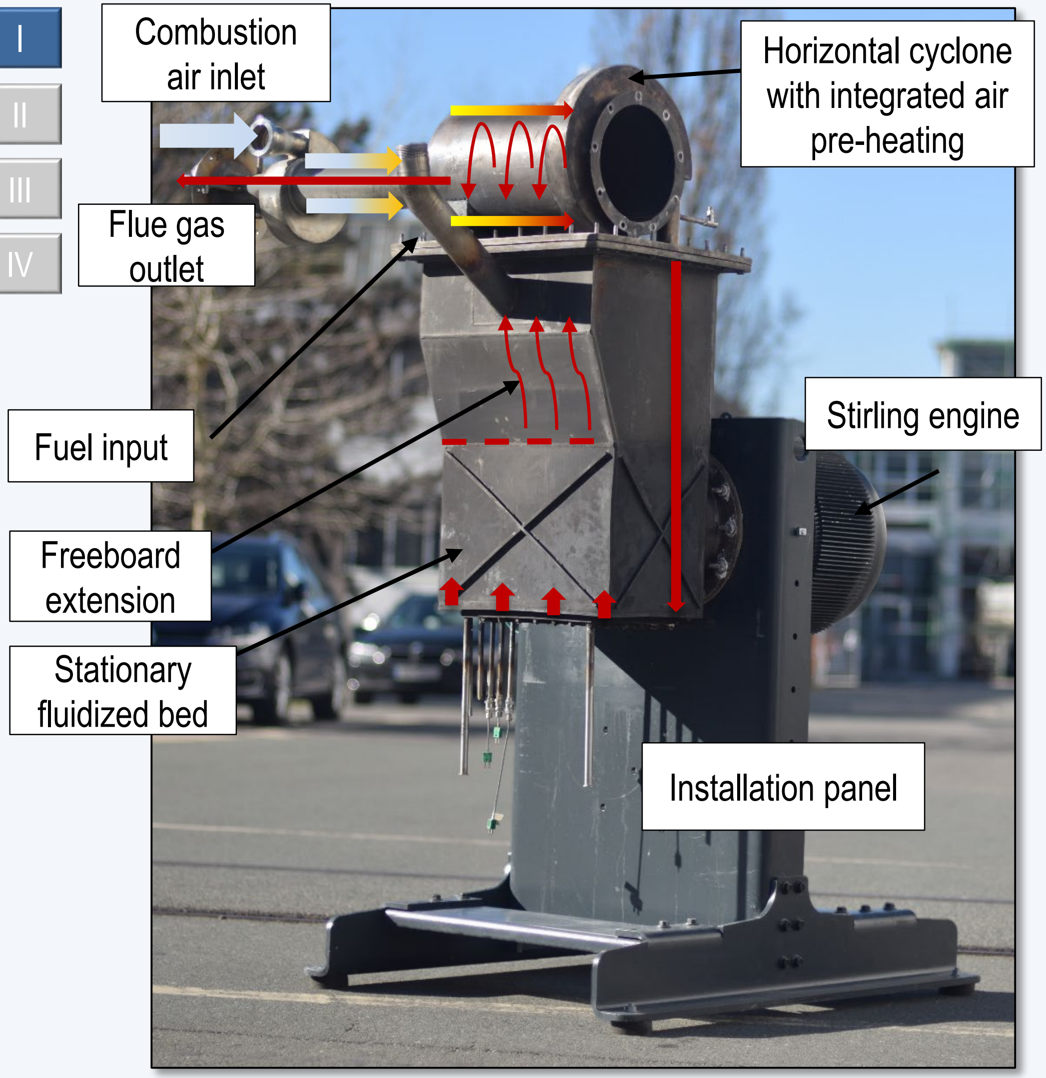
Setup of the pilot plant



	Pilot plant
Rated thermal input	45 kW_{th}
Rated electrical output	5 kW_{el}
Stirling engine	Frauscher Thermal Motors Type A600 α-Stirling
Working fluid	Helium, 40 bar
Installation site	Mobile container (autarkic operation)

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Preliminary conlusion

✓ Upscaling & Conception of the pilot planned successfully completed

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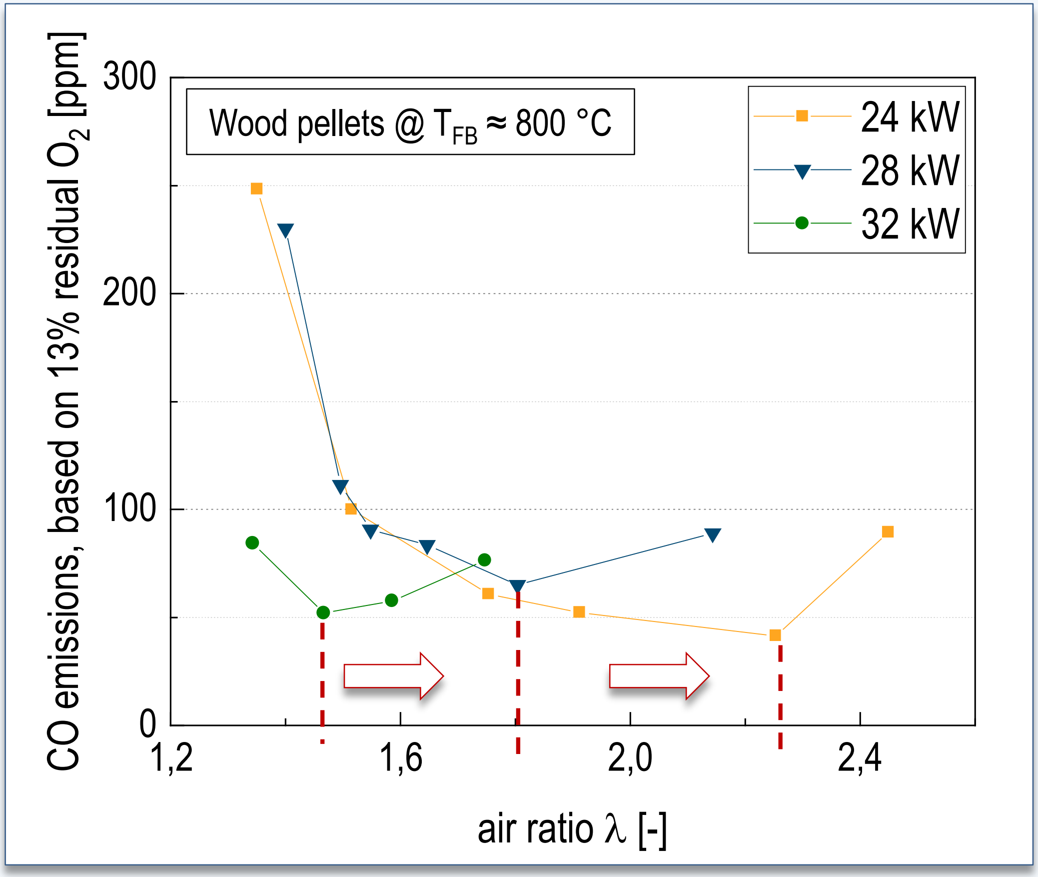
Characterization tests at EVT



- Overall air flow affects the CO emissions significantly
- Optimum of residence time and turbulence determines CO emissions
- Dust emissions are independent of the operation point below the limits of the 1. BImSchV

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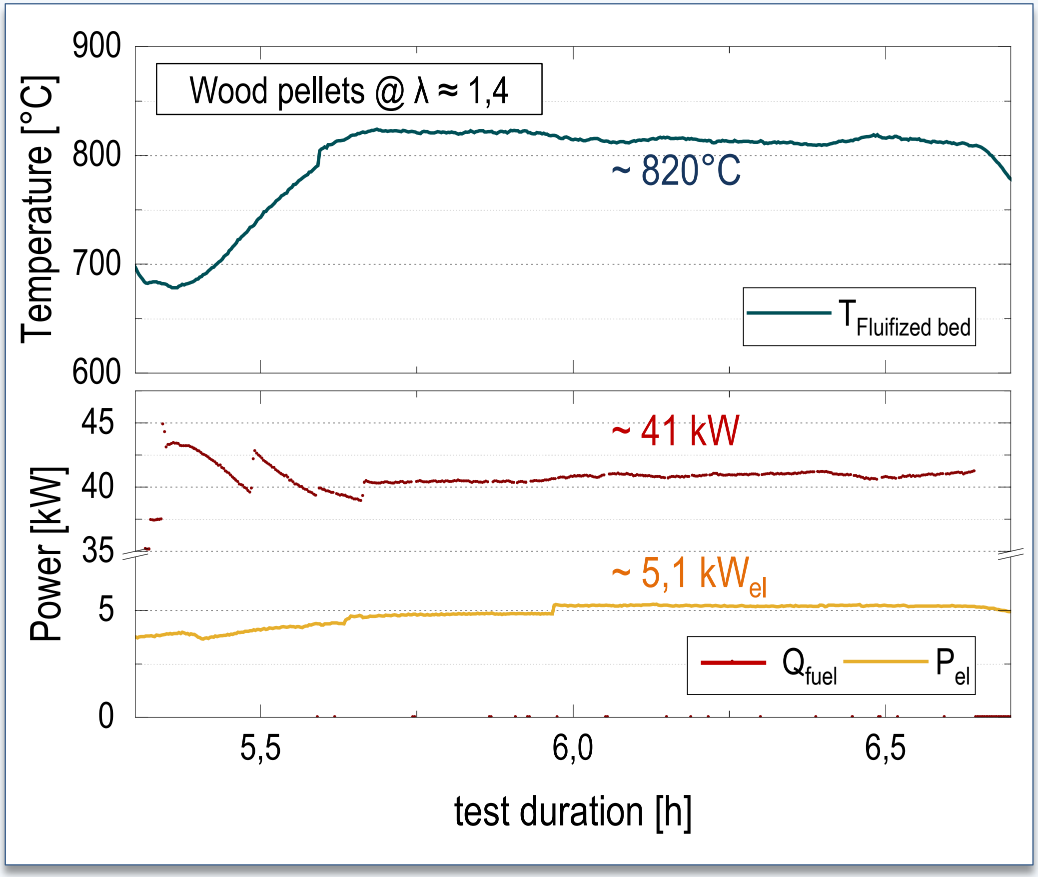
Influence on Stirling engine



Increase of engine power output by:

- Increase of $T_{\text{Fluidized bed}}$
- Decrease of T_{Cooling}
- Increase of fluidization u/u_0
- Increase of process pressure p_{Helium}

⇨ Optimum of the overal plant is a combination of optimal emissions, electrical output and efficiency

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Preliminary conlusion

- ✓ Upscaling & Conception of the pilot planned successfully completed
- ✓ Pilot plant fulfills with wood pellets the limits of 1. BImSchV
- ✓ Stirling engine realizes its nominal performance of 5 kW_{el}

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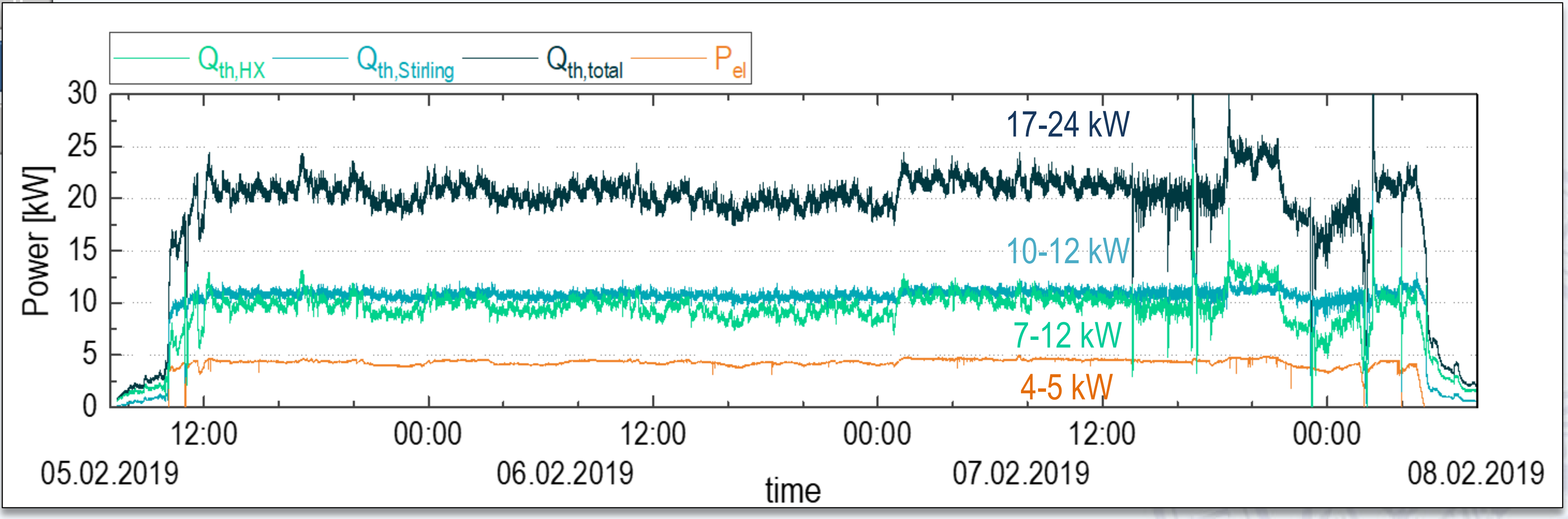
72h-test in lab environment at EVT

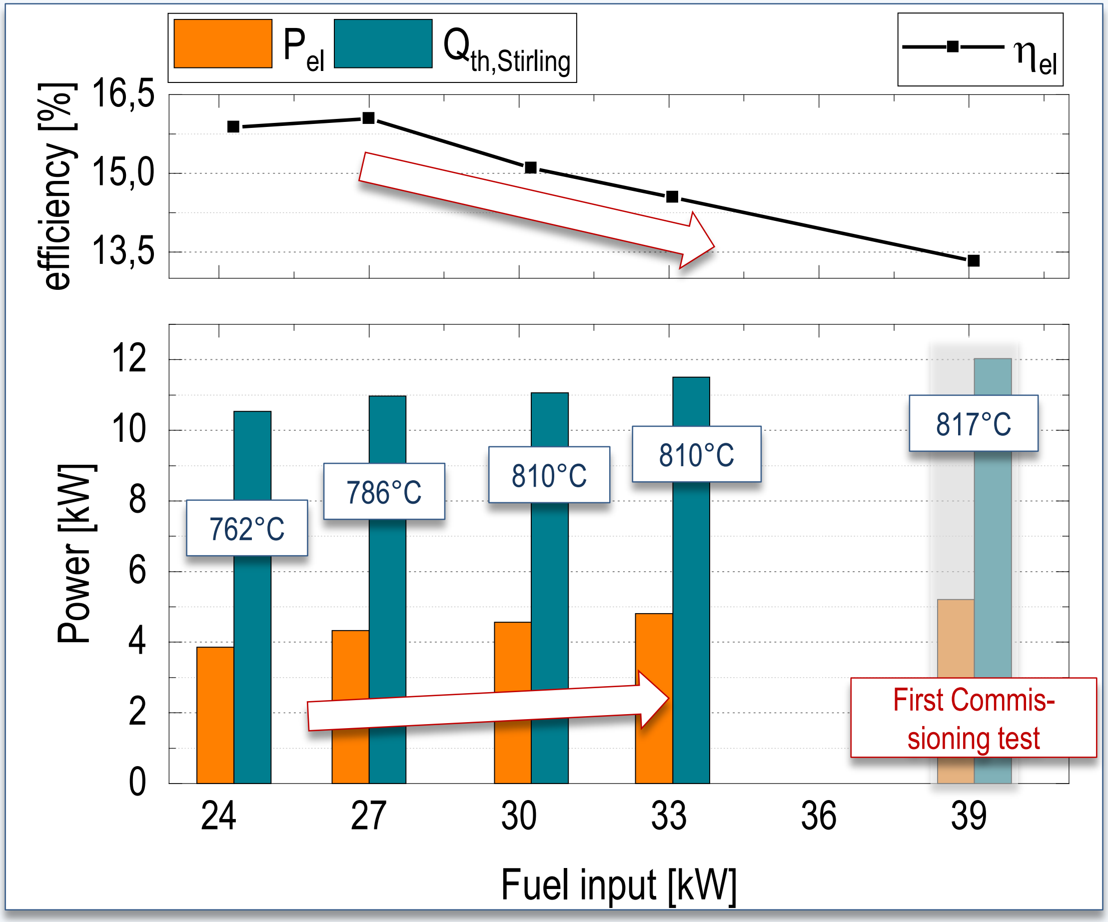
→ Intention: Determination of control parameters and first experience of longterm operability



- CO emissions are constantly below the limits of 1. BImSchV
- Thermal and electrical power output vary depending on fuel input and cooling temperature
- Good controlability by adaptions of Q_{fuel} or air ratio

⇨ Robust system despite small-scale plant solution

Efficiency considerations



- $Q_{th,Stirling}$ results as functions of the electrical output and the Stirling efficiency
- Overall electrical efficiency depends on the load condition

⇨ Assumption: at higher rated thermal input the thermal release in the fluidized bed proportionally decreases

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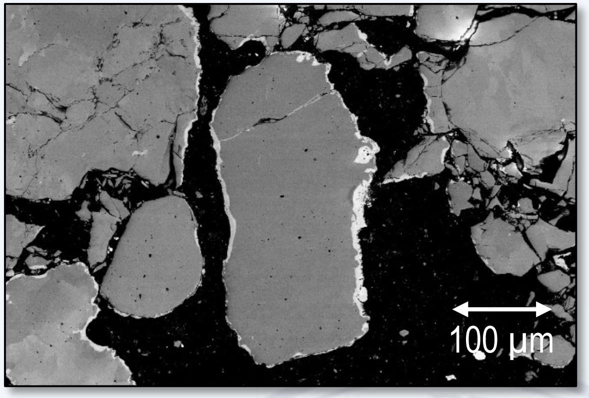
Conclusion bed material

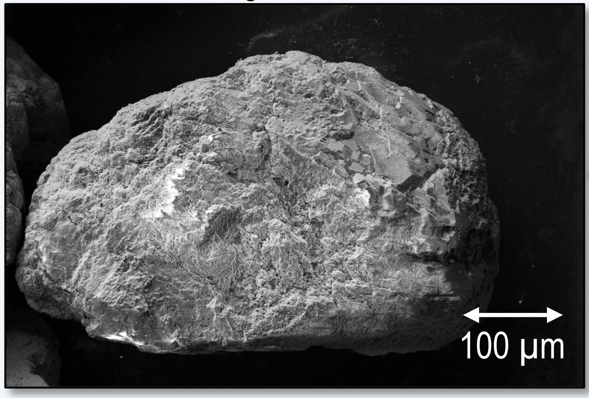
I | II | III | IV

- No variations of the pressure drop in the fluidized bed during test time
- No agglomerations in the bed material detectable

REM images, HR 0,1-0,6T after 90h

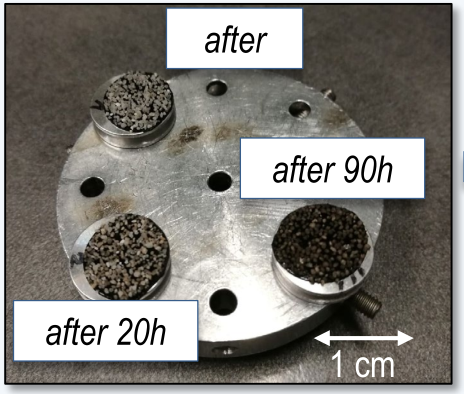


REM images, HR 0,1-0,6T fresh

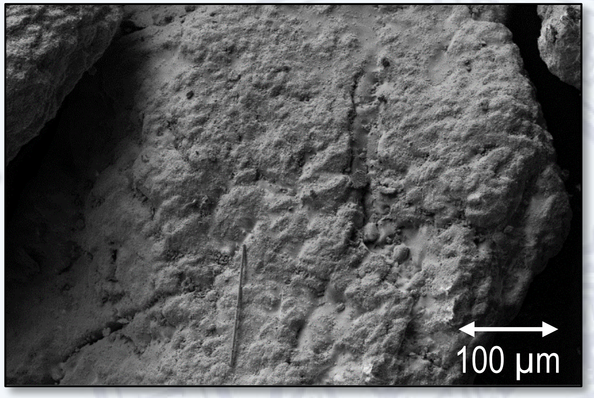


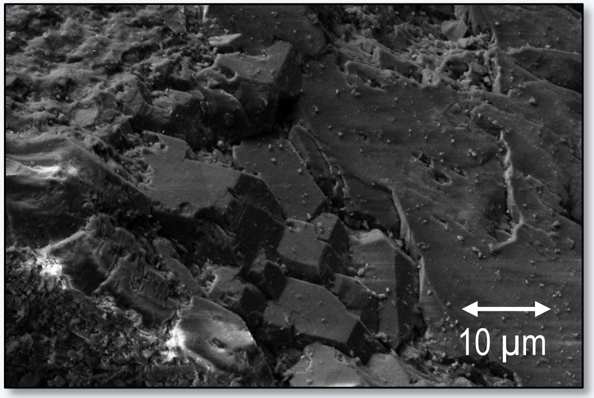
fresh

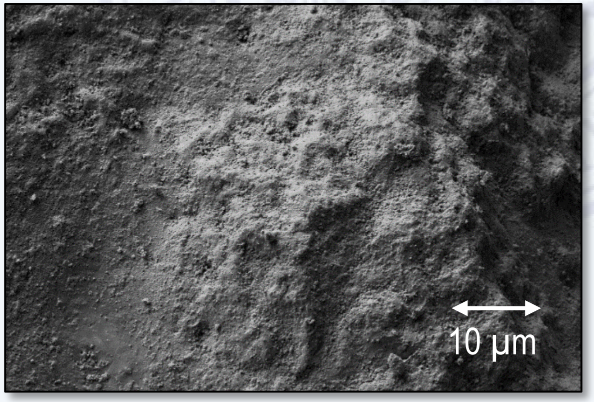
Comparison bed material



after 90h







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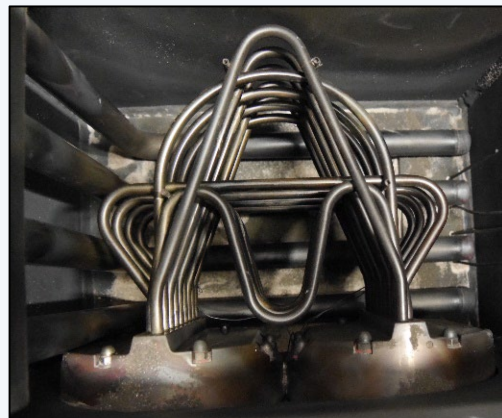
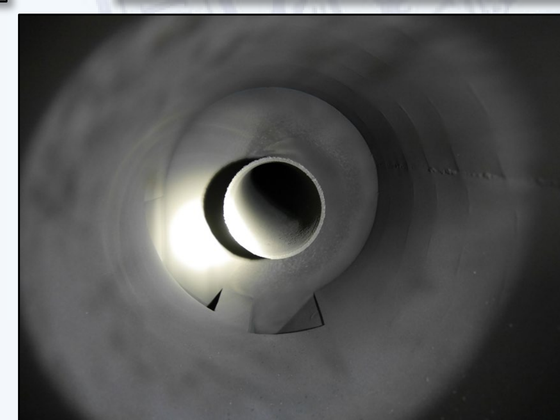
Conclusion system components

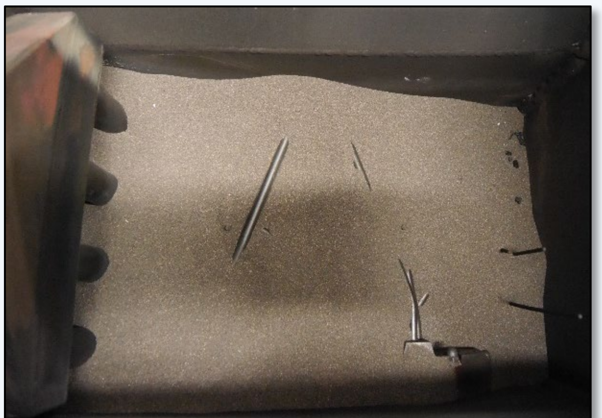
- No fouling or slagging at heat exchanger surfaces, in the reactor or in the cyclone
- No detectable erosion at heat exchanger surfaces or reactor walls

Heat exchanger of Stirling engine after longterm test



Horizontal cyclone after longterm test





Fluidized bed reactor after longterm test

Condensing flue gas heat exchanger after longterm test

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Preliminary conlusion

Motivation
Characterization
First long-term
Field test

- ✓ Upscaling & Conception of the pilot planned successfully completed
- ✓ Pilot plant fulfills with wood pellets the limits of 1. BImSchV
- ✓ Stirling engine realizes its nominal performance of 5 kW_{el}
- ✓ Longterm test in lab-environment demonstrates process stability & longterm operability
- ✓ Pilot plant achieves electrical efficencies of approx. 15 % and fuel utilization rates of 90 % in lab

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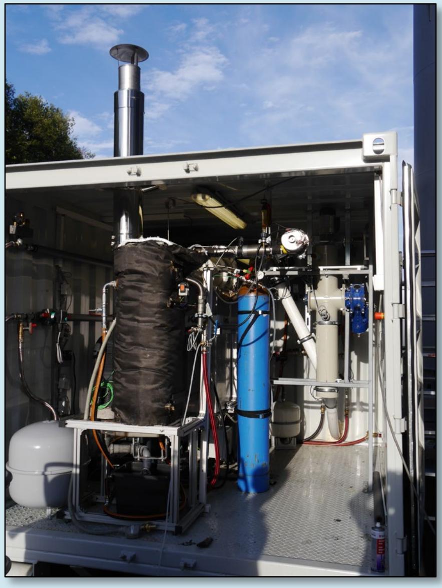
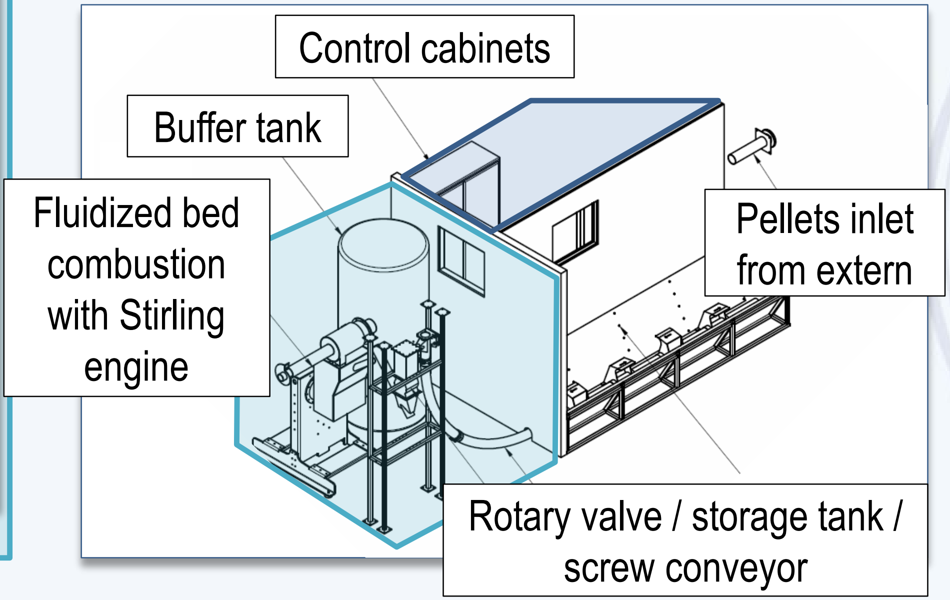
Installation at field test environment


Exterior view container

Pellets factory in Wunsiedel, location for field test plant


Opertaion room container




Control room container

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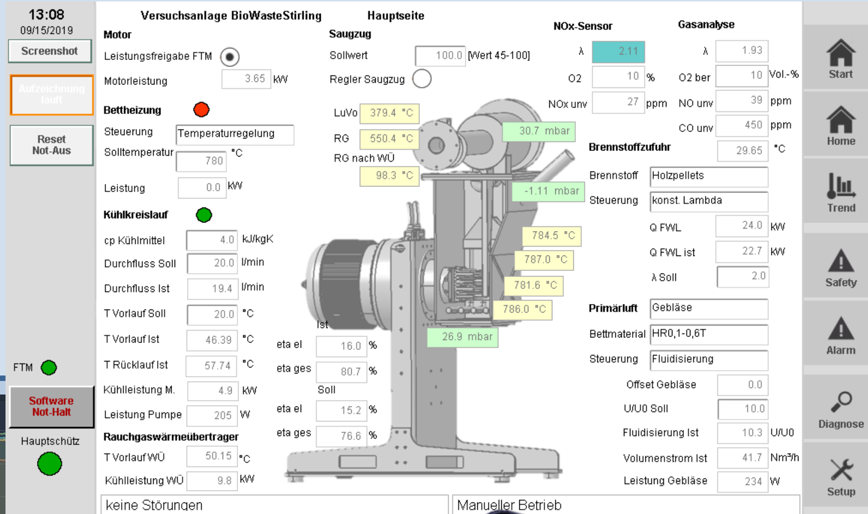
Control staregy & remote maintenance

I
II
III
IV

- Self-programmed control system (SPS)

  Remote maintenance by VNC
- Monitoring of parameters via visualization by Grafana

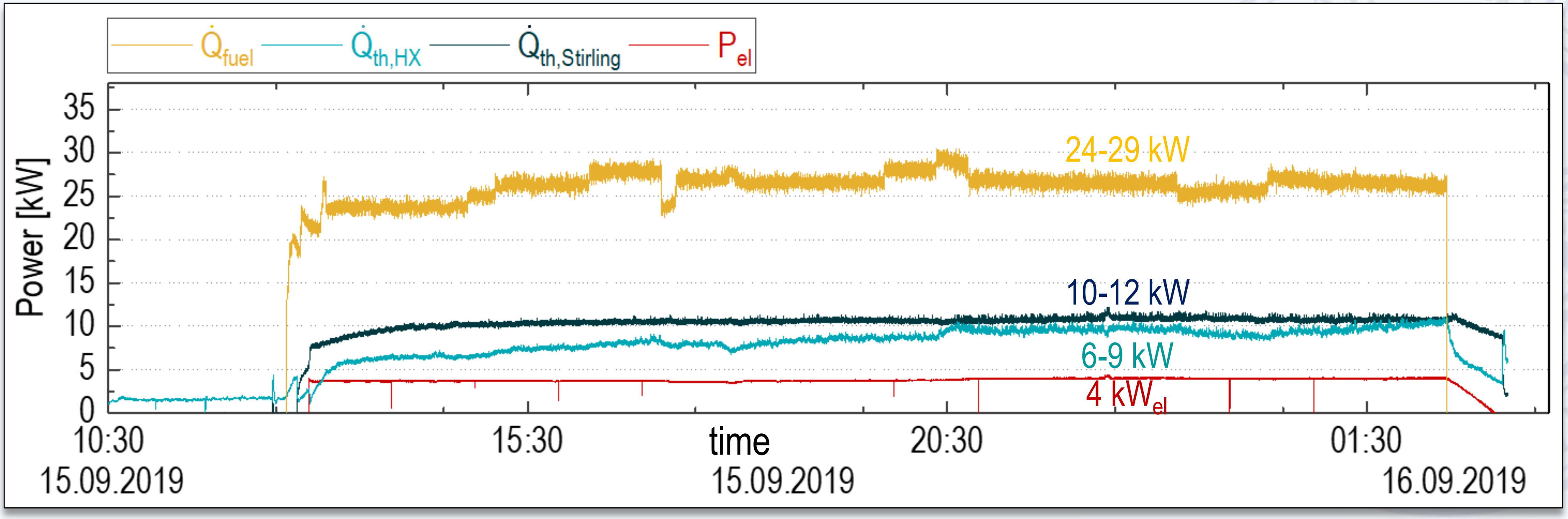
User interface



Visulatization by Grafana

First results of field test plant

- Low CO emissions from lab tests confirmed
- Decrease of P_{el} & $Q_{th,HX}$ (approx. 5-10 % each) because of higher cooling temperatures
- Constant CHP coefficient



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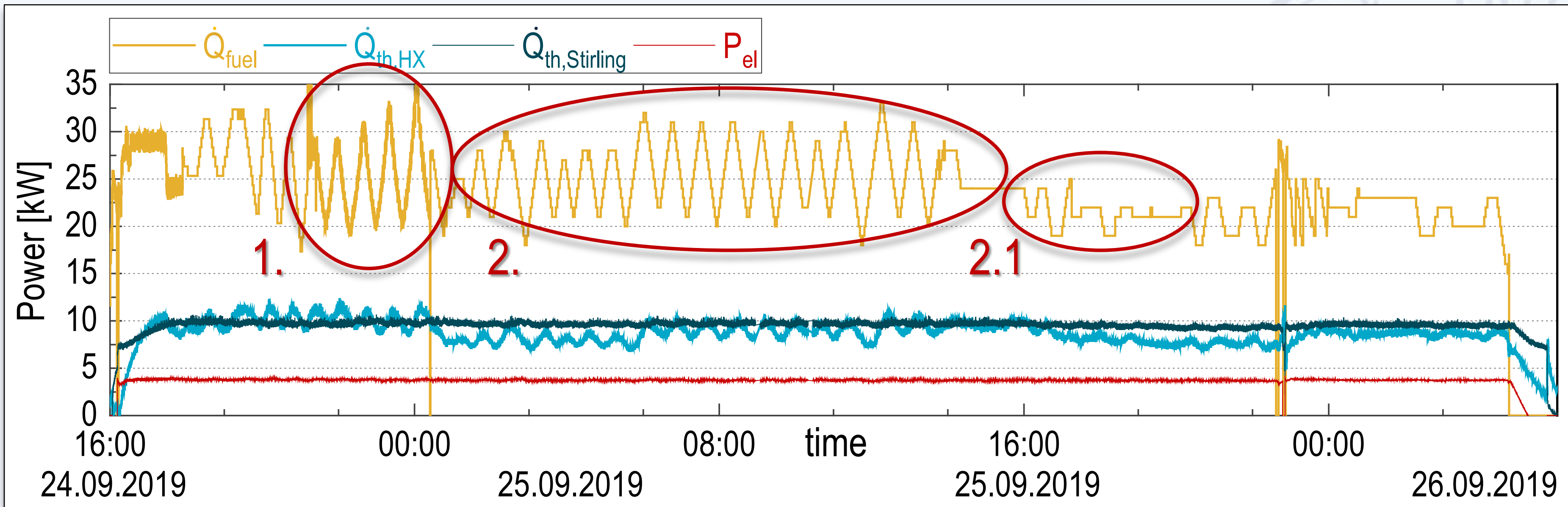
Unsupervised operation & control strategy

- Automated Start-up until defined operation point and shut-down without problems possible
- Short interventions during automatic operation point control necessary
- Safety functions in order to shut-down automatically are working

→ Further development of control strategy adapted to the new field test circumstances



1. Temperature control by Lambda adaptation (indirect Q_{fuel})

2. Temperature control by direct adaptation of Q_{fuel}

2.2. Temperature control with higher tolerance

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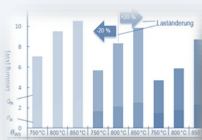
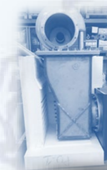
Conlusion & Outlook

- ✓ Upscaling & Conception of the pilot planned successfully completed
- ✓ Pilot plant fulfills with wood pellets the limits of 1. BImSchV
- ✓ Stirling engine realizes its nominal performance of 5 kW_{el}
- ✓ Longterm test in lab-environment demonstrates process stability & longterm operability
- ✓ Pilot plant achieves electrical efficencies of approx. 15 % and fuel utilization rates of 95 % in lab
- ✓ Installation and commissioning in field test environment successfully completed





- ➢ Longterm test with different solid woody fuels and biogenic residues
- ➢ Development of an efficient bed material managament for the continious operation

Thank you for your attention!

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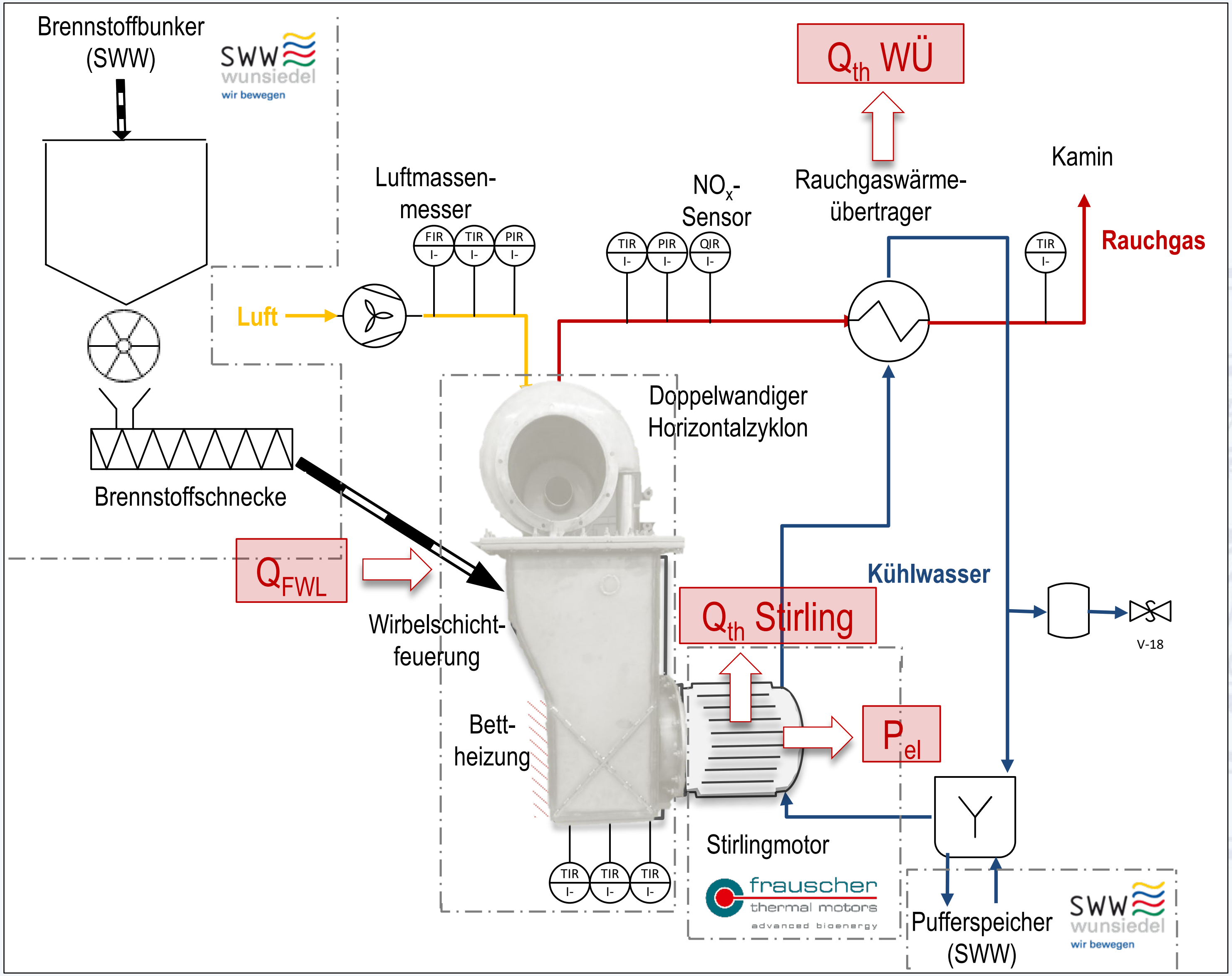
Overall plant setup



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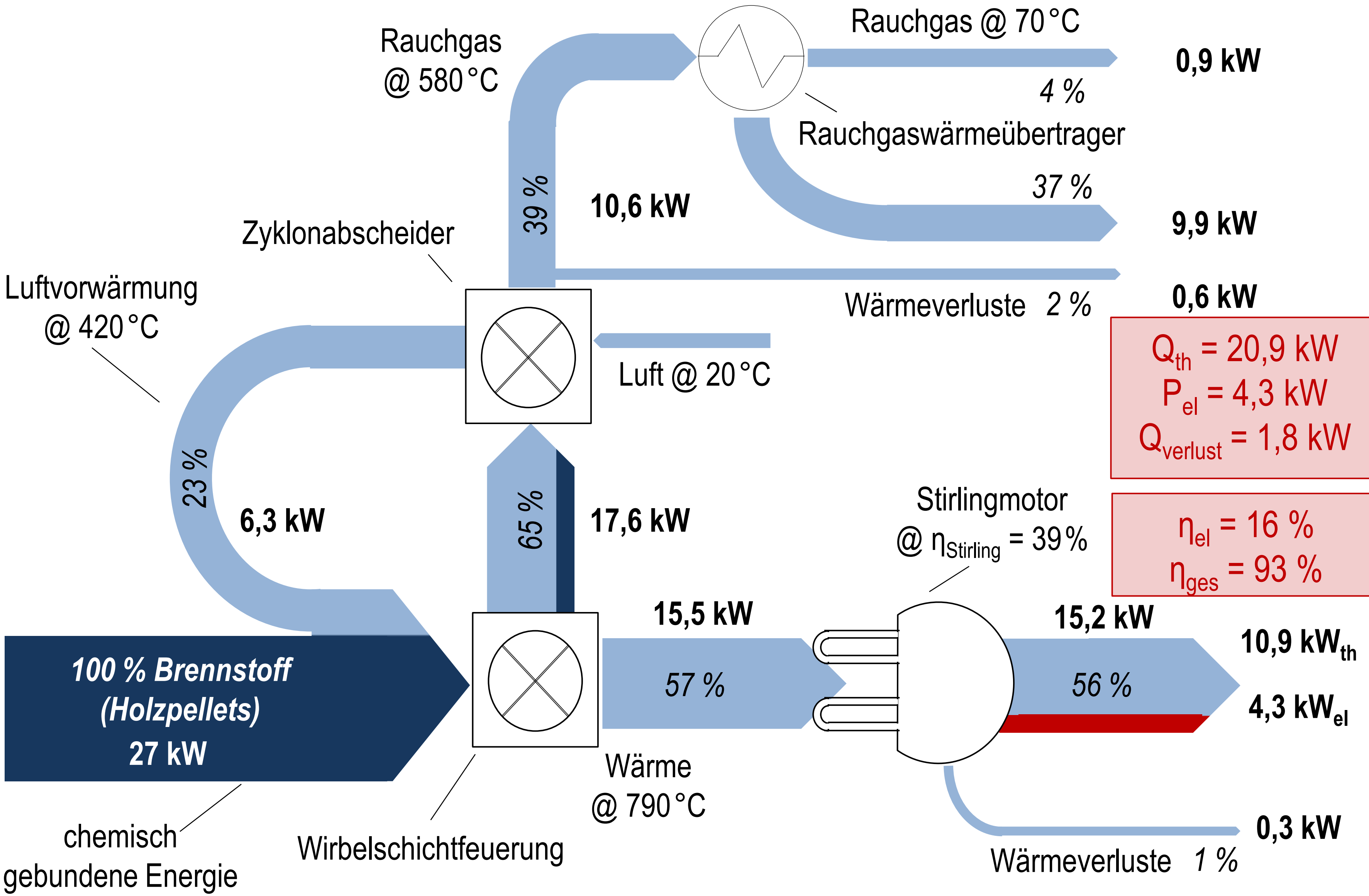
Sankey Diagramm



Q_{th} = 20,9 kW
P_{el} = 4,3 kW
$Q_{verlust}$ = 1,8 kW

η_{el} = 16 %
η_{ges} = 93 %