FINAL REPORT

Wood chip feeding technology of the future for small-scale biomass boilers – BioChipFeeding

FP7 Call- Research for SMEs
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Leader: HET - Heiz- und Energietechnik Entwicklungs-GmbH
DI Thomas Bauer
www.BioChipFeeding.com

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Executive Summary

Max. 1 page

Summary description of project context and objectives

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Description of the main S&T results/foregrounds

System Overview

Figure 1 shows an illustration of a heating plant using the BioChipFeeding-system for feeding the wood chip boiler. The BioChipFeeding-system can be structured (regarding the material flow) into two subsystems: Feeding Step 1 and Feeding Step 2.

Feeding Step 1 handles the wood chips stored within the wood chip bunker using a gripper system attached to an automatic crane system. Beside the functionality to transport the wood chips from the bunker to Feeding Step 2, the sensors equipped at the gripper provide the ability to analyse the wood chips regarding the properties: moisture content, particle size and color. Besides the screening of this properties, the gripper is used to determine the filling level of the bunker.

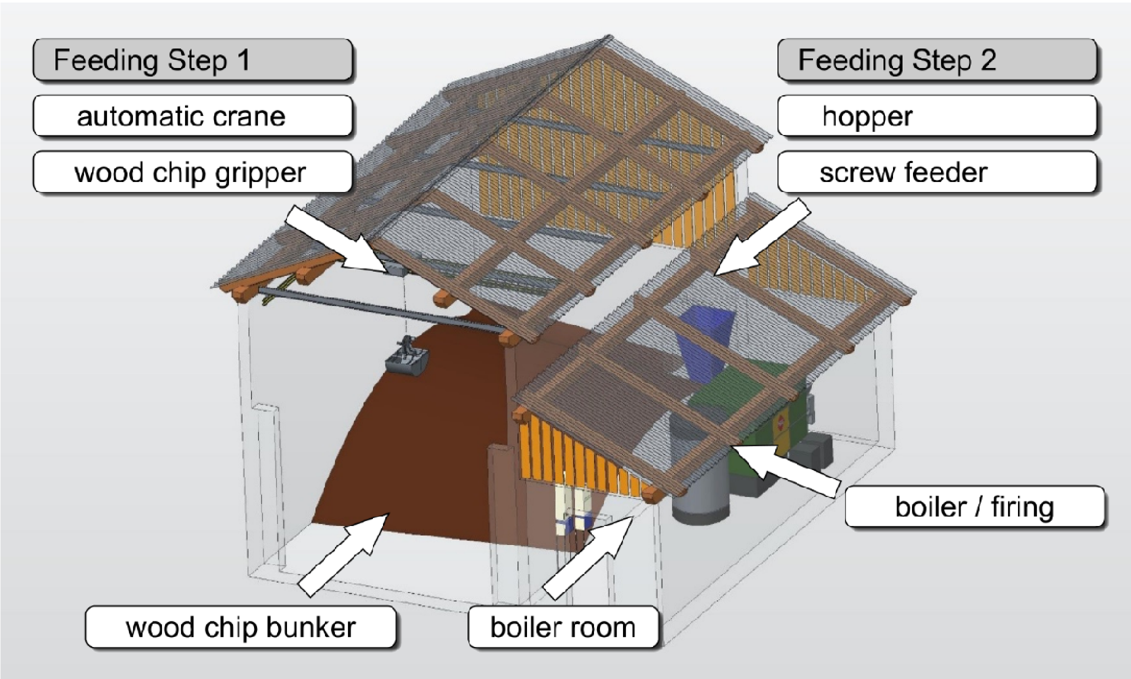

Figure 1: System Overview

Using the wood chip properties and filling level information from the bunker, the implemented algorithm of the feeding control decides according to the current operating status reported by the boiler control which portion of the available wood chips is the most suitable. When possible, the feeding control tries to blend different qualities of the wood chips in order to support a stable combustion of the boiler.

Led by the feeding control, the gripper grabs the wood chips within the bunker and transports them to the hopper of Feeding Step 2, where different qualities of wood chips are blended to a calculated target quality. Continuing through the screw feeder, the wood chips are further transported and dosed by the stoker screw to the firing of the boiler.

Development and Design of Feeding Step 1

Feeding Step 1 needs to cover two main functions:

- Manipulation/transport of the wood chips starting at any point of the wood chip bunker up to the defined material flow interface between Feeding Step 1 and Feeding Step 2 – the hopper.
- Providing information of the wood chips stored within the bunker regarding wood chip quality and quantity.

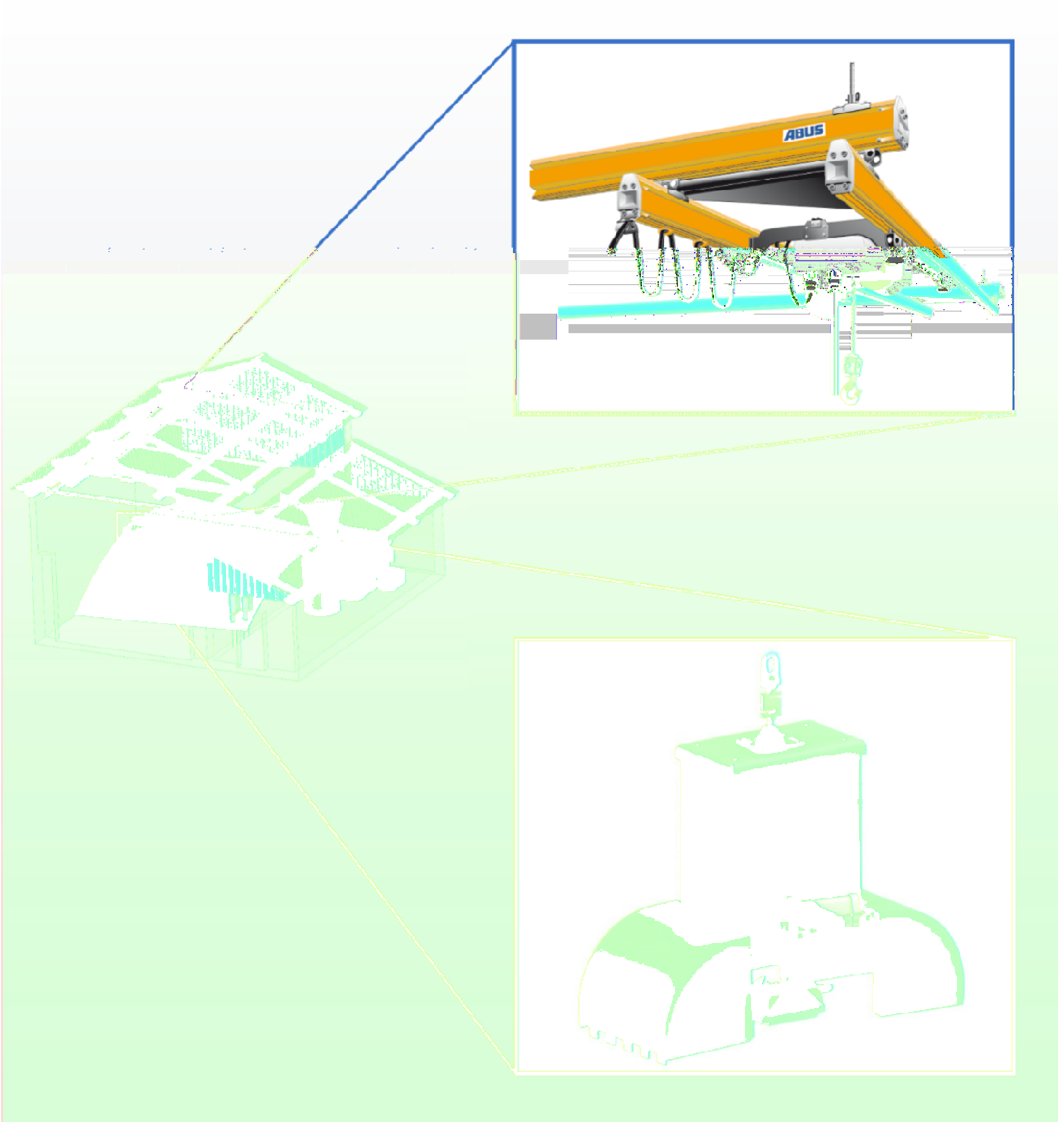

Figure 2: core components of Feeding Step 1

In order to do so, a system was developed based on the VDI guideline 2221 "Systematic Approach to the Design of Technical Systems and Products"[1] containing two core components shown in Figure 2: a modular wood chip gripper with built-in sensor technology to provide the needed information and a semi-automatic[2] crane system to move the gripper to its target position within the bunker.

[1] Verein Deutscher Ingenieure: VDI 2221 – Methodik zum Entwickeln und Konstruieren technischer System und Produkte, Beuth Verlag GmbH, 1993

[2] The crane system is intended to be manually operated by the manufacturer, but was technically upgraded to serve as an automated system.

Crane system

Several crane systems from eight manufacturers were evaluated in a methodical decision process[3] leading to the ABUS ZHB system as the most suitable. Though the ABUS crane system offers no automation as a standard, the system was chosen mainly because of its high modularity regarding operable area and load capacity. Other systems, technically on par with ABUS' system were omitted because of economic aspects. Table 1 shows a summary of the crane system chosen.

Table 1: ABUS ZHB system

Key facts of the crane system			
Mechanical Construction	• Aluminium shape • Fully adoptable to relevant measures • Modular construction system	Agitators	• Asynchronous motor • 400V; 50Hz • Contactor control provided • Conductor lines
Crane girder	• Length: 4500mm (up to 12m) • crane travel: 5/20 m/min • trolley travel: 5/20 m/min	Hoist	• Capacity: 250kg (up to 4t) • Hoist speed: 2/8 m/min • Hook path: 3000mm (up to 32m) • Power: 0.09/0.35kW

The system was upgraded to provide an automated mode using laser distance sensors and is fully integrated into and controlled by the feeding control.

Wood chip gripper

Based on a detailed specification of the entire heating plant the objectives for the development process as well as the boundary conditions were derived for the wood chip gripper. Using the methodical development process provided by the VDI guideline 2221, starting with the determination of the functions and their structures and carrying on with the search for solution principles and their combinations, a layout of key modules could be developed, leaving enough scope for the installation of the needed sensors. Through its modular design, the developed layout offers the possibility to attach different clamshells to the mainframe and thus providing usability when being operated in systems of different heating capacities. In the course of the project clamshells providing a loading capacity of 35 liters and 75 liters were designed.

Figure 3 shows three spotlights of the development process: On the top left side, the identified functions and their structure are shown. The bottom left side of the images shows the found practicable solutions that are able to fulfil the functions. These solutions were evaluated in order to develop the layout of the key modules shown on the right side of the image.

As main actuator for the movement of the clamshells two linear drives built by the company ATP Antriebstechnik were chosen. Each drive provides a force of 6000 newton over a positioning distance of 100mm. The asymmetrical installation position (see Figure 4) of the linear drives allows the positioning of the moisture content measurement sensor and the image recognition system in the middle of the gripper's mainframe and thus enables theses sensors to capture the largest possible portion of the woodchips in the gripper, respectively underneath the gripper.

[3] see Deliverable D2.1 (Detailed design of the gripper system equipped with fuel screening sensors) for details

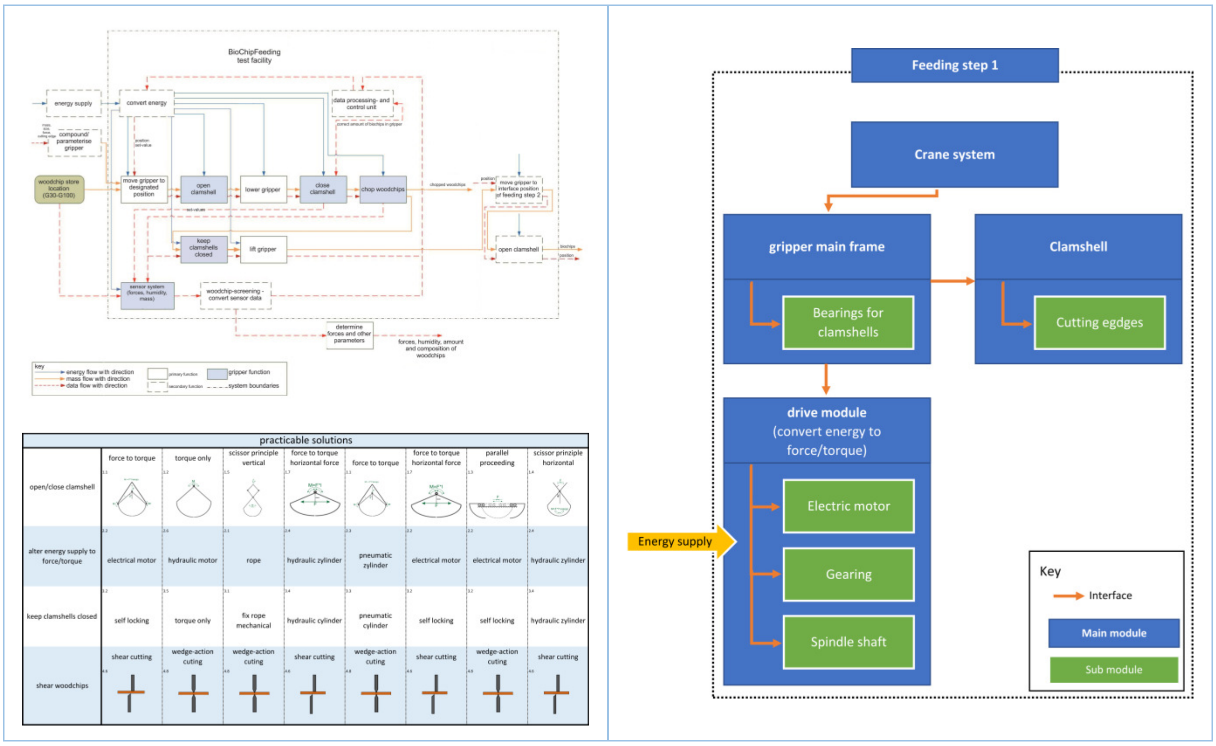

Figure 3: excerpt of the results of the development process

For the operation of the moisture content measurement sensor a second actuator system has been installed (see Figure 5) in order to provide a constant contact force of 250 newton. The movement of this sensor is performed using a spindle linear table of the manufacturer Igus GmbH. The built-in ball joint allows the system to evenly press the sensor against the loaded wood chips regardless of their topology.

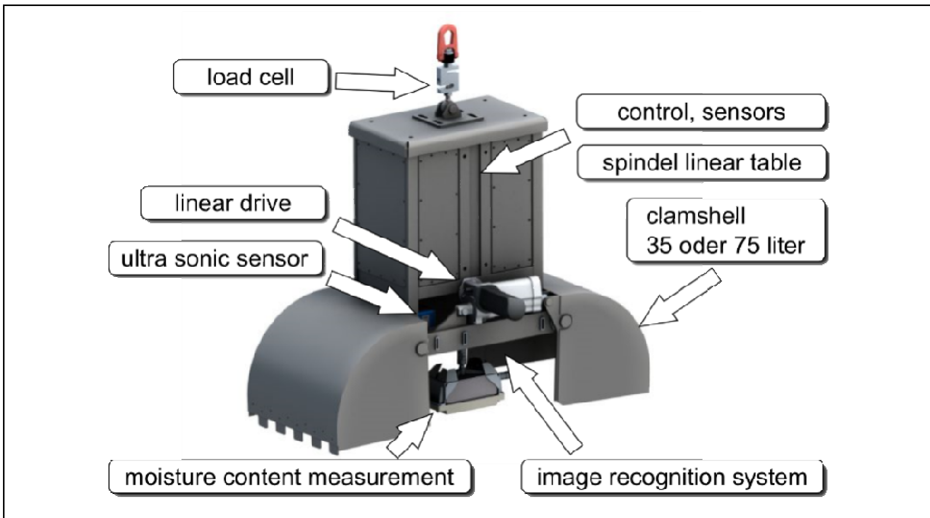

Figure 4: wood chip gripper

Figure 5: MCM system

Sensorial concept

In order to provide the feeding control with the needed information a comprehensive sensorial concept was developed, covering the positioning and inclination of the gripper within the bunker as well as the capturing of the wood chip quality. In the list below, the different sensors are assigned to their measurement task within the system:

- Capturing of the **loaded wood chip mass**:
  load cell (Co. ME-Meßsysteme GmbH)
- Determination of the **positioning of the gripper alongside of the hoist's chain**:
  position underneath the trolley – draw wire sensor (Co. Waycon)
  position above wood chip level: ultrasonic sensor (Co. Wenglor)
- Determination of the **positioning of the gripper alongside and transversely crane track**:
  laser distance senor (Co. Wenglor)
- Determination of the **inclination of the gripper**:
  Inclinometer (Co. ME-Meßsysteme GmbH)
- Determination of the **moisture content of the loaded wood chips:**
  moisture content transmitter (Co. Schaller)
- Determination of the **particle size and color of the wood chips:**
  image recognition system (see following section for details)

The two key sensors of the system – the moisture content measurement system and the image recognition system – are described in detail in the following section.

Moisture content measurement

In order to choose a suitable sensor system for the determination of the wood chip's moisture content, sensors using different physical principles (conductivity, microwaves and time domain reflectometry) were evaluated. Based on a first test series under laboratory conditions a sensor using the conductivity measurement principle was chosen[4]. The sensor is attached to the actuator system described in the previous section. In the course of Task T4.1 (test series without boiler operation[5]) the sensor was tested under installation conditions.

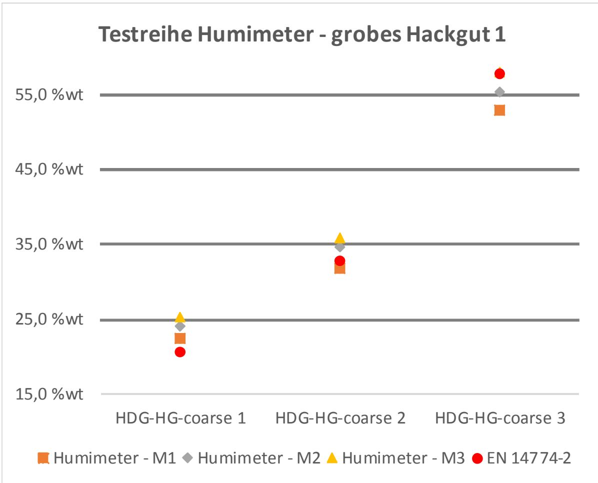

Figure 6: excerpt result of the measurement series for the verification of the moisture content sensor

Figure 6 shows an excerpt of the results of the measurement series done for the verification of the sensor. The test series was done using wood samples of different moisture content and particle size with varying contact forces provided by the actuator system. The actual moisture content of the samples was determined using the method specified within the Standard EN 14774-2 represented by the red dots of Figure 6.

Using the developed system, the moisture content of the wood chips can be determined with an average deviation of under five percent points, which is sufficient for the classification of the wood chips as stated in the section Control Algorithm on page 19.

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[4] See Deliverable D2.1 (Detailed design of the gripper system equipped with fuel screening sensors) for details

[5] See Deliverable D4.1 (Report of test runs for cold operation including recommendations for optimisation) for details

Analysis and optimisation of Feeding Step 2

TUM/fml's task during the project was to analyse and propose improvements for feeding step 2. This feeding step starts with receiving material from the gripper and ends with the transport of wood chips into the furnace. Corresponding boundary conditions for the feeding process were defined in the "book of technical specifications".

The feeding system can be split into three main parts, which, among others, are shown in Figure 7. They are the hopper (including an agitator/mixer) with a screw feeder at the bottom, a rotary gate valve and the stoker screw feeder, which leads to the furnace. Within the project, the rotary gate valve was not part of the analyses, as it is a standard part and merely used for fire safety issues.

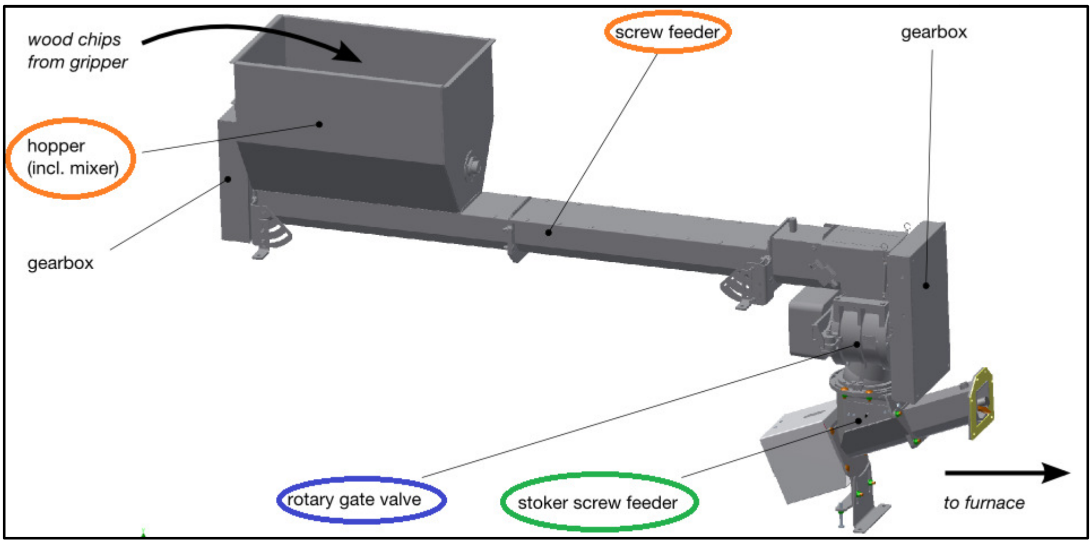


Figure 7: Overview of the components of feeding step 2; the main components are the hopper with mixer and screw feeder on the bottom (orange), the rotary gate valve (blue) as well as the stoker screw feeder (green).

A more detailed view of the hopper/agitator/screw feeder assembly is provided in Figure 8. The agitator prevents the wood chips from arching and is mounted above the open trough zone of the screw feeder. As soon as the wood chips leave the area underneath the hopper, the trough consists of a fully enclosed profile. This screw feeder setup was used for experimental measurements of the driving torque, mass flow and effective power consumption. Beforehand, the wood chips had been classified into three different qualities, which were referred to as "low", "medium" and "high" quality, based on their expected calorific value. For dimensions and operating conditions of the system as well as the measurement results, please refer to the corresponding reports and [Zitat1]. In order to characterise the wood chip's flow behaviour, basic bulk material experiments were carried out. These included angle of repose, angle of slip, particle size distribution and bulk density measurements.

All these data, including those from the screw feeder, were used to calibrate and validate a discrete element (method) material model for the "low" quality wood chips. Especially the validation against the results from the hopper/agitator/screw feeder system were computationally demanding. In the end, one simulation of the hopper and agitator system took about 30 hours on a 20 CPU workstation.

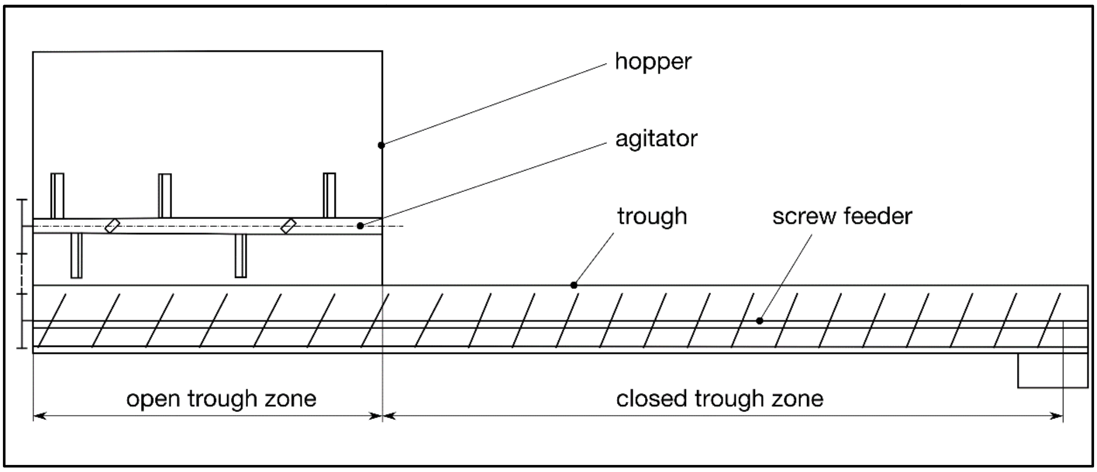


Figure 8: Schematic setup of the screw feeder; the hopper and its agitator are mounted on top of a screw feeder.

Overview of experimental results from the screw feeder

The results from the basic bulk material tests were in good agreement with the literature. It could be verified between the experiments that wood chips, despite lacking cohesion effects, are a poor-flow material which tends to arching. This effect is based on interlocking between the wood chips and abetted by the fibrous nature of wood.

Figure 9 displays different results over time from the screw feeder experiments. These results were measured for the “low” quality wood chips. The hopper was filled with wood chips and agitator and screw feeder (driven by the same motor) were run until the hopper was empty and the screw feeder trough completely emptied (see [Zitat1] for details). In the lowermost part of Figure 9, the effective power consumption of the motor and the mechanical power consumption of the drive shaft are displayed. The latter was computed from the revolution speed and the torque measured at the drive shaft.

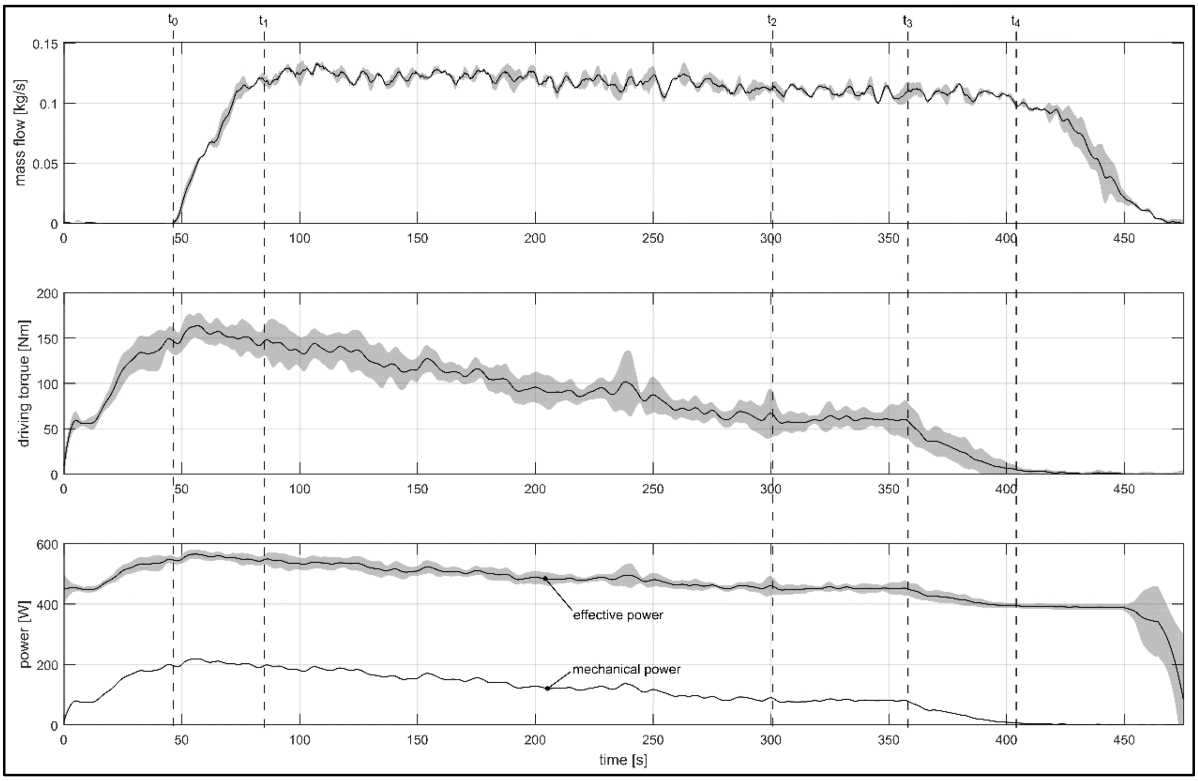


Figure 9: Mass flow, driving torque and power consumption for the "low" quality wood chips over time, including 95 % confidence interval band for N=8 experimental runs.

Starting from t=300 s in Figure 9, the agitator has lost contact with most of the wood chips, due to the decreasing fill level inside the hopper. After this point in time, the driving torque is dominated by the screw feeder. Therefore, it can be concluded that the torque and thus the power[6] to drive the screw feeder is significantly lower than the power to have the agitator stir through the wood chips. The overall maximum torque to drive both, the screw feeder and the agitator, is roughly 150 Nm, as compared to slightly more than 50 Nm for the screw feeder on its own. Hence, it was decided to investigate on optimised operating parameters for the agitator within the hopper.

Results from discrete element simulations

As mentioned above, the results from the screw feeder experiments and bulk material tests were used to calibrate and validate a discrete element material model for the low-quality wood chips. The discrete element method (DEM) is a numerical simulation method, which can be used to model the flow behaviour of systems of thousands of particles (modelled as spheres or clumps of spheres) and their interaction with bulk material handling equipment; specifically mechanical loads on the latter. Discrete element method primarily demands for CPU time and is usually run in parallel. For large

[6] At constant revolution speed.

models with hundreds of thousands of particles, the computation duration can be as long as days or weeks.

The material model which was used to simulate the screw feeder and stoker screws is based on spheres. Since wood chips are non-spherical, rolling friction was harnessed to account for the shape of them. This is a common approach in discrete element modelling [Zitat2, Zitat3].

Screw feeder parameter study

As mentioned in the previous section, the overall driving power of feeding step 2 is mainly influenced by the interaction of the agitator with the wood chips. Therefore, a parameter study was carried out. It focused on the positioning of the agitator within the hopper and its aim was to investigate, whether the agitator's location will affect the driving torque of feeding step 2.

Within the parameter study, the real-life setup of the screw feeder/hopper/agitator system was used as a reference, which is the base to compare different configurations against. The driving torque and mass flow for a total of twelve configurations was computed. The two main factors of the parameter study were the horizontal and vertical position of the agitator inside the hopper and in another configuration the direction of rotation of the agitator was reversed. In order to reduce variance of the results, the computations were repeated at least three times. Please refer to the second BioChipFeeding periodic report or [Zitat4] for a more detailed description of the simulation setup.

Results for the vertical position change of the agitator are displayed in Figure 10. The agitator's driving torque decreases with an increasing vertical position. This is due to having to stir less wood chips. Even though the risk of arching increases with a higher position of the agitator, no such effect was observed in the discrete element simulations. Simulatively mounting the agitator at a height of 280 mm was the maximum possible translation due to limitations in design and resulted in the lowest torque values. Even just translating the agitator by 40 mm yielded a significantly lower torque demand.

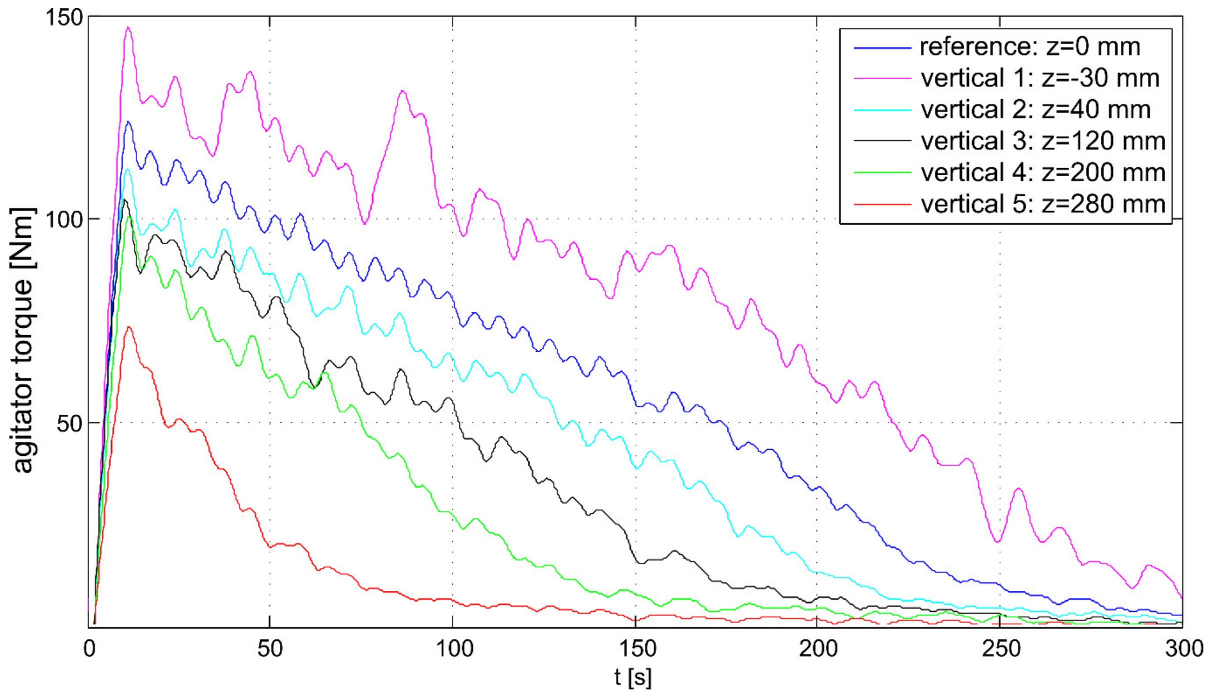


Figure 10: Influence of the vertical position of the agitator on the agitator's driving torque during hopper emptying.

The results from configurations with mutual horizontal and vertical translation of the agitator showed that the positive effect on the torque due to the vertical displacement can be enhanced by horizontally shifting it.

Comparison of two stoker screw design variants

In addition to the parameter study, the validated discrete element material model was used to compare two stoker screw design variants against each other. The stoker screw is the final part of feeding step 2, which feeds wood chips directly into the furnace. It is mounted underneath the rotary gate valve.

Two variants, as depicted in Figure 11, were compared against each other, with respect to the mass-related energy consumption and possible feeding problems like blockage or jamming for different mass flows. The design on the left-hand side of Figure 11 (Stoker 160) is the new design and features an altered trough geometry and inclination, while the existing design (TBZ 150) on the right-hand side is a horizontal screw conveyor with an upside down U-shape trough.

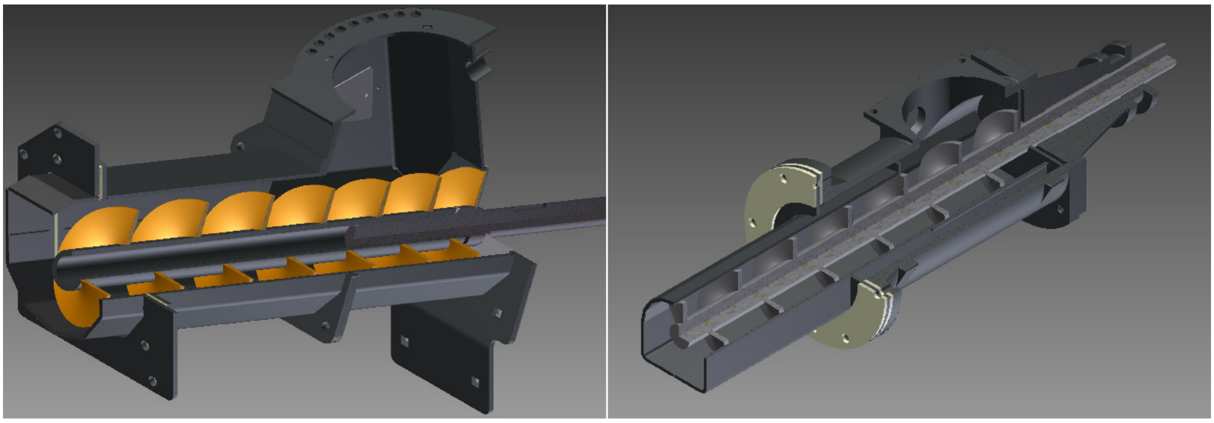


Figure 11: Proposed (left) and existing (right) stoker screw feeder designs from HDG Bavaria.

A comparison between the designs' respective driving torques is shown in Figure 12. The results for Stoker 160 are displayed both ways, in original and corrected. The correction was necessary, in order to account for the inclination and the resulting lifting work for the wood chips. For the low and medium mass flow (1. and 2.), both variants require about the same torque. However, Stoker 160 demands for roughly 85 % more torque for the high mass flow (3.)

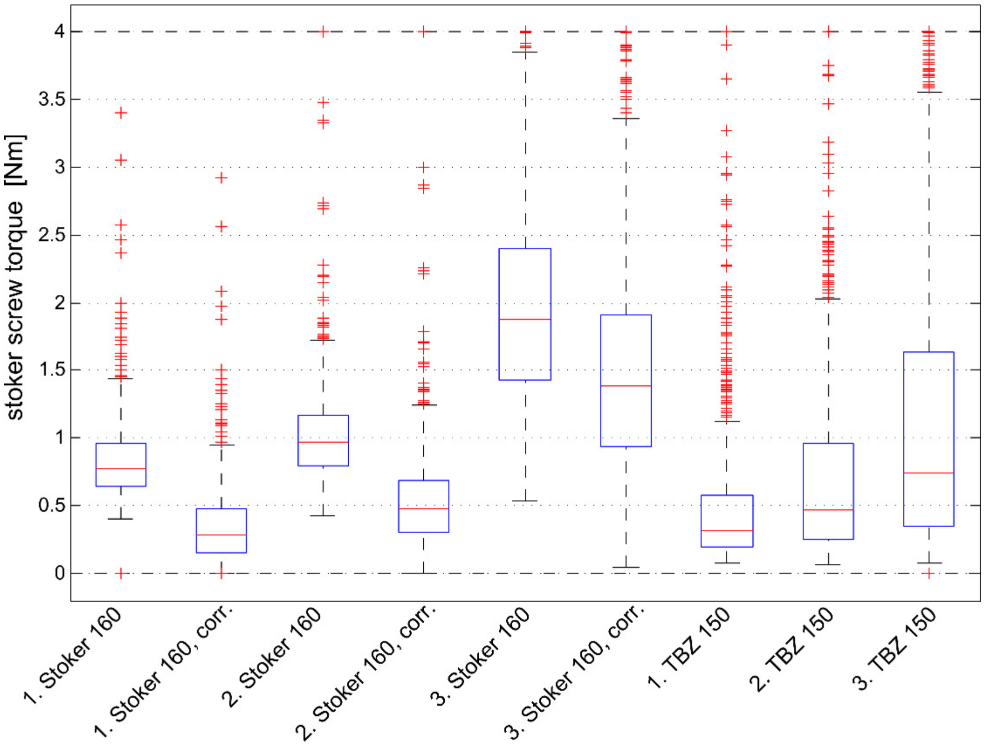


Figure 12: Boxplots of the designs' driving torques. The results for Stoker 160 were corrected for the inclination (corr.).

When looking at the mass-related energy consumption, listed in Table 2, one can see that the driving torque is generally lower for the existing design (TBZ150). Hence, the resulting loads in components will be lower, too.

The mass-related energy consumption is lower for the new design. Nonetheless, this only holds true for the lifting-work-corrected values. Given the fact that it is operated with inclination, it loses the energy efficiency over the existing design. Proposed optimisation measures for the new stoker screw design include using it in horizontal orientation and considering to stay with the existing design for high mass flows.

Table 2: Driving torque (median, corrected) and mass-related energy consumption for Stoker 160 and TBZ150; values in brackets show the uncorrected medians.

Mass flow	**77 kg/h**		**93 kg/h**		**244 kg/h**	
variant	*1. Stoker 160*	*1. TBZ150*	*2. Stoker 160*	*2. TBZ150*	*3. Stoker 160*	*3. TBZ150*
Torque [Nm]	0.288 (0.773)	0.318	0.484 (0.970)	0.468	1.39 (1.87)	0.746
E' [mWh/kg]	2.35 (6.39)	4.54	3.95 (7.91)	6.69	11.3 (15.2)	10.6

System Design and Concept of the Overall Control System

Overall Control System

The control system is in charge of controlling the feeding step 1, i.e. transporting woodchips from the unloading area and main storage to the intermediate storage via an automated crane and gripper. The screw conveyor and the boiler use existing control systems and therefore are not part of this description, because there are no further developments to be done in the control systems of these components. As part of the modular approach of the whole concept this can be seen as advantage for the product costs of the system, as it realizes the usage of existing devices where possible. The developed crane and gripper control system is also in charge of picking the correct chips and detecting errors that occur inside the crane and gripper control system. The crane and gripper control system receives information and data from the boiler via an existing Modbus interface. Via this interface the crane and gripper control system receives information about the operational state of the boiler and the actual mass flow. An interface to the image recognition system is used to receive data about particle sizes and foreign materials in the storage, even if the image recognition itself is only included as potential functional add-on in the project.

General Functionality

Once the system is switched on, it is the turn of the worker to choose the mode: automatic, manual or extended mode for troubleshooting. Normally the system will be in automatic mode, but before feeding chips, the initialization step of the system is performed automatically in order to properly taking into account the amount of chips available in the storage and their qualities. Initialization is also obligatory after refillment of the unloading area in the storage from outside and also after other changes inside storage. After the selection of the automatic mode no further user interaction is needed, except the system is shut down or an error occurs. In the automatic mode the crane and gripper system is stopped as soon as an error shows up. The automatic mode reacts autonomously to the boiling process. The actual boiler load is transferred via Modbus to the crane and gripper controlling system. There are several load operation states: ignition, low load, high load and full load plus standby. The control system is setting automatically the priorities to different woodchip qualities and mixtures to be loaded into the intermediate storage regarding these load operation states.

Usually the automatic mode will work like this:

1. Receive information from the boiler about the boiler load state,
2. Analyse available woodchip qualities inside the storage based on pre-sensored information stored in the quality maps
3. Decide which quality or mixture of qualities should be taken,
4. Grip woodchips and transport them to the intermediate storage
5. Update the quality maps every time they change and be aware of errors in the meantime.

Therefore even in automatic mode, a situation can occur that the system is not feeding the intermediate storage, e.g. if the boiler is stopped, working at very low loads or an error occurred inside feeding step 2 or inside the boiler itself. This „spare time“ or stand by is used by the gripper and crane control system to update the quality maps of the storage with additional and refining autonomous measurements and transporting woodchips from the unloading area into the storage. Spare time is detected by filling sensors inside the intermediate storage which are directly giving the information of a full or empty intermediate storage to the crane and gripper control system.

As soon as an error is detected the controlled devices are turned off and automatic mode is finished as part of the prototype safety concept. The error description is shown on the user screen. A qualified worker is needed to access extended operation mode for troubleshooting. This mode is secured via a physical safety key. As soon as the safety key is turned the extended operation mode is activated and the gates to the storage can be passed to get to the crane or gripper system and solve the problem. Before turning the key the whole system is blocked. In extended operation mode all actuators can be directly controlled from the worker, all safety or limit switches are turned off to allow failure debugging. In extended operation mode the control system allows the worker in charge to drive the actuators also to positions, which are not allowed during automatic mode. This means the worker is responsible for system safety and should be conscious of his actions, i.e. enhanced experience with the system is needed. It is also important for the worker to have eye contact to the crane and gripper during this operation mode, therefore the user panel is positioned in a way that the whole storage can be surveyed. Elimination of the failure has to be confirmed by the worker on the user screen. Extended user mode cannot be left before failure is solved, i.e. error no longer detected by the control system and failure elimination is confirmed by user. After this step the safety key is turned back by the worker and user can choose next operation mode.

Additionally a manual operation mode is foreseen, which can be chosen by the user at every time during automatic mode, after system start-up or after successfully finished extended operation mode. In manual mode the crane and the gripper can be moved via direct user inputs, e.g. to drive the crane to a specific position or to grip woodchips at a desired position inside the storage. During manual mode the user is responsible for crane safety, e.g. crashing against objects inside the storage. The manual mode can be used to transport woodchips into the intermediate storage to feed the boiler, but all the information about the quality of the woodchips is not considered for the automatic mode. As soon as leaving the manual mode to automatic mode, which is possible all the time, the automatic mode will “clear” the intermediate storage by letting go down the filling to the lower filling-sensor level and then restart filling it up regarding the actual load state of the boiler.

Hardware Setup

The concept for the controlling hardware consists of one main industrial PC with the central control algorithm and 3 bus couplers with several in- and outputs which are located in 3 different switching cabinets and connected via EtherCAT. For the main controlling unit and the bus couplers as well as for the in- and output cards components from Beckhoff Automation GmbH are used. The following diagram (Figure 13) gives a schematic overview of control units and hardware components for the controlling system. It is divided into three sub controlling units: the main control, the crane control and the gripper control.

main control	crane control	gripper control
• industrial PC (soft PLC) and bus coupler • safety control, safety in- and outputs • interface to control panel • interface to inamge recognition system and boiler	• bus coupler • interface to positioning system (x,y) and chain hoist length sensor • interface to crane control • safety switch off and conductors for power supply of crane	• bus coupler • interface to gripper weight and tilt sensors • interface to distance measurement (gripper-floor) • interface to gripper actuators and moisture meter

Figure 13: basic concept for the overall process control system

The sub controlling units are connected via Ethercat, the main control has interfaces to the user control panel, the image recognition system, which runs on a second industrial PC and the boiler.Following Sensors and Drives/Actuators were used:

Sensor/Drive/Actuator	Task
Light Barrier IELT / IELR	Woodchip Level in Intermediate Storage
Laser Distance Sensors DT35	Position of crane in x and y direction
Draw Wire Sensor SX120	Length of Winch / Chain Hoist
Force Sensor KD9363s	Weight of Gripper and Load
Ultrasonic Sensor USM603U035	Distance from Gripper to Woodchip Surface in storage
Tilt Sensor ME IS 28	Inclination Angle of Gripper (x and y direction)
Linear Actuator LMR03	Closing / Opening the Gripper
Moisture Meter / Humimeter	Moisture of Woodchips
Stepper Motor NEMA23XL	Pressing Humimeter onto Woodchips inside of the Gripper

A detailed overview of all the components is given in Deliverable D2.3 – Detailed design of the process control.

Safety Concept

For safety issues the controlling system is equipped with certain functionalities to prevent personal injury and property damage. Therefore a safety controller and safety in- and outputs are integrated into the controlling system. If a person is entering the storage the crane system and the gripper are disconnected from the power supply and the winch for the gripper is mechanically blocked. A safety light barrier is integrated into the entrance gate of the storage to detect safety relevant situations and shut off the crane. In addition several Emergency Stop Buttons are installed at the user control and at the access points to the storage to shut off the system in emergency situations.

Circuit Diagram

The configuration of power supply splits in several parts, including the main control cabinet for the industrial PC, the control cabinet on the Abus crane and the control cabinet on the gripper. The power supply for the control system is separated from the power supply for the crane and the gripper to prevent any interference. To avoid current peaks in our control circuit, which can occur when the linear motors or the stepper motor on the gripper are switched on the power supplies of the gripper motors and of the controlling components are electrically separated from each other. The detailed description of the power supply concept can be found in Deliverable 2.3.

Control Algorithm

The control software is implemented using Twincat V3, an IDE and runtime provided by Beckhoff Automation and widespread in the industry. It uses IEC 61131-3 standards and all the controlling code was written using an object oriented approach to ensure simple adjustability for the later use by the SME project partners.

The process starts with an initialization of the system. After that the user can choose between the manual and the autonomous, i.e. continuous, operation mode. The autonomous operation mode as major outcome of this project is described in the following paragraph, for further details on the overall control strategy see also Deliverable D2.3

In autonomous operation the algorithm handles the monitoring of the storage, the material selection and transport, updating of the quality maps and the intelligent feeding of the intermediate storage. First the control unit communicates with the boiler to obtain the current operation (ignition, stand-by or one of the three continuous modes: low, high and full load). During the ordinary operation the storage is fed with biochips, if the current mass in the intermediate storage falls below a predefined level.

During the continuous operation it is necessary to derive the area that is tangible for the griper due to restrictions of the topology of the storage. Next the tangible area is further restricted based on the quality of the wood chips. The algorithm computes the suitable qualities, defined by their ash- and moisture content. The idea is to limit the qualities to those, that can be fed to the intermediate storage and keep its parameters within certain limits. Finally the allowed qualities are superimposed with the height profile of the previous step. The so obtained tangible area lays the basis for the steps to come. This includes the feeding of the intermediate storage with bad qualities, with material featuring the needed priority or finally by mixing the available materials.

The algorithm tries to get the material with the highest priority value, depending on the loadmode of the boiler. In this case priority ranges from 1 to 15 with 1 as the highest priority. Initially it checks if material defined by the recent priority which results in the desired quality after mixing in the intermediate storage is present. If so the algorithm primary uses bad quality material (e.g. high moisture and high ash content). If no suitable material is present the algorithm tries to mix the material with the desired priority value from two components. It first feeds the worse material, the better later on. Due to the results of the evaluation of the prototypes some adaptions to the underlying priority maps for the algorithms where defined and implemented to the control algorithm (Figure 14).

ignition

Ash content - optical ind.	low		Moisture content, wet basis →		high
dark	Priority 5	Priority 6	Priority 9	Priority 12	Priority 15
↑	Priority 2	Priority 4	Priority 8	Priority 11	Priority 14
bright	Priority 1	Priority 3	Priority 7	Priority 10	Priority 13

low load

Ash content - optical ind.	low		Moisture content, wet basis →		high
dark	Priority 11	Priority 5	Priority 3	Priority 12	Priority 15
↑	Priority 10	Priority 2	Priority 1	Priority 8	Priority 14
bright	Priority 9	Priority 6	Priority 4	Priority 7	Priority 13

high load

Ash content - optical ind.	low		Moisture content, wet basis →		high
dark	Priority 15	Priority 5	Priority 3	Priority 10	Priority 13
↑	Priority 14	Priority 4	Priority 6	Priority 2	Priority 12
bright	Priority 9	Priority 8	Priority 7	Priority 1	Priority 11

full load

Ash content - optical ind.	low		Moisture content, wet basis →		high
dark	Priority 11	Priority 8	Priority 9	Priority 12	Priority 15
↑	Priority 10	Priority 5	Priority 4	Priority 7	Priority 14
bright	Priority 1	Priority 2	Priority 3	Priority 6	Priority 13

Figure 14: priority maps

Details can be seen in Deliverable D 6.1 results of tests with the optimized system.

After the selection of the material quality to grab the handling strategy for storage management decides where to grab the material in the storage in case a specific quality is available in serveral locations inside the storage. This selection process is realized respecting several conditions: flatten the storage topology to increase potential positions to grab material and reduce ways for navigation in storage. In spare time the picking routine is also be used to transfer material from unloading area to main storage. For the deposition of material the process for emptying the storage is basically reversed. The goal is to continuously fill the storage starting from a defined position. If possible material of the same quality is placed nearby. Moreover areas whit too large gradients are prevented.

Detailed information about the algorithm, implemented class diagram and underlying risk analysis can be found in Deliverable 2.3.

Data recording and Visualization is directly integrated in the graphical user interface of the system. System data can be visualized directly on the integrated 19” touchscreen of the system or be exported in standard formats, e.g. Microsoft Excel. Recent Activity of the system is presented to the user on this touchscreen in form of a graphical animation of the crane and in textual form. The user interacts with the system via software buttons on this touchscreen.

System Design and Algorithm Description of the Image Recognition System

Objectives and Tasks of Image Recognition System

The main purpose of the Image Recognition System is to provide the control system with information about the visual properties of fuel at a certain location within the fuel storage. These properties have been specified to be the average wood chip particle size at the surface as well as the mean fuel quality at this location. Further tasks are the detection of oversized chips or foreign objects which might damage the stoker or obstruct the grate, as well as the detection of large accumulations of saw dust. In these cases the Image Recognition System alerts the control system of its findings.

Sensor Architecture

The Image Recognition System consists of two GigE Vision industrial Ethernet cameras, two 100W LEDs as light sources driven by an Ethernet capable flash controller and a computer for image acquisition and evaluation. Auxiliary components are an Ethernet switch connecting the cameras and the flash controller to the image acquisition computer and two DC-DC switching power supplies providing the components with their required voltage from a common 24V power line.

The camera system operates independent from the control system. After power up, it enters an idle state waiting for a trigger signal from the control system, upon which it acquires a sequence of images illuminated alternatingly by LED1 and LED2 and generates an exposure sequence. After evaluating these images statistics are transferred back to the control system. All operations are performed autonomously, the only interaction necessary between control system and image recognition system are the initiation of the image acquisition (control system → image recognition system) and the subsequent feedback of the evaluation metrics (image recognition system → control system).

Algorithm Description – Segmentation

Woodchip particle segmentation is performed with an adapted shape-from-shadow approach motivated by the shape detection algorithm proposed by Raskar et. al.[7] for their non-photorealistic camera. To ease segmentation we strive to acquire images in which the chip area is overexposed up to the exception of the cast shadows arising from lateral illuminating the scene. The resulting image pair $\{I_{LED1}, I_{LED2}\}$ is fused into a single image I_{MIN} by taking the pixel wise minimum of $\{I_{LED1}, I_{LED2}\}$. Individual wood chips are segmented by seeded region growing the distance transformation of a binarized I_{MIN}. The results are refined by separating the segments into star-convex blobs.

Segmentation was tested on image sequences acquired both in the lab as well as during the test runs at the BIOS prototype plant. Since no ground-truth data is available for the segmentation task only qualitative evaluation was performed.

Algorithm Description – Sawdust Detection

Sawdust detection is based on the statistics of the segmentation without post processing. The sawdust flag is raised if the segmentation results in a few connected components where the bounding box covers a large area of the image, yet the filled areas of these connected components are considerably larger than the component areas themselves. Small areas with a size comparable to that of individual wood chips are ignored for sawdust detection.

7 Non-photorealistic Camera: Depth Edge Detection and Stylized Rendering using Multi-Flash Imaging, Raskar et. al., SIGGRAPH 2004.

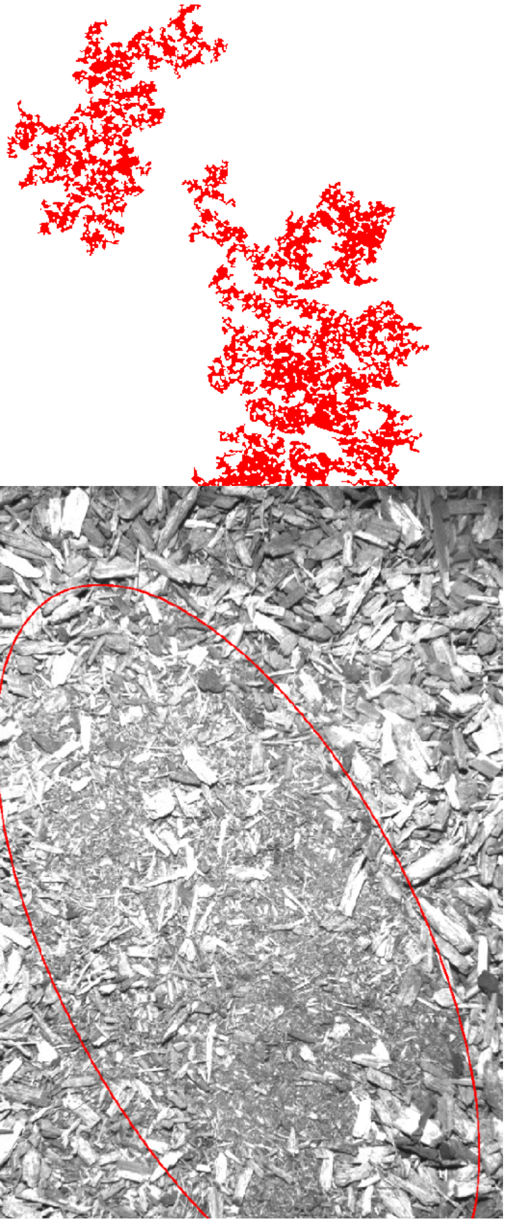


Figure 15 Exemplary result of the sawdust detection. Left: segmentation result without star-convex separation applied motivating the criteria for classification as sawdust. Right: Illustration of the detection.

Algorithm Description – Woodchip Size Estimation

Metric information is obtained by fitting a plane into a subset of the 100 best matching 3D point correspondences from sparse stereo reconstruction of the fuel surface. The segmentation is then projected onto that plane and by this pixel areas measured in pixels are transformed into a metric measurement in mm². Since the control system utilizes the mean chip size only and due to the flat-shaped nature of wood chips this approximation is sufficient.

Algorithm Description – Overlarge Wood Chip Detection

An overlarge object is detected and the corresponding flag raised if the segmentation yields an individual chip with an area or a major axis length exceeding a predefined threshold. This requires the objects surface and texture to behave in such a way that it appears as a single contiguous area in the segmentation. Overlarge particles of the same substance as the fuel (i.e., wood in most cases) can be expected to meet this constraint. Particles of foreign material will be detected by the foreign object detection. Since handling is the same for both overlarge wood chips and foreign material a

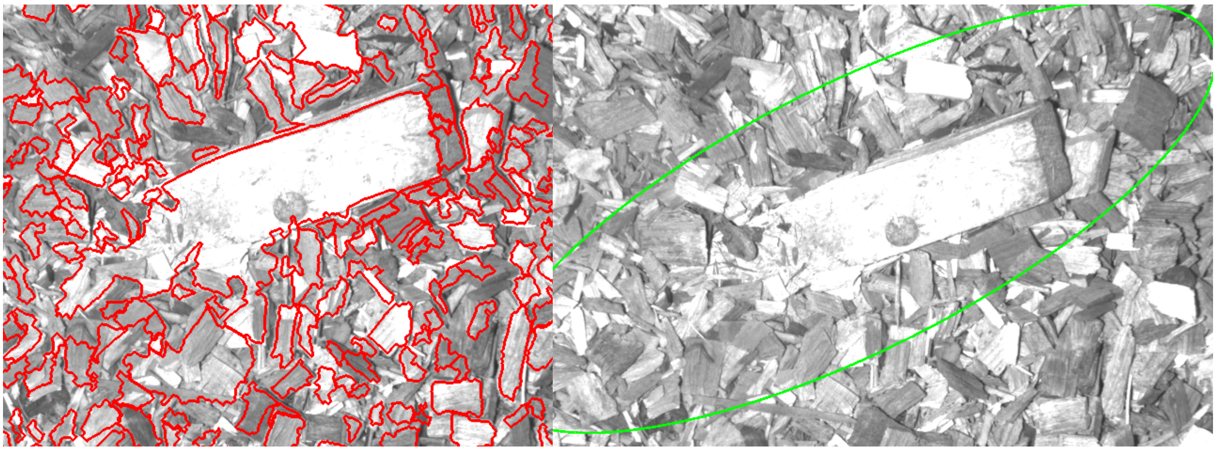
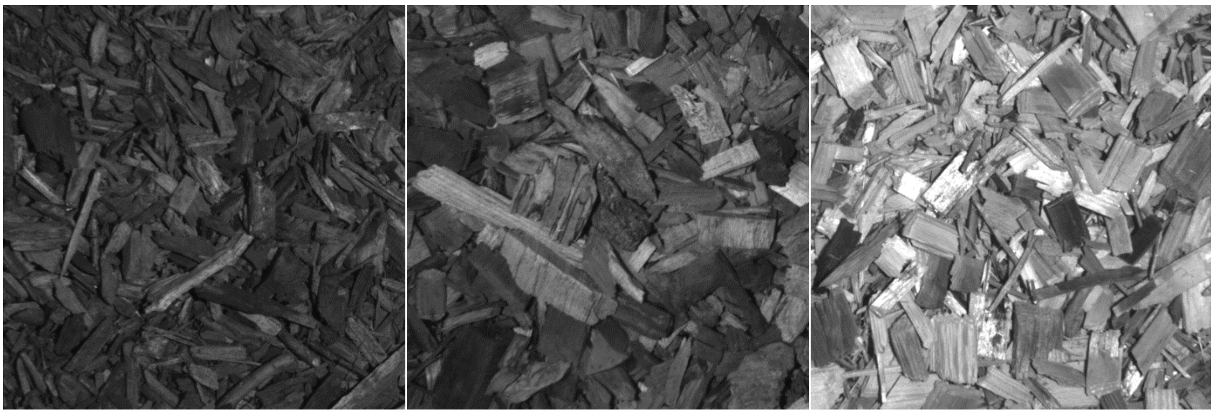


Figure 16 Segmentation (left) and detection (right, illustration) of an overlarge wood particle

detection by both algorithms does not pose a limitation to the performance.

Algorithm Description – Quality Estimation

The fuel quality is tied to the optical fuel brightness. Bright fuel is thought to contain just a small amount of ashes and be of high quality, dark fuel with a large relative bark content is thought to be of low quality with a rather high ash content. In order to assess the fuel brightness reliably the radiometric response functions of the sensors are calibrated according to the method proposed by Debevec et.al.[8]. Fuel quality is then determined by calculating the radiance map of a fuel sample and classifying it according to the radiance histograms of images of fuel samples of the predefined quality classes.



8 Recovering High Dynamic Range Radiance Maps from Photographs, Debevec and Malik, SIGGRAPH 1997

Figure 18 Images of dry samples pertaining to the three classes, acquired with the same exposure time of 4ms. From left to right: class 3 (high bark content), class 2 (small bark content), class 1 (almost bark free).

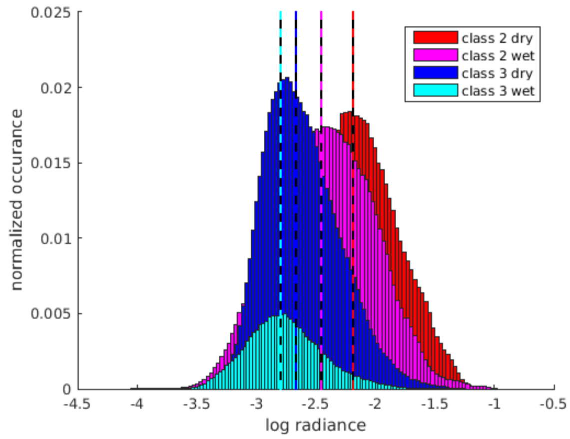
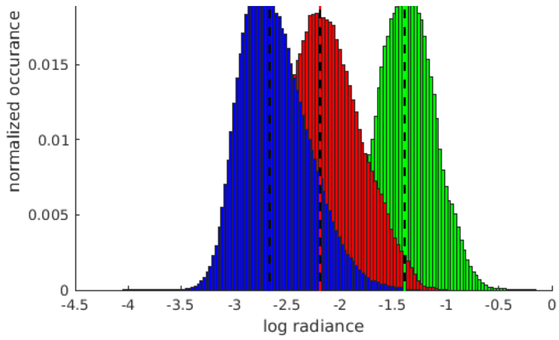


Figure 17 Histograms of radiance maps for different fuel classes. Left: comparison of histograms for dry fuel classes, class medians are shown as dashed lines. Right: histograms and medians for both dry and wet samples for classes 2 and 3. A wet sample for fuel quality class 1 was not available.



Tests have shown that comparison of the median radiance is enough to classify fuel samples correctly. As one would expect, a wet sample from a certain class results in a lower radiance measurement. In most cases however correct classification was still possible, especially so when restricting radiance measurements to segmented areas only.

The algorithm was tested during the scheduled test runs at the BIOS prototype plant.

Algorithm Description – Foreign Object Detection

The objective of the foreign matter detection is to alert the control system of the presence of foreign objects on the surface of the fuel pile with a size that may either jam or even damage the stoker screw or obstruct the grate of the furnace to an extent that may impair the performance of the boiler. It is not necessary to detect every foreign particle and obviously it is not possible to detect foreign matter completely covered below the fuel surface.

Foreign object detection is based on sparse coding of image patches, following the algorithm proposed by Lu et.al[9]. A foreign object is detected and the corresponding flag raised if a certain image area cannot be explained by sparse combinations of pre-learned bases vectors with just a reasonably small reconstruction cost.

The sparse bases combinations were trained on images of various wood chip sizes and qualities, testing was performed on images of the same wood chip samples with metal objects (different bolts,

9 Abnormal Event Detection at 150 FPS in MATLAB, Lu, Shi and Jia, ICCV 2013

a ring cut from a circular piece of pipe, and a steel strut) placed in them. The foreign objects were in some cases partially covered by fuel, in other cases they were completely visible.

A further limitation of the current system is its inability to correctly handle previously unseen types of biomass fuel. This may be tackled by providing the user with an option to start a re-training phase or alternatively by an online updating scheme.

Figure 19 Sample images of the test objects and some of the fuel types used for training respectively testing the foreign object detection.

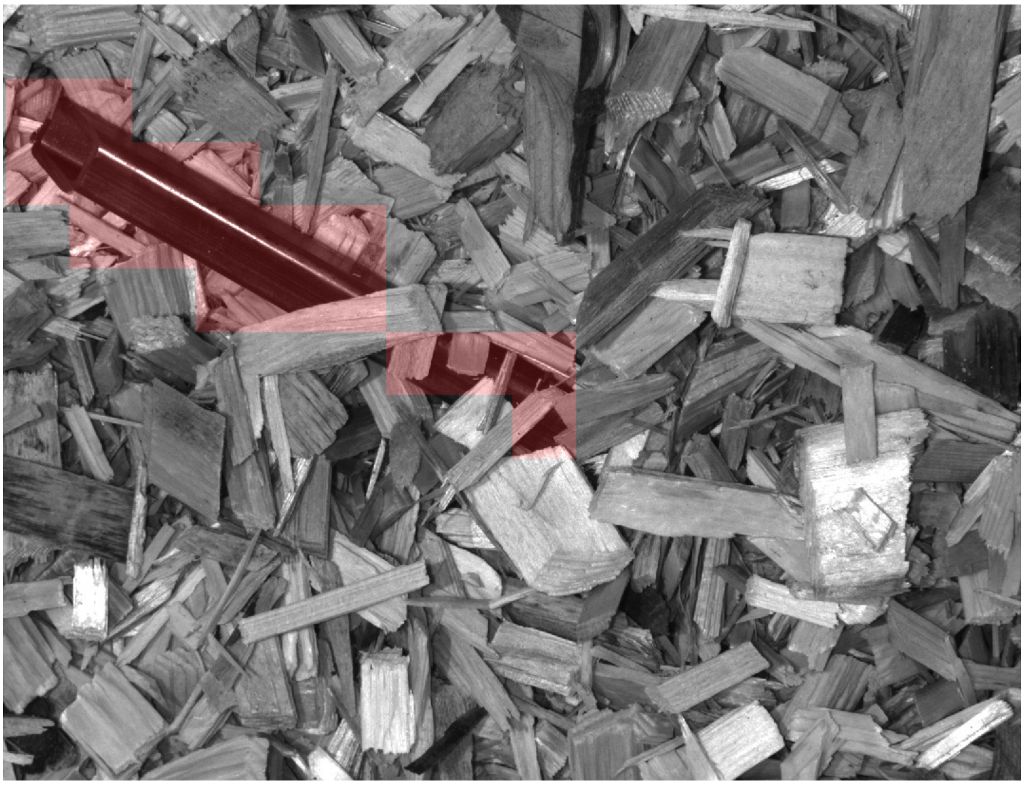


Figure 20 Example of a foreign object (steel strut) partially covered by wood chips. Patches detected by the system as foreign are marked in red.

References

[Zitat1] Rackl, M.; Günthner, W.A.; *Experimental Investigation on the Influence of Different Grades of Wood Chips on Screw Feeding Performance.* Submitted to *Biomass & Bioenergy*; under review (status: 12.10.2015)

[Zitat2] Wensrich, C.M.; Katterfeld, A.: *Rolling friction as a technique for modelling particle shape in DEM.* Powder Technology 217 (2012), p. 409-417.

[Zitat3] Wensrich, C.M.; Katterfeld, A.; Sugo, D.: *Characterisation of the effects of particle shape using a normalised contact eccentricity.* Granular Matter 16(2014), 3, p. 327-337

[Zitat4] Rackl, M.; Top, F., Günthner, W.A.; *DEM-based study on the interaction of an agitator with a screw-conveyor-discharged hopper.* Accepted poster presentation for PARTEC 2016 – International Congress on Particle Technology, 19-21.April 2016; Nuremberg.

The potential impact

Max. 10 pag

The address of the project public website, if applicable as well as relevant contact details

Project's webpage

The project's website is available using the link **www.BioChipFeeding.com**

The website is structured into seven pages:

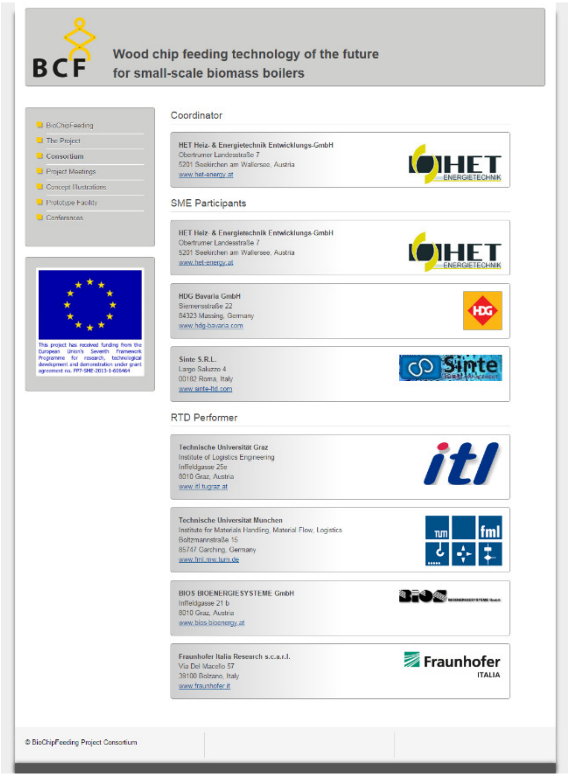
- BioChipFeeding (Start page/landing page)
- The Project (Information about the project and its main objectives)
- Consortium (List of all consortium members, including contact information)
- Project Meetings (Information about the project meetings, stated in the list of deliverables – all other meetings are not listed)
- Concept Illustrations (Videos and Images, illustrating the basic concept of the project)
- Prototype Facility (Information about the prototype plant in Massing, Germany)
- Conferences

Menu item "BioChipFeeding"

Menu item "The Project

Menu item "Conferences"

Menu item “Consortium”



Menu item “Concept Illustrations”

Menu item “Project Meetings”

Menu item “Prototype Facility”


Wood chip feeding technology of the future
for small-scale biomass boilers

- BioChipFeeding
- The Project
- Consortium
- Project Meetings
- Concept Illustrations
- Prototype Facility
- Conferences

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no. FP7-SME-2013-1-606464

Project Meetings

Kick Off Meeting	Location: Massing - Germany	Date: Oct 1st - Oct 2nd 2013
Topics	• Project overview • Presentation (introduction) of the partners • State-of-the-art of woodchip feeding systems • Visit at the HDG showrooms and test stands • Overview over the work packages • Detailed discussion of the work to be performed in WP1, Definition of the boundary conditions and development of a detailed concept • Summary and final definition of boundary conditions and target values for the new technology as well as relevant interfaces between the different main components	
Project Meeting	Location: Garching - Germany	Date: June 16th - June 17th 2013
Topics	• Report/protocol of the last meeting • Update results TU-Graz, Grippertechnlogy • Update results TU-Munich, Auger – technology • Feeding Algorithm Fraunhofer Italia Research • Organisational Topics	
Final Project Meeting	Location: Massing - Germany	Date: September 28th 2015
Topics	• Report/protocol of the last meeting • Update results: optimized prototype - HDG, Fraunhofer Italia • Update results Image data processing - TU-Graz • Organisational Topics	

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Furthermore, project logo, diagrams or photographs illustrating and promoting the work of the project (including videos, etc…), as well as the list of all beneficiaries with the corresponding contact names can be submitted without any restriction.

Use and dissemination of foreground

Section A

This section should describe the dissemination measures, including any scientific publications relating to foreground. Its content will be made available in the public domain thus demonstrating the added-value and positive impact of the project on the European Union.

Template A1

List of all scientific (peer reviewed) publications relating to the foreground of the project.

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[13] (if available)	Is/Will open access[14] provided to this publication?
1	*Economic transformation in Hungary and Poland'*		*European Economy*	*No 43, March 1990*	*Office for Official Publications of the European Communities*	*Luxembourg*	*1990*	*pp. 151 - 167*		yes/no
2										
3										

List of scientific (peer reviewed) publications, starting with the most important ones										
NO	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place	Year	Relevant pages	Permanent identifiers (if available)	Open access

Template A2

List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities[15]	Main leader	Title	Date/Period	Place	Type of audience[16]	Size of audience	Countries addressed
1	*Conference*		*European Conference on Nanotechnologies*	*26 February 2010*				
2								
3								

List of dissemination activities

NO	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries adressed

Section B

(Confidential or public: confidential information to be marked clearly)

This section should specify the exploitable foreground and provide the plans for exploitation. All these data can be public or confidential; the report must clearly mark non-publishable (confidential) parts that will be treated as such by the Commission. Information under Section B that is not marked as confidential will be made available in the public domain thus demonstrating the added-value and positive impact of the project on the European Union.

Part B1

The applications for patents, trademarks, registered designs, etc. shall be listed according to the template B1 provided hereafter.

The list should, specify at least one unique identifier e.g. European Patent application reference. For patent applications, only if applicable, contributions to standards should be specified. This table is cumulative, which means that it should always show all applications from the beginning until after the end of the project.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.

Type of IP Rights[18]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)

Type of Exploitable Foreground[19]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[20]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	Ex: New superconductive Nb-Ti alloy			*MRI equipment*	*1. Medical 2. Industrial inspection*	*2008 2010*	*A materials patent is planned for 2006*	*Beneficiary X (owner) Beneficiary Y, Beneficiary Z, Poss. licensing to equipment manuf. ABC*

In addition to the table, please provide a text to explain the exploitable foreground, in particular:

- Its purpose
- How the foreground might be exploited, when and by whom
- IPR exploitable measures taken or intended
- Further research necessary, if any
- Potential/expected impact (quantify where possible)
-