WP3 Summary
Biomass to Advanced Heat and Power

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Tasks and Overall Objectives (2017-2020)

1. Extension of solid biomass fuels for combustion and gasification processes.
2. Burner optimization using validated chemical kinetics and fluid dynamic modeling to reduce harmful emissions
3. Process integration of biomass combustion systems
4. Energy system integration to avoid fossil fuel peak supply
5. Thermal recovery of phosphorus from waste biomass

➢ Development of clean and efficient heating systems with wood, as well as alternative solid biomasses to increase the substitution of fossil energy carriers
Research Partners

FHNW
T. Griffin

HSLU
T. Nussbaumer

HES-SO
R. Röthlisberger

PSI
O. Kröcher

PSI
C. Ludwig
Achievements during the period

- **Clean and Efficient Heating Systems with Solid Biomass**
  - Burner/Plant designs finalized and implemented in the market
    - Two-stage combustion systems for low-emissions:
      Retrofit Wood Gas Burner (TRL 5→6) / Wood Log Boiler (TRL 6→7)
    - Wood Dust Burner for high temperature process heat in asphalt plant (TRL 6→7)
    - Screw Burner for high ash fuels (TRL 3→4)

- **Pretreatment and Characterization Technologies**
  - Pilot and Demonstration Plants for Torrefaction and Hydrothermal Carbonization
  - Field, in-situ measurement of heating value of wood chips (XyloChips)
  - Mobile pelletizing unit
Achievements during the period

- Process/Energy System Integration within biomass combustion systems
  - Development and long-term testing of an integrated particle separator in a pellet boiler (OekoSolve)
  - Exhaust gas after-treatment with different filtration systems (XyloClean)
  - Demonstration plant for 300 °C process heat using a mixture of wood chips and grain residues (Grate Combustor)
  - Modeling and strategies developed for thermal energy storage for load management to reduce CO$_2$ emissions
Cooperation with the Public Sector

- T. Nussbaumer (HSLU) represents Switzerland in the IEA Bioenergy Task 32 on Biomass Combustion and Co-firing

- Planned district heating networks, a pre-condition for the application of automated biomass heating plants and CHP plants

- Conducted the Quality Management (QM) System for the planning of automated wood combustion plants

- Developed for Swiss Federal Office of Environment (BAFU) a measurement method and procedures for pollution control regulations for heating systems
  - Guidance to affect greatest impact for emissions reduction

- Worked with municipalities on the primary treatment of waste water to capture nitrogen and phosphorous
Task 1: Extension of Solid Biomass Fuels
High Temperature Process Heat with Biomass

- Remaining potential of solid biomass (>10 PJ/a) of low quality with high ash, nitrogen and moisture
- Application: Process heat at 300 °C for food production at largest Swiss bakery
- 650'000 t/a for bread flour, 25% residues = 750 GWh/a
  - Fuel mixture of wood and dry wheat residues → mixing before combustor
- New solutions required due to ash:
  - Ash melting at < 800 °C for wheat (> 1200 °C wood) → avoided by flue gas recirculation (FGR)
  - Deposit formation in heat exchanger and cyclone cause increase Δp and frequent maintenance

Example of ash slagging product (here from wood residues)
Task 1: Extension of Solid Biomass Fuels Process heat for largest Swiss bakery

- Targets on efficiency (85%) and emissions (CO, NO\textsubscript{X}, PM) achieved during stat. operation
- Measures planned and implemented to improve availability (shock air cleaning, geometry adaptations etc.)
- Concept for continuous plant monitoring established, plant optimization performed, and annual reporting for authority prepared and agreed upon
- "Investment Case" for the IEA Strategic Study on Renewable Heat: 2018
Task 1: Extension of Solid Biomass Fuels
HTC Pilot Plant with Gregio Energie AG

- **Objectives**: Develop and optimize the process of hydrothermal carbonization of wet bio-wastes. Focus is on the energy and nutrients recovery from HTC-coal and HTC-process water.

- **SFOE P&D Project**: Partners: GRegio Energie AG, FHNW, ZHAW

- **Specific tasks for FHNW**
  - Physico-chemical characteristics of HTC-coal
  - HTC coal: not suitable for standard comb. methods
  - Mass and Energy flow analysis of the HTC plant
  - Determine the production costs of HTC-coal

- **Status**: Ongoing Project (End October 2020)

**Operating conditions**
- Plant capacity: 4 - 30 [t/day]
- Retention time: 1 - 6 [h]
- Temperature: 200 - 220 [°C]
- Pressure: 20 - 22 [bar]
- Feedstock: sewage sludge
Task 1: Extension of Solid Biomass Fuels Project “Gasification/Combustion”

- **Objective:** Gasification-combustion of different biomasses (solids screened from biogas plants, cork, HTC-coal) for heat production
  → separation/optimization of gasification/combustion

- **Specific tasks:**
  - Potential and costs of these biomasses for high temperature process heat in Switzerland
  - Physico-chemical analyses of biomass
  - Instrumentation of the gasification plant
  - Performance of field tests with selected designs

- **SFOE Project:**
  - Partners: GRegio Energie AG, AHT Syngas, Li&CO, FHNW

- **Status:** Started in 2020
Task 1: Extension of Solid Biomass Fuels

Pyrochar: Additional Energy and Biochar

- **Objective:** Investigate the suitability of using biogenic residues (horse manure, HTC-coal etc.) to produce an energy-rich gas and biochar through a pyrolysis process.

- **Feedstocks:** Horse manure, coffee by-products, grain residues, tree bark, residues from biogas plants.

- **Specific tasks:**
  - Develop the pyrolysis process and product characterization at laboratory conditions
  - Application in field with industrial partner

**SFOE Project:**
Partners: Kaskad-E, Bioburn AG, APD, FHNW

**Status:**
Master-Thesis at FHNW and development of laboratory test facility
Task 1: Fuel Pretreatment and Characterization

In Field Quality Measurement: XyloChips

- Continuous measurement system for mass and moisture content in field
  - Precision of mass measurement <0.5% (lab), <1% (field)
  - Difference w.r.t norm meas.: moisture = 0% (lab), 2.7\(^1\) resp. 5.3\(^2\) % (field)
  - Difference w.r.t norm meas.: energy <3% (lab), <5% (field)

- Project will be pursued in the frame of a “P&D” project financed by the Swiss Climate Foundation (Start in September 2020)

\(^1\) infra-red sensor
\(^2\) microwave sensor
Task 2: Clean and Efficient Heating Systems with Solid Biomass High Ash Fuel/Screw Burner

- **Burner design** for solid biomass with high ash, nitrogen and moisture

- Challenges are:
  1. Ash slagging and fouling
  2. High emissions of fuel NO\(_X\) and PM

- Design and scale-up (35 to 150 kW) supported by fluid and kinetic modeling
  - Similarity theory and correlations to identify key parameters
  - Combined fuel bed chemistry and 3D-flow CFD model of original and scaled burner

Investigation of swirl injection
Task 2: Burner Optimization Using Validated Chemical Kinetics and CFD Modelling

- For CFD modelling with chemistry, one detailed and two reduced kinetic schemes were compared for an opposed-jet-burner [1].

- An own reduced kinetic scheme for reasonable computation time and best fit with detailed scheme was implemented in Fluent to model C-H-species producing CO, CH$_4$, C$_6$H$_6$ and N-species producing NO$_X$.

- Scale-up and optimization of a screw burner were performed [2].

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Task 2: Burner Optimization Using Validated Chemical Kinetics and CFD Modelling

Wood dust burner for gravel driers for asphalt production with Ammann Switzerland

Staged Burner Design with Swirl
Project Goals achieved and support market introduction

- Biomass-fired combustor to replace coal use for industrial heating applications
- Fulfill emission limits (< 100 ppm CO, <50 ppm NOx, at 17% O₂), also retrofittable to existing coal dust or oil burners

Approach:

- Emissions, burnout controlled by preparing fuel with small particles and optimizing fluid dynamics within the burner
- Establish design rules, supported by a validated CFD model
  - Trade-offs between measures for low CO and those that reduced NOx (swirl, primary air)
Task 2: Burner Optimization: Heitzmann Innosuisse Project

- Development of a wood boiler with vertically arranged log wood to reach a more uniform gasification zone

- Focus on:
  - CFD optimization of primary air supply and geometry of the mixing element

- Project goals achieved:
  - $< 400 \text{ mg/m}^3 \text{ CO, } < 20 \text{ mg/m}^3 \text{ PM}$ in steady operation
  - $< 2'500 \text{ mg/m}^3 \text{ CO during start}$
  - $\geq 90\%$ boiler efficiency
  - Approved by certified testing lab with market introduction in 2020

Prototype: Low-emission wood log burner
Task 2: Burner Optimization: Era-Net Project: Low-Emi Micro Stove

- Pellet Stove with
  - 1 - 4 kW space heat
  - CO $<130$ mg/Nm$^3$, PM $<13$ mg/Nm$^3$
  - high efficiency (ca. 95 %).
  - new stove design with an advanced control concept and integrated sensors

- Project Partners:
  - BIOS, Graz (A): Stove design
  - FHNW: Control concept
  - LAMTEC (D): Manufacturer of CO$_e$ and lambda sensors
  - RIKA (A): Manufacturer of stoves

numerical tool developed to simulate the process parameters and emissions
Task 3: Integration of Particle Removal

Integrated particle separator

1. Successful integration between two heat exchanger passes (at max. 400°C) with various manufacturers. **TRL 8**
   - < 20 mg/m³ fine particles and particle removal rate > 60%

2. The new Innosuisse-project should enable the integration for boilers with only one heat exchanger pass (450 - 800°C). (70% of boiler market) **TRL 3**
   - Development of:
     1. a new high temperature insulator
     2. new electrode and voltage control
     3. design rules for the best electrode position
Task 3: Process Integration: Combined Power and Heat (Micro GT)

- CHP with wood combustion and novel heat exchanger/GT
  - Motor generator and power electronics characterized
  - First turbomachinery investigated on a test bed equipped with electrical boiler and heat exchanger
  - Final turbomachinery will be tested during phase 4
  - Integration with wood boiler once turbomachinery/HX proven

Combined heat and power boiler (1 kW<sub>e</sub>, 4 kW<sub>th</sub>)

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Task 3: Process Integration: PyrOxy: Oxidative Pyrolysis for Biochar, Power and Heat

- Production of biochar and cleaned syngas
Task 3: Process Integration: PyrOxy: Oxidative Pyrolysis for Biochar Power and Heat

- Simultaneous production of biochar (non-activated and activated) and treatment of the syngas generated by volatile components
  - reduced tar content to enable operation of a conventional piston internal combustion co-generation engine

- Numerical modelling of the chemical kinetics of wood-pyrolysis-generated tar realised in a PhD thesis in collaboration with Morocco

- Status:
  - Experimental reactor study of oxidative pyrolysis of lignocellulosic biomass (wood and other sources) ongoing, to enable numerical model calibration
  - Ongoing: development of the activation reactor, which will also perform the syngas tar reduction
Task 4: Energy system integration: Biomass plant with energy storage

- Biomass plants are unsuited for rapid load changes and part-load and often use a fossil boiler for these demands in a bivalent system.
- To enable a monovalent biomass system w/o fossils, a thermal energy storage can be added.
- The system is modeled to derive:
  1. dimensioning rules for the storage and
  2. develop control concepts.
- The targets is to enable:
  1. a monovalent biomass supply
  2. an optimized storage management and boiler operation for low emissions (i.e. avoid start and stop operation in summer)

Task 5: Thermal recovery of Phosphorus from waste biomass

**Improved Hard Process**

- Thermal recovery of P from waste bio-resources to produce benign, resource depleted material to attain a circular material loop

- **Industrial & Academic Collaboration:** Outotec GmbH (Germany), Proman Consulting (Austria), De La Salle University (Philippines) & Santander University (Colombia)

- In-house TGA-ICP OES system utilised to study the thermochemical behaviour and instantaneous detection of the volatilised species (including P)

- Laboratory trials on waste biomass such as Sewage Sludge, Sewage Sludge Ash, Bones showed P recovery rates between ~20-95wt.-%.

  → Samples with high concentration of Fe prevented P volatilisation and produced slag.

- 2x International student exchange projects, 1x semester project (EPFL) and 1x Master Project (EPFL/TUM)
Cooperation with the public sector
Impact of Particle Filter in Saas-Fee

- Development and validation of a dilution independent measurement method **DIEM** enables easy and accurate online measurement over chimney exits (PM and CO)

- > 20 Electrostatic Precipitators (ESPs) were successfully evaluated during a winter season → Separation efficiency 70 +/- 10%

- The benefits of ESPs have been proven in the field, the function must be guaranteed by monitoring and maintenance

- Extension to measurement of open fireplaces, grills as well as alternate biomass-firings
WP3 Key Achievements and Contribution to Swiss Energy Strategy 2050

- Assist an increased use of solid biomass thanks to broadening the feedstock to high-ash fuels.

- Support the reduction of the pollutant emissions of wood burning appliances, enabling a larger use of the solid biomass energy potential, without affecting human health and impacting adversely the environment.

- Support a reduction of the fossil fuel share in heating thanks to improved process control concepts for biomass heating plants combined with heat storage capacities.
WP3 Activities: Impact beyond 2020

- Further development of primary (staged combustion) and secondary measures (ESP's, catalysts, filtration systems, etc.) for clean biomass based combustion systems
  - Combustion design will be extended to other high temperature applications (including pyrolysis/gasification as the initial conversion process).
  - Utilization of novel CO/HC/O₂ sensors

- Support more efficient utilization of biomass energy content via decentralized production of power and heat pursued in MicroXyloCogen and PyrOxy.

- Process and system integration will be further improved to ensure optimum conditions at varying load.
  - Innovative control concepts and thermal energy storage
WP3 Activities: Outlook beyond 2020

- Support the disposal of solid and liquid residues
  - Independent disposal routes for biomass residues are needed to avoid excessively high disposal costs.
  - Technical opportunities to influence and increase the quality of the residues based on initial results from work performed in this period
  - Utilization of biochar (reduction of ash, storage of CO$_2$)

- Large number of applications-oriented projects with industrial partners have led to results that are being applied in the field and will be further supported by WP3 research teams.
Acknowledgement