The Swedish National Energy Administration

RESEARCH PROGRAMME

Small scale combustion of biofuel

- English summaries of the research reports

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Rapport/study Energimyndighetens forskningsprogram Småskalig förbränning av biobränslen – sammanfattning and utvärdering	*English title* STEM's research program on the small scale combustion of biomass – Summary and assessment	
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1 ER 25:1998	*Fax* +46-33 13 55 02	*Summary (pages)* 1 (1)

SUMMARY

In the years 1993-1996, STEM, the Swedish National Energy Administration, has managed a research program within the area "Small scale combustion of biomass". The aim of the program has been to "compile information on and promote the development of better equipment for the combustion of biomass within the size interval from domestic boilers up to 10 MW, with aspects such as environmental impact, efficiency and cost being considered".

About fifteen open research projects have been conducted within the programme. Examples being the development of a technique for measuring gas concentrations within combustion chambers, analysis of the best available technology for domestic boilers and for boilers in the interval 0.5 - 10 MW, mathematical modelling of combustion in small boilers, the examination of catalytic methods for reducing emissions, the systematic minimisation of emissions from small plants and the development of a quality marking system for pellet burners. In addition, a number of projects addressing product development have been funded through the programme. An integral part of the program has concerned the development of an information and education package intended for use by local authorities and the general public amongst others, in courses, lectures and seminars for contractors.

This report gives an account of the activities undertaken, summarises the results achieved and gives an evaluation of the activities based on interviews with a number of people representing different groups of consumers. The general view is that the program has stimulated the development in an environmentally important area and that it has bettered the contacts between researchers and consumers like the manufacturing industry. Finally some proposals are given for the next program period.

Rapport/study Miljön and småskalig pelletseldning	*English title* Small scale pellet combustion and the environment	
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SUMMARY

The combustion of wood pellets in small scale heating systems with an effect below 20 kW has increased strongly. It has been estimated that 1,500 small units were operational for the heating of houses during the winter of 1995/96.

Stack emissions from three pellet burners and two pellet stoves were studied carefully in the laboratory, with different pellet qualities being tested. When the fraction of fines increased, the NO_x emissions also increased by about 10%. As the reference fuel, 8 mm pellets were used. In most cases, tests with the 6 mm pellets gave significantly lower emissions of CO and THC.

Eleven stoves, burners and boilers were studied in a field test. The results show that the plants consistently have higher emissions in the field than under conditions when the plants are adjusted with a stack gas monitoring instrument. One can conclude that it is difficult for the operator to adjust the plant without a monitoring instrument.

The emissions from the plants tested give an estimation of stack gas emissions from small-scale pellet combustion. There is a large difference between the "best" and "worst" types of technology tested. The range of the emissions recorded is given below. The interval considered is that of normal combustion. During inappropriate conditions, the emissions are significantly higher.

- CO 80 - 1000 mg/MJ
- Tar 0.3 - l9 mg/MJ
- THC (as methane equivalents) 2-100 mg/MJ
- NO_x < 50-70 mg/MJ
- Dust emissions 20-40 mg/MJ

The emissions from heating with pellets are lower than for wood combustion and, for the best technology, they are close to the emission levels for oil burners. Although wood and pellets

have the same origin, to burn them in an environmentally friendly way, they need to be burnt under different conditions. The combustion of pellets could be further improved by improving the control of the air and fuel flow, thereby creating more stable conditions for the combustion.

Rapport/study	*English title*	
Analys av dagens bästa teknik för biobränsleeldade pannor mellan 0,5 and 10 MW	An analysis of the best existing technology for biomass fired heating plants between 0.5 and 10 MW	
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3 ER 19:1998	+46-33 13 55 02	1 (3)

SUMMARY

The purpose of the present project was to study the best technology available for biomass fired heating plants in the interval 0.5 to 10 MW from an emission point of view. Emission measurements have been conducted at 21 plants of different type and size: one stationary fluidised bed, fourteen boilers with moving grates, four boilers with fixed grates, one pellet burner and one boiler with a gasification oven. The plants were fired with different fuels: fuels like woodchips, bark, sawdust and grass, and refined fuels like briquettes and pellets. The plants were chosen to be representative of the best available or the most common technology.

The flue gases were analysed for CO, NO_x, total hydrocarbons (THC), methane, ethylene, acetylene, ammonia, nitrous oxide, CO_2 and O_2. The measurements were usually made at the heat loads and under the operating conditions given at the time of testing. However, in a few cases, measurements were made at different loads and air settings.

The excess-air ratio varied considerably between the plants. Mean values of the O_2 content of between 4 and 15% (dry gas) were recorded. For plants without O_2 control, i.e., the smaller ones, the O_2 content was between 8 and 15%. These plants are operated at high excess-air ratios as a precautionary measure in the event of variations in the fuel feed rate and the fuel quality. In certain cases, especially in plants fired with woodchips, the time-dependent variations in the excess-air ratio were large, while they were smaller in plants fired with pellets or briquettes. For boilers with O_2 control, the O_2 content varied between 4 and 9.5%. Systems in which the excess-air ratio was controlled through the secondary air fan showed more stable excess-air ratios than those in which it was controlled through the fuel feed rate.

In most of the plants, the emissions of unburned gases were relatively low, the CO content, for example, was below 400 ppm and the THC content was 5 ppm at most. Most of the plants had moving grates and were fired with unrefined fuels. A few plants using refined fuels also

showed such results. No emissions could be recorded of volatile organic compounds, with the exception of four plants where small amounts of methane (max 30 ppm) were found for short periods. However, at two plants with moving grates fired with refined fuels, a CO content of up to 9600 ppm and a THC content of up to 1300 ppm were recorded. They were accompanied by increased levels of methane, ethylene and acetylene.

The boilers with fixed grates were fired with refined fuels and showed small emissions of unburnt material provided that the heat load was sufficiently high. At lower loads, the emissions of CO and hydrocarbons increased. This was also the case for the pellet burner, where THC contents of up to 100 ppm and methane peaks of up to 113 ppm were measured at lower loads. For the boiler with gasification oven, low emissions of unburnt material were recorded when firing with moist woodchips or a mixture of bark and dry woodchips, while the emissions were higher when firing a mixture of bark and sawdust. Generally, a low and/or varying heat load was accompanied by higher emissions of unburnt hydrocarbons.

The NO_x emissions were between 35 and 230 mg/MJ and in about half of the tests the emissions were above 150 mg/MJ. These emissions are high in comparison with the oft used emission limits of 50 mg/MJ for larger plants and modern oil burners. To a large extent the emission from grate boilers depends on the nitrogen content of the fuel. Chips from lumbering waste with a high nitrogen content gave emissions of 150 mg/MJ or more, while the levels for sawdust and refined fuels made from sawdust were between 50 and 100 mg/MJ. The correlation between the nitrogen content in the fuel and the corresponding NO_x emission was quite good over the entire interval of 0.1 to 0.6% N in the fuel. Lower emissions than expected from the nitrogen content can be explained by high contents of unburnt fuel contributing to the reduction of NO_x. The higher NO_x emissions can probably be explained by irregularities in the fuel movement on the grate giving rise to spots where the fuel bed is thin and the fuel burns at high excess-air ratios, as well as by other irregularities.

With the aim of reducing the NO_x-emissions, experiments were conducted in three plants. With the fluidised bed, the emissions could be lowered by 35 to 45% by reducing the 0_2 content by about 2 percentage points, although this was accompanied by an increase in the content of unburnt fuel. With the moving grates, changing the combustion air distribution, decreasing the excess-air ratio and recirculating the flue gas were investigated. The reduction in the NO_x emission through changing the air distribution was 10 to 15%. Larger effects were not found, in part this can be attributed to the damper systems and the other regulating equipment in these rather small plants prohibiting radical changes in the air distribution. When the O_2 content was decreased by 1 percentage point, the NO_x emission did not decrease significantly, while the levels of unburnt fuel increased somewhat. In the experiment with flue gas recirculation, the NO_x emission decreased, but the unburnt fuel content became unacceptably high.

The following conclusions can be drawn from the measurements:

1. The excess-air ratio in small biomass-fired heating plants is often high. The smallest plants have no system for O_2 control. The introduction of regulation in smaller units and the improvement of the existing regulation in larger ones would be desirable to increase the boiler efficiency whilst retaining the combustion efficiency.

2. The emissions of CO and hydrocarbons are normally low with CO levels of a few hundred ppm and THC contents below 5 ppm. There are normally no emissions of volatile organic compounds (VOC), with the exception of a few ppm of methane. There are plants with higher emissions of unburnt fuel where higher levels of primarily methane are recorded. Low and/or variable heat loads lead to an increase in the emission of unburnt fuel. On/off control in its present form is not acceptable at low loads. There is a need for the development of designs which can handle low and variable heat loads better whilst retaining the combustion efficiency. The need is perhaps greater for plants using refined fuels, since they are often operated under more variable conditions. In this context, a special area here is the pellet burner, which is often used for converting oil-fired plants to biomass ones.

3. The emissions of nitrogen oxides are high compared to those from larger plants, often above 150 mg/MJ. These levels are probably not acceptable if the use of small plants becomes extensive. The emission level depends to a large extent on the nitrogen content as well as on the behaviour of the fuel on the grate. The simplest way to substantially reduce a high NO_x emission is to substitute an unrefined fuel with a high nitrogen content with a refined fuel with a low nitrogen content. Existing plants cannot be tuned to give appreciably lower NO_x emissions without retrofitting. The possibility of developing technology for NO_x reduction on a smaller scale should be studied.

4. It is not possible to explain the combustion events in detail from the measurements performed. Nevertheless, these measurements do indicate critical factors from an emission point of view. Among other things, irregularities in the combustion chamber and on the grate are shown to be important factors for the combustion efficiency and for the emissions.

5. More extensive and systematic measurements are needed at individual plants in order to be able to propose measures by which to reduce emissions. The measurements conducted here are from a field study, which has primarily been performed under the existing operating conditions.

Rapport/study Analys av dagens bästa teknik för vedeldade villa pannor	*English title* An analysis of the best existing technology for wood fired central heating	
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4 ER 20:1998	*Fax* +46-33 13 55 02	*Summary (pages)* 1 (3)

SUMMARY

The purpose of the present project was to study the emissions from some of the best available wood-fired central heating boilers on the market. The aim was to identify the critical factors which determine the emission levels by means of emission measurements and by temperature measurements in the combustion chamber. Four boilers with different design characteristics have been included in the project all of which use reversed combustion and fan-assisted combustion air supply and have been shown to have low tar emissions in environmental tests performed earlier. Boiler A is a boiler with a rather large mass of ceramics and has a large volume of water. Boiler B has a small cast-iron grate and a small water volume. Boiler C is a boiler with a tertiary air supply and has an accumulator tank incorporated. Boiler D has a zirconia-cell probe for continuous control of the excess air ratio. The measurements have been made with the boilers in accumulator operation, i.e., at the maximum heat output, since they are intended for operation under these conditions. In addition to normal operating conditions tests have been made with high moisture contents of the fuel, a large draught and a low boiler temperature at the start of the test. Measurements have been made of the excess-air ratios, the CO content, the total hydrocarbons (THC), NO_x and of a number of volatile organic compounds (VOC) in the flue gases as well as of the combustion temperatures below the grate.

In all tests the emission levels varied strongly in the different phases of the combustion cycle. During the start-up phase the excess-air ratio is high and the combustion temperature is low. This leads to high emission levels of CO and of unburnt hydrocarbons. When the combustion stabilises, the combustion temperature increases and the levels of unburnt material decrease rapidly. In the last part of the combustion cycle when only a small amount of fuel remains, the excess-air ratio increases and the combustion temperature decreases, which leads to much higher emissions of CO, but not normally of unburnt hydrocarbons since the fuel has been almost devolatilized at this stage. Perturbations also occur during the continuous phase when fuel bridges are built up which then collapse leading to irregular emission peaks of unburnt material.

A clear correlation could be established between the temperature below the grate and the emissions of unburnt material. At temperatures below 800 ^{O}C the CO and hydrocarbon content of the flue gases increased strongly. These conditions occur in the start-up phase and in the last part of the combustion cycle. During the start-up phase heat is consumed in warming up the grate, the burn-out zone and the boiler water. In the last part of the cycle, the cooling effect of the combustion air introduced is larger than the heat release from the combustion so the temperature decreases. This phase is longer for boilers A, B and C where the air supply is constant, than for boiler D where the air flow is continuously adjusted to maintain a constant oxygen content in the flue gases.

Mean values have been calculated for the emissions for three periods: the start-up phase, the environmental test period, i.e., the whole test excluding the start-up phase, and for a period with a continuously high combustion efficiency. For the environmental test period the CO emissions for boilers A-C normally lay in the interval 900 - 1,300 mg/MJ and for boiler D they fell in the interval 500 - 700 mg/MJ. For the same periods, the THC emissions for boilers A and B were 60-150 mg CH_4/MJ, for boiler C they were 25-80 mg/MJ and for boiler D 13-40 mg/MJ. The NO_x emissions for boilers A, B and D fell in the interval 100-115 mg/MJ and for boiler C in the interval 80-95 mg/MJ. The emissions of VOC components for boilers A and B were 20-60 mg/MJ and for boilers C and D they were 10-25 mg/MJ. During the start-up phase the emission levels of CO, THC and VOC components varied from test to test, but they were consistently much higher than during the rest of the combustion cycle. Thus a substantial part of the total emission from the boilers was attributable to the start-up phase. This is also confirmed by a higher flue gas tar level during periods including the start-up phase than those excluding it.

When firing fuel with a high moisture content, the levels of unburnt material emitted increased many times compared to the normal case for boilers A and B. For boiler C the increase was much smaller, and boiler D showed no increase at all. Furthermore, the NO_x emissions from boilers B and D increased by about 20% when moist wood was used.

For boilers A and B the levels of unburnt material during stable periods with good combustion efficiency were about half of the mean values for the whole test period excluding the start-up phase. For boilers C and D, CO levels of below 50 mg/MJ and THC levels of below 20 mg/MJ were measured indicating that the burn-out efficiency in these boilers is very good when combustion is as intended. For these boilers the VOC emissions are either not detectable or detectable at levels of a few mg/MJ. For boiler C a very high efficiency was recorded when the combustion was stable. However during the tests disturbances did occur, probably due to the fact that the fuel charges were only 50% of the maximum fuel volume, resulting in the build-up of fuel bridges and the subsequent blocking of primary air inlets as the fuel bridges collapsed. An environmental test conducted previously has confirmed the low emission levels of the boiler when combustion is stable. The control of the excess-air ratio for boiler D leads to very stable combustion with low emission levels. Disturbances in the fuel stacking did not influence the emissions from this boiler at all.

In conclusion, it can be stated that the best technology available today for wood-fired central heating boilers enables wood firing to take place with significantly lower levels of unburnt fuel being emitted than the models given environmental approval previously. The behaviour of the fuel in the fuel chamber gives rise to smaller or larger disturbances in the combustion process. It is therefore important to develop and apply technology which minimises the influence of these disturbances on the emissions. An example of such technology is the zirconia-cell probe, which is incorporated in boiler D. Another important area is to minimise the emissions from the start-up phase when a considerable proportion of the emissions from boilers using advanced combustion technology is produced. Novel methods should be developed for the rapid ignition of the fuel. It can be concluded that the emissions of VOC are considerably lower than in measurements on boilers given environmental approval earlier. To a large extent the emissions occur during the start-up phase and after fuel charging.

Further studies in a laboratory test rig are needed to understand how the start-up procedure and the disturbances during continuous operation can be influenced and to better comprehend their consequences. Studies of different methods for supplying the combustion air should also be made in such a rig and the importance of the residence time examined.

Rapport/study	*English title*	
Elda pellets direkt i vanliga vedpannor	Burning pellets in ordinary wood-fired boiler	
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5 ER 17:1998	+46 510 252 35	1 (1)

SUMMARY

This project shows that it is possible to use pellet-fuel in an ordinary small boiler without using a pellet-burner.

Our method includes three steps: a new kit (pellet-adapter), an accumulator tank and a mechanical door to provide a stable draw. The pellet adapter operates best in boilers which are made for firing wood or other biomass. We have built and tested six different kinds of adapters that are representative of many of our most general boilers. Our adapters can be used in more than 100,000 small houses in Sweden.

We can describe our method briefly as being a method for the provision of the most stable burning conditions possible and intended to make the process stable throughout the firing-cycle. The accumulator tank makes the energy requirement stable, the mechanical door controlling the draught makes the airspeed inside the combustion chamber stable and the pellet adapter ensures stable gasification of the pellet-fuel.

Our adapters are made of stone and steel. They reduce the ordinary grate to one third. This is necessary because pellets contain more energy per litre than wood and convection-section of all ordinary boilers is constructed for the efficient burning of wood. The adapter also includes an "after-burning-chamber" for a secondary gas burning process not in contact with water cooled areas and with a "fall-in-system" for the transport of pellets into the firing zone.

The results of this project show that it is possible to fire pellets in a simple manner in an ordinary boiler. The adapter gives an improved environmental performance and is more efficient. Economically it is possible to reduce the cost of heating to 40-50% that of oil.

We have shown that both self-draughted and ventilator-operated boilers can be converted into pellet firing boilers. These are only the smallest of the so called "combination-boilers" and it should be noted that some of the boilers using overflame technology are difficult to convert.

Rapport/study Försöksrigg för parameterstudier och studier av konstruktionselement i vedeldade villapannor	*English title* Test rig for studies to determine parameters for the components appropriate to wood-fired domestic boilers	
Författare/ author Monica Axell, Lennart Gustavsson, Bo Leckner	*Organisation* SP Swedish National Testing and research Institute Chalmers University of Technology	
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6 ER 21:1998	*Fax* +46-33 13 55 02	*Summary (pages)* 1 (2)

SUMMARY

The purpose of this preliminary study was to define the type of factors that should be investigated in a proposed test rig for wood log firing and to propose a design for such a test rig. The bases of this preliminary study were provided by the experiences from the project "Analysis of the best available technology for small-scale wood-fired boilers", experiences from the standard tests for the environmental certification of boilers and a literature survey.

The combustion of logs of wood is a complex process because of the characteristics of the fuel and because the boiler is batch-wise. The temperature levels required and the supply of air for combustion vary during the combustion cycle.

The interaction between the boiler design, the characteristics of the fuel and the behavior in the combustion chamber completely determine whether one obtains a good and stable quality of combustion. Modem boilers with down-draught firing periodically function very well, with low levels of emissions and a high combustion efficiency. Further development requires a lengthening of these periods of stable combustion. To achieve this it is important to find general models providing an increased understanding of the combustion processes in batch-wise wood log combustion.

The combustion process in a boiler can be separated in two parts: 1) the fuel bed, the grate and the combustion air supply; 2) the combustion of the gases generated. Existing knowledge of the latter part, gas phase combustion, is relatively good. In contrast, there is much less known about the behavior of the fuel bed in interactions with the primary air inlet, the grate and the secondary air inlet, whence the test rig will focus on these phenomena.

Thus the purpose of test rig is the following: It is designed to make it possible to investigate the behavior of the fuel bed under the influence of a number of construction parameters and different types of fuel. Of special interest is the study of the interaction between the fuel bed and the supply of primary air between the fuel bed and the grate and between the fuel bed and combustion chamber. In addition, the test rig will be so designed that subjects involving the burn-out chamber can be studied.

A proposal for the design is proposed. In the test rig one can vary the position and design of the primary and secondary air inlets, the grate type, the amount and ratio of primary and secondary air, the blowing or suction combustion air fan as well as the temperature profile of the burn-out chamber. A proposed test scheme is presented as well as a list of parameters to be measured.

Rapport/study P-märkning av pelletsbrännare, utveckling av ett kvalitetsmärkningssystem	*English title* P-marking pellet burners: Developing a system for the certification of quality	
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7 ER 22:1998	*Fax* +46-33 13 55 02	*Summary (pages)* 1 (1)

SUMMARY

A quality marking system for pellet burners with a nominal heat output of maximum 25 kW has been developed. The system is a P-marking system, which means that SP, the Swedish National Testing and Research Institute, is responsible for the certification of the system. The certification rules and the test method have been developed in cooperation with the manufacturers of pellet burners and the authorities concerned. A project group has managed the work which has been conducted with funding from the Swedish National Energy Administration.

Nowadays small scale pellet burning is an economically interesting option for domestic heating. The number of burners sold is rapidly increasing, as are the number of manufacturers. As a comprehensive system for the quality marking or approval of pellet burners has not been established, it was considered important to develop such a system.

Certification rules defining the technical requirements with regard to the safety functions, efficiency, emissions and operational reliability are presented. The requirements in terms of the technical documentation, the installation and the maintenance instructions and quality assurance in the manufacturing process are also formulated. P-marking also includes requirements for monitoring the production process.

The technical requirements have been discussed with the manufacturers at a number of meetings and the certification rules and the test method have been circulated twice for consideration. The relevant authorities and other parties have also expressed their views in the course of the project. The test method has been validated on four different burners.

The system has been very positively received by both manufacturers and authorities, and the first P-marked burners should have appeared on the market during the autumn of 1997.

Rapport/study Katalytisk reduktion av emissioner från småskalig förbränning av biobränsle	*English title* Reduction of emissions from small scale biomass combustion with catalysts	
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8 ER 23:1998	*Fax* +46-155-263 052	*Summary (pages)* 1 (2)

SUMMARY

A study has been made of the prospects for using catalytic techniques for the abatement of emissions from the small-scale combustion of biomass. The results show that there is great potential for catalytic techniques and that the emissions of CO and unburnt hydrocarbons can be reduced, and that indirectly the emissions of NO_x can be reduced.

The aim of the project was to methodically indicate the requirements that the catalyst and the boiler must meet to enable low emission combustion utilising this technique. Furthermore, it was intended to develop new catalyst that meet these requirements in the project and to apply the catalyst on small-scale stoves. Through experimental work, these appliances have been evaluated and conclusions drawn concerning the optimisation of the technique.

TPS Termiska Processer AB, the Department of Chemical Technology at KTH, Perstorp AB and CTC-PARCA AB have collaborated closely in this project. The development of new catalysts has been conducted by KTH in collaboration with Perstorp, while the work performed by TPS has been directed towards the integration of the monolithic catalysts in two different stoves that CTC supplied. In addition, a net based catalyst developed by KATATOR has been tested.

Within the project it has been verified experimentally that a 60% reduction of the CO-emissions can be achieved for the monolithic catalysts in a wood-fired stove. Further, this can be achieved without even optimising the design. Experiments on a smaller scale and under well controlled conditions have shown that a reduction of CO of almost 100% can be achieved. The parameters that limit the conversion in the catalyst, and thereby prevent low emissions levels being reached, have been identified as

- The short residence time
- Mass transport limitations caused by the large channel width
- The uneven temperature profile across the catalyst
- Insufficient mixing before the catalyst

Within the project it was shown that the emissions during the start-up phase could be reduced by preheating the catalyst and, since the emissions during this phase are large, this implies that the total emissions can be greatly reduced by solving the practical problems with the preheating. Minor alterations of the stove design have resulted in lower emission levels. Of course it is advantageous if the concentrations can be reduced through the introduction of simple modifications, e.g., changes to the combustion zone and the flow through it and after the grate. The results also show the need for the integration of the catalyst in the stove to be optimised. A moderate reduction in the emissions can be achieved by applying the catalyst in the chimney after the stove, however, to obtain a high conversion in the catalyser and really low emissions, the catalyser ought to be integrated in the stove at the design phase.

Rapport/study Katalytiska metoder för begränsning av skadliga utsläpp från förbränning av biobränslen	*English title* Catalytic methods for the limitation of harmful emissions from the burning of biofuel	
Författare/ author Tihamer Hargitai, Fredrik A Silversand, Johan Janner	*Organisation* Ideon AB	
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9 ER 24:1998	*Fax* +46-46 2862299	*Summary (pages)* 1 (2)

SUMMARY

This project concerned the use of catalytic methods for the purification of gases resulting from the small-scale combustion of biofuel. The main goal was to develop an active, durable and inexpensive catalyst based on catalytically active wire-mesh structures.

The first task was to develop a technique for manufacturing the wire-mesh catalyst. The work consisted primarily of finding a way to make a ceramic layer stick to a metal substrate. It was important that the layer was thermally stable and would not come off easily. The next stage was to investigate different techniques for enlarging the specific surface of the ceramic layer. Finally research concentrated on finding different catalytically active materials for the combustion reactions desired.

The wire-mesh catalyst used was manufactured by a thermal-spray technique, whereby a polymer/alumina layer is sprayed onto a metal substrate, comprised of a wire-mesh. The specific surface of the porous layer could then be enlarged by depositing alumina into the macro-pore system. Finally the active material (Pd/Pt or Pd/Pt/V/Cu**)** was incorporated into the pore system.

The combustion experiments were performed in a lab-reactor where the temperature, flow rate and composition of the flue-gas could be varied across a great range. The catalytically active wire-mesh nets had a diameter of 90 mm.

The investigation included the combustion of carbon monoxide (CO) and the most common VOCs from wood burning (ethene, propane, butadine, methane, ethyl alcohol, benzene and terpenes), in addition to which, the catalytic combustion of carbon, soot particles and tar was studied. Studies were also made of the influence of the mesh number, the number of wire-meshes in series, the flow rate, the specific surface area and the load of active material in the

catalyser.

Thermal deactivation tests were performed at three different temperatures and with two different compositions of active material. The resistance against chemical deactivation was studied by impregnating the catalyst with solutions containing deactivating species, e.g., alkaline and rare alkaline earth metals.

Preliminary long time trials were carried out in a wood-fired stove over a period of 160 hours. A scan of different regenerating methods showed that the catalytic activity could be completely regained.

The tests in the commercial wood-fired furnace included experiments as well as theoretical calculations of the conversion of carbon monoxide. The results from the model tallied well with the experimental results.

Rapport/study Förbränningskontroll av pelletsbrännare	*English title* Combustion control in pellet burners	
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SUMMARY

This study investigated whether it is technically and economically possible for small pellet burners to use a control system that regulates combustion.

Measurements have been made on three different burners with the result that it is possible to control all of them. With the right selection of components, this can be achieved at an economically acceptable price.

The conclusion is that there are both technical and economic advantages to the inclusion of control. The conclusion is based primarily on the ability to guarantee a high combustion efficiency, which is necessary to achieve an economic installation for the end customer. On top of this, control of this type gives much better options for the minimisation of environmentally detrimental effects. It should be noted that the mechanical construction itself is what provides the ultimate limit on the performance.

Rapport/study Datorbaserade konstruktionshjälpmedel för miljövänligare biobränsleeldade pannor and kaminer	*English title* Computerised design tools for more environmentally friendly biomass boilers and stoves.	
Författare/ author Roger Hermansson, Magnus Lundqvist	*Organisation* Div of Energy Engineering Lulea University of Technology	
Address Avdelningen för Energiteknik LuleåTekniska Universitet SE-971 87 LULEÅ 11 ER 8:1999	*Telephone* +46-920 91116 *Fax* +46-920 910 47	*E-mail* roger@mt.luth.se *Summary (pages)* 1 (2)

SUMMARY

This report evaluates the suitability of the program CFX as a tool for designing future furnaces and stoves with a lower environmental impact than is presently possible. Calculations have been carried out with CFX4.2 for a wood stove with a cylindrical secondary combustion chamber. The gases from the primary zone pass through a "neck" into the secondary chamber. The secondary combustion air is provided through a number of holes positioned on either side of the neck. Two different configurations have been modelled for the secondary air supply and tested experimentally, one with 20 holes on each side of the neck and the other with 10. The results of the calculations have been compared with the experimental results.

The first calculation took no combustion chemistry into account. The purpose of this calculation was to enable a qualitative comparison to be made of the mixing between the gases and the secondary combustion air for the two configurations of secondary air supply. The results show that the second configuration gives significantly better mixing of the gases and the secondary air. This was substantiated by the experimental results which showed that the emission of unoxidised combustible gases (CO) is lower for this configuration due to better mixing.

Two models have been tested that incorporate the combustion process. One is the "Mixed is burnt" combustion model, which assumes that fuel and oxidant cannot coexist at the same place and time. This model does not take the temperature and time dependence of the reactions into consideration, whence the results of the calculations show that all the combustible gases are completely oxidised before leaving the secondary combustion chamber. The other model that has been used includes the chemical kinetics in a simplified way. This model takes the time and temperature dependence into consideration when calculating the reaction rate. For the calculations, the combustible gases have been assumed to consist of

carbon monoxide which reacts with the oxygen in the combustion air to form carbon dioxide. The results of these calculations show that the emission of carbon monoxide is 13 ppm, which is of the same order as the experimentally measured emissions despite the fact that only one reaction has been included in the model.

The results of the calculations show that CFX is an excellent tool for simulating combusting flows in complex geometry's like furnaces and stoves. In just a short time it is possible to evaluate how different configurations will affect the combustion process. In the search for improved designs, the use of this tool, even in the present primitive form, could save a considerable amount of time and money that would otherwise need to be spent on trial and error experiments. By using the chemical model it is possible to estimate the emissions of different species, although one should aim to include the complete list of combustible gases and their reaction paths for product formation to get more precise predictions.

Rapport/study Rökgaskanaler för pelletskaminer		*English title* Flues for pellet burners
Författare/ author Jörgen Andreásson, Monica Axell, Hans Wennerholm Peter Gummérus, Marie Rönnbäck Bengt-Erik Löfgren, Benny Windestål	*Organisation* SP Swedish National Testing and research Institute Chalmers University of Technology Äfab	
Address Box 857 SE-501 15 BORÅS	*Telephone* +46-33-16 50 00 +46 31 772 1431 +46 510 262 35	*E-mail* x.x@sp.se energy.conversion@ chalmers.se bengtlovfgren@hotmail.com
12 ER 26:1998	*Fax* +45-33-13 55 02	*Summary (pages)* 1 (2)

SUMMARY

Many houses in Sweden are heated by direct electrical heating. The decision to transform Sweden into a sustainable ecological society (and to close down the nuclear power plants in the long term) has resulted in the need to transform the Swedish heating system. At present, installations that reduce the electrical power requirement in houses heated by direct electricity are subsidised. Such installations include wood stoves and central heating. This fact, in combination with the increasing production of wood pellets – Sweden currently has the largest installed production capacity in the world – makes pellet stoves an attractive alternative for houses without a central heating system.

Since pellet stoves are new on the Swedish market, there is limited experience of the function, operation and safety of such stoves and of the emissions from them. The objective of this project was to study the importance of the installation in terms of these features and to produce a basis for P-marking rules for pellet stoves.

Two pellet stoves were installed, each of which was tested with three different chimney diameters (80, 100 and 153 mm). In order to evaluate the combustion efficiency, safety aspects, condensation and corrosion in the chimneys, the stoves were tested under different operating conditions with continuous measurements being made of the emissions and flue gas temperature.

The combustion performance was satisfactory for all three chimney diameters and although the chimney temperatures were rather low in some cases, there was no visible sign of condensation. As expected, the draught was found to depend on the chimney diameter so an appropriate diameter should be stated in the installation instructions. With the smallest chimney, a backflow of flue gases was observed through the convection fan during the start

up phase when the chimney was cold. Thus chimney sizes of 80 mm or less are not recommended.

The insulation for chimney diameters of 80 and 100 mm consisted of a 10 mm air gap. The connections between the chimney parts conducted heat, resulting in heat losses.

The installation instructions should contain guidance about how to install and position the stove to facilitate cleaning and the removal of ash. Instructions for carrying out chimney sweeping and cleaning should also be included.

The risk of corrosion in the chimney has been deemed to be quite small in most cases. Corrosive conditions may, however, arise if incomplete combustion occurs or if the pellet is produced from bad (contaminated) raw materials. As a consequence, the demands imposed upon the choice of material for chimneys used in combination with pellet stoves need to be at least as rigorous as those imposed on chimney material for oil combusting stoves.

Rapport/study Datorbaserade konstruktionshjälpmedel för miljövänligare biobränsleeldade pannor och kaminer	*English title* CFX a tool for designing future furnaces and stoves with less impact on the environment	
Författare/ author Björn Kellström,	*Organisation* LTU, Luleå University of Technology	
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13 ER 8:1999	*Fax* +46 920 91047	*Summary (pages)* 1 (2)

SUMMARY

This report evaluates the program CFX as a tool for designing future furnaces and stoves with less impact on the environment then is possible with the present technique. Calculations with CFX4.2 have been carried out for a cylindrical secondary combustion chamber for a wood stove. The gases from the primary zone pass through a "neck" into the secondary chamber. Secondary combustion air is provided through a number of holes placed at each side of the "neck". Two different configurations for the secondary air supply have been modeled and also tested experimentally, one with 20 holes on each side of the "neck" -and the other with 10 holes. The results of the calculations is verified by the experimental results.

The first calculation included no combustion chemistry. The purpose of this calculation was to get a qualitative comparison of the mixing between the gases and the secondary combustion air for the two configurations of secondary air supply. The results shows that the later configuration gives better mixing between the gases and the secondary air. This is also verified from experimental results which shows that the emission of unoxidised combustible gases (CO) is less for the later configuration. This is a result of the better mixing.

Two models that include the combustion process has been tested. One is the "Mixed is burnt" combustion model which assumes that fuel and oxidant cannot coexist at the same place and time. This model does not take the temperature and time dependence of the reactions into consideration. Therefore the results of the calculations shows that all the combustible gases is completely oxidized before leaving the secondary combustion chamber. The other model that has been used include the chemical kinetics in a simplified way. This model takes time and temperature dependency into consideration when calculating the reaction rate. For the calculations the combustible gases has been assumed to consist of carbonmonoxide which reacts with the oxygen in the combustion air to form carbondioxide. The results of these calculations show that the emission of carbonmonoxide is 13 ppm which is in the same order as the experimentally measured emissions despite the fact that only one reaction for the carbonmonoxide to form carbondioxide is included.

The results of the calculations show that CFX is an excellent tool for simulating combusting flows in complex geometry's like furnaces and stoves. In short time it is possible to evaluate

how different configurations will affect the combustion process. In practical research for development of improved designs, the use of this tool, even in the present primitive form, can save considerable time and money that would otherwise be spent on trial and error experiments. By using the chemical model it is possible to estimate the emissions of different species. Although the complete list of combustible gases and their reaction paths to form products should be included to get more exact predictions.

Rapport/study Kväveoxidemissioner från mindre biobränsleeldade rostpannor - en litteraturstudie	*English title* Nitrogen oxide emission from small-scale biomass boiler	
Författare/ author Daniel Olsson	*Organisation* Chalmers University of Technology	
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14 ER 12:1999	*Fax* +46 31 772 3592	*Summary (pages)* 1 (2)

SUMMARY

A literature study has been carried out to find mechanisms for control of nitrogen oxide emissions from small-scale biomass fired combustion devices. The underlying nitrogen chemistry has been studied. Three paths of nitrogen oxide formation has been identified:

- Thermal NO_x
- Prompt NO_x
- Fuel NO_x

Out of these three mechanisms only fuel NO_x is of interest, and the others are neglected at the temperature level concerned.

The results from this study have been used to identify limitations and possibilities for NO_x and CO abatement. A beacon has been to find efficient methods for NOx abatement at the same time as complete burn-out of the fuel is of greatest importance.

The NO_x abatement work of many of the Swedish manufacturers of small-scale combustion devices is described. This gives valuable insight in the practical possibilities and limitations in strive for low NO_x emissions.

From the literature and the contacts with manufacturers some factors of great importance for NO_x emission control have been identified. These are:

- The fuel (nitrogen content, shape, size, the height of the fuel layer and the tendency of the fuel to stick).
- The stoichiometry in the volume above the fuel bed (should be 0.6 - 0.8). The mixing of the gases above the fuel bed.
- The mixing of tertiary air into the main gas flow.
- The thermal load of the combustion chamber (residence time).

All the secondary measures studied but selective catalytic reduction have been rejected. Selective catalytic reduction could be a possible solution to the NO_x emission problem if it is necessary to further lower the emissions from these small-scale biomass combustion devices despite the cost.

Rapport/study Eldningstester med olika pelletskvalitéer	*English title* Combustion tests with different pellets diameters	
Författare/ author Albert Bachs, Jan-Erik Dahlström Henrik Persson och Claes Tullin	*Organisation* ENVIVE AB JEDBiosol AB SP Swedish National Testing and research Institute	
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15 ER 7:1999	*Fax* +46 5453 1001	*Summary (pages)* 1 (1)

SUMMARY

Eight different pellet qualities with the diameters 6, 8 and 10 mm, from eight different producers has been tested in three pellet burners and two pellet stoves. The objective was to investigate how different diameter affect the emissions of CO, OGC and NO, Previous experience has indicated that could have significant importance for the combustion. This was not verified in the study. It showed contradictory that the diameter has a minor effect on the combustion result.

The study shoves that different combustion equipment give different emission. For e g hydrocarbon emissions the difference is a factor 2,2 between the "best" and the "worst" equipment fired on full load. The difference increases to 2,7 with lower load. The choice of fuel has a big importance for the quality of the combustion. For hydrocarbons the emissions could in an extreme situation differ with a factor 25 between "best" and "worst" fuel. More normally the difference is about a factor five.

Nitrogen oxide emissions are to a major part related to the nitrogen contents in the fuel. The difference between the "best" and "worst" fuel is in the range of a factor two. Tests with the same fuel in different equipment gives a variation of 20-30%.

The combustion result depends on both the pellet quality and the equipment and there is no fuel that is good in al equipment. The big variation in combustion results shows that there is a big indifference between fuels used for small scale heating.

Rapport/study P-märkning av pelletskaminer, utveckling av kvalitetsmärkningssystem	*English title* P-marking system , a quality marking system for pellet stoves	
Författare/ author Lennart Gustavsson, Henrik Persson, Jörgen Andreasson, Albert Bachs, Björn Björkman, Jan-Erik Dahlström och Bengt-Erik Löfgren	*Organisation* SP Swedish National Testing and research Institute ENVIVE AB Äfab	
Address Box 857, SE-501 15 Borås Box 8006, SE-650 08 Karlstad Lotsgatan 6, SE-531 30 Lidköping	*Telephone* +46 33-16 55 23 +46 54 53 33 50 +46 510 262 35	*E-mail* lennart.gustavsson@sp.se ab@envive.se bengtlovfgren@hotmail.com
16 ER 9:1999	*Fax* +46 33-13 19 79	*Summary (pages)* 1 (1)

SUMMARY

A quality marking system for pellet stoves with a nominal heat output of max. 15 kW has been developed. The system is a P-marking system, which means that SP, Swedish National Testing and Research Institute, is responsible for the certification system. Certification rules and test method have been elaborated in cooperation with manufacturers of pellet stoves and with the authorities concerned. A project group has managed the work, which has been conducted with funding from Swedish National Energy Administration.

To replace electrical heating of small houses is today a high priority task. An interesting alternative is to install a pellet stove, provided with an automatic fuel feed system and which can cover a considerable part of the heating demand. This technique is today established in USA. In Sweden the interest is increasing rapidly, partly because of a greater access of pellet fuel and partly because of recent political proposals. Today there is no established, complete system for quality marking or approval of pellet stoves. It has therefore been considered important to develop such a system.The certification rules defines technical requirements with regard to safety functions, efficiency, emissions and operational reliability. Requirements concerning technical documentation and the contents of installation and operating instructions as well as concerning quality assurance in the manufacturing process are also formulated. The system also includes requirements on surveillance inspection.

The technical requirements have been discussed with the manufactures during a number of meetings. The certification rules and the test method have also been circulated for consideration at two stages. The authorities concerned and other parties have also expressed their views under way. The test method has been validated on seven different stoves during the course of the project.

Rapport/study Matematisk modellering med inriktning på förlopp i biobränsleeldade småpannor	*English title* Mathematical modelling of combustion related processes occurring in small-scale, log-fired boilers	
Författare/ author Jenny Larfeldt Bo Leckner	*Organisation* Chalmers University of Technology	
Address SE-412 96 Göteborg	*Telephone* +46 31-772 14 31	*E-mail* energy.conversion@entek. .chalmers.se
17 NUTEK-projekt nr P-810-1	*Fax* +46 31 772 3592	*Summary (pages)* 1 (1)

SUMMARY

This report treats mathematical modelling of combustion related processes occurring in small-scale, log-fired boilers. A model of the drying and pyrolysis of a single log of wood, a model of gas phase combustion reactions and a model of the elementary composition of fuel released from a log-fire have been developed and used

Rapport/study Rökgasåterföring till pelletsbrännare	*English title* Recycling flue gas in pellets burner	
Författare/ author Bengt- Erik Löfgren; Tommy Blohm;	*Organisation* Äfab Milab	
Address Lotsgatan 6, SE-531 30 LIDKÖPING Box 6008, SE-580 06 LINKÖPING	*Telephone* +46 510 262 35 +46 13 311 604	*E-mail* bengtlovfgren@ hotmail.com tommy.blohm@milab.se
18 ER 11:1999	*Fax* +46 510 252 35	*Summary (pages)* 1 (1)

SUMMERY

Operational problems are often encountered in small scale pellet burners because combustion leads to ash collecting where the pellets are burned. This ash can then sinter gently or disturb the air supply through the pellets' bed in some other way. Modern domestic pellet burners usually use the primary air to transport the ash away from the combustion zone. Lower efficiency is associated with a reduced airflow, and thus with the ability of the burner to keep the combustion zone free. Disturbances to the airflow have become an issue. In addition to these operational problems, technical problems associated with combustion can arise that affect both the efficiency level and the environmental performance.

When problems do arise, they often occur in combination with changes in the load. That is to say, in connection with starting and stopping the burner, or when the required output for the building is rapidly changed. To meet this change in demand, the producers try different solutions based on rapid starts and stops and/or trying to run the burner in a modified manner. In larger burners it is not uncommon for the exhaust to be recycled to regulate the combustion.

In many of the pellet burners used today there is a considerable surplus of air when one tries to reduce a burner's power output, and almost all burners have problems with the collection of ash.

The aim of the study
By recycling flue gases and mixing them into the air being used for combustion, one ought to be able to control and regulate the results of the combustion process and, through this, influence the efficiency and the environmental performance. The aim of this preliminary investigation was to *study the influence of recycling* on the output from the combustion, particularly with regard to the air surplus**,** turbulence and stability. Of additional interest were the influence recycling had on the excess air and environmental performance (CO and OGC).

Furthermore, the aim has been to ascertain the possibility of being able to govern the admixture of recycled flue gas in the combustion process automatically using a lambdasond

and O_2-regulation. This could be the opening for a whole new generation of small pellet burners with an improved and more stable production, with a good environmental performance and that can automatically correct for disturbances to the air flow from different sources, from uneven pellet quality or from a changed output.

Results

Our test results show that recycling of flue gas *has a positive influence* on the combustion results. The technique is very interesting for the regulation of combustion in small pellet burners and to achieve good combustion performance, even when a variable and/or low load is required. Recycling the flue gas back into the combustion results in a number of technical advantages:

- Higher temperature of the air being combusted gives a more rapid combustion process.
- The more stable gas flow through the burner gives similar turbulence for different loads and improved removal of the ash.
- Better use of fuel in the combustion zone.
- Lower air surplus and lower emissions of CO and THC.
- Reduced sensitivity to unevenness in the pellet quality.

However, our investigations do also show that there are difficulties associated with controlling the regulation by only regulating the O_2. Recycling influences the flow of flue gases and therefore the draught conditions in the burner, which in its turn *strongly influences the combustion results*. In certain cases, these relationships disturb and counteract each other to such an extent that the desired regulatory effect completely disappears. We have attempted to install a simple flap against counter draughts in the exhaust pipe, but although this has improved the situation considerably, *it is probably not enough* to completely compensate for the changes in under-pressure .Thus, on the downside, one must note:

- It is likely that automatic compensation for under-pressure would be absolutely necessary.
- Regulation puts a higher demand on the competence of the installer.

2 Ongoing studies

ongoing studies Optimerad ved/pelletspanna med rökgaskondensering: Förstudie	*English title* Flue gas condensation in a domestic boiler burning wood logs or pelletised wood - a prestudy	
Författare/ author Niklas Berge, Magnus Berg *Address* Studsvik, SE-611 82 Nyköping	*Organisation* TPS Termiska Processer AB *Telephone* +46 155 2213 79	*E-mail* niklas.berge@tps.se
2.1	*Fax* +46 155 26 30 52	*Summary (pages)* 1 (1)

SUMMARY

The aim of this ongoing prestudy is to investigate the feasibility of using flue gas condensation in a domestic boiler burning wood logs or pelletised wood. Flue gas condenser has been used for some period in natural gas or oil-fired small-scale boilers but has been avoided in wood burning systems due to high ash and tar content in flue gas. With pellet-firing or catalytic flue gas cleaning the tar en-fission is in general so low that this is no obstruction.

Calculations prove that with normal moist wood there is a significant gain in boiler efficiency when reducing the flue gas temperature from today's 150-250^{o}C. In particular when part of the steam in the flue gases is condensed the efficiency gain can be of the order of 10% or more.

One possible advantage with a flue gas condenser is the particle collection on the water film on the cooling surfaces but also other combustion products can be collected such as heavy hydrocarbons, organic acids etc. As dry wood is used in this kind of applications the amount of condensed water at normal condenser temperatures are low.

In the project an existing boiler at TPS laboratory has been equipped with a condenser and the experimental work is just to be started.

ongoing studies Katalytisk minskning av utsläpp från småskalig vedeldning	*English title* Development of catalysts for abatement of the emissions from small-scale combustion of wood	
Författare/ author Emilia Björnbom and Magali Ferrandon	*Organisation* Royal Institute of Technology	
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2.2	*Fax* +46 8 10 85 79	*Summary (pages)* 1 (1)

SUMMARY

The goal of the project is to develop catalysts for abatement of the emissions from small-scale combustion of wood. The idea is to convert the harmful compounds (mostly organic compounds and carbon monoxide) in the flue gases into harmless products such as carbon dioxide and water. Using catalysts the conversion may be realised at moderate temperatures thus avoiding the risk for formation of nitrogen oxides.

The catalysts, which have been studied so far are selected among the well known catalysts for total oxidation of organic compounds. They contain noble metals, metal oxides or combinations of both of them. The latter are in the focus of our interest. These catalysts are much cheaper than the catalysts based only on noble metals, such as platinum and palladium. Moreover these catalysts have sufficient activity and most of them have high thermal stability and resistance to chemical deactivation, which is of importance for their practical application.

ongoing studies Katalytisk reduktion av emissioner från småskalig förbränning av biobränslen	*English title* Catalytic abatement of emissions from small-scale combustion of biofuels	
Författare/ author Magnus Berg	*Organisation* TPS Termiska Processer AB	
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2.3	*Fax* 0155-22 13 98	*Summary (pages)* 1 (1)

SUMMARY

The aim of the project is to develop the technology for catalytic abatement of emissions from small-scale combustion of biofuels. Both commercially available catalysts and catalysts developed by the other partners within the project group (KTH and KATATOR) have been used to optimise the integration of different catalysts in a domestic boiler. Together with primary measures, which reduced the concentrations upstream of the catalyst, very low emissions of unburned could be achieved. The conversion over the catalyst was over 80% and the mean value of CO over the standard testing period was below 200 ppm. The risk of plugging due to fly ash in the flue gas as well as the long-term deactivation were also evaluated. In the continuation of the project the lifetime of the catalyst will be further evaluated. As part of this investigation field tests are planned in collaboration with boiler manufacturer.

ongoing studies Katalytiska metoder för begränsning av skadliga utsläpp från förbränning av biobränslen - Etapp II	*English title* Catalytic abatement of emissions from small-scale combustion of biofuels	
Författare/ author Tihamer Hargitai, Fredrik Silversand m.fl.	*Organisation* KatatorAB	
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2.4	*Fax* 046-286 22 99	*Summary (pages)* 1 (1)

SUMMARY

Activity measurements show that most detrimental emissions from small-scale combustion of bio-fuel are easily combusted at temperatures between 200, and 500 ^{o}C on suitable catalysts. The main problem by using catalyst in this application are different deactivation processes. Deactivation is mainly caused by fouling mechanism, where alkaline-aerosol-particles are deposited onto the catalyst's surface, thus causing increased resistance to mass transfer. Alkaline deactivation increase linearly with time and dramatically with the temperature. Studies have shown that the catalyst temperature should be limited to 500 ^{o}C operation temperature to avoid rapid alkaline deactivation. It is however possible to regenerate the catalyst completely by means of a simple washing procedure with acidified water. With the present knowledge it is necessary to regenerate the catalyst 5 times every season.

ongoing studies Katalytisk reduktion av emissioner vid småskalig förbränning av biobränslen - åldring och applikation	*English title* Catalytic abatement of emissions from small-scale combustion of biofuels	
Författare/ author Mikael Ohlsson och Sven Järås	*Organisation* KTH, Royal Institute of Technology	
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2.5	*Fax* +46 8 108579	*Summary (pages)* 1 (1)

SUMMARY

The goal of this project is to develop catalyst that fulfil the requirements of activity and pressure drop that is needed with special attention to the agening phenomena. Specially metallic carrier and ceramic cordierite will be used. Of the emission most attention will be paid to the CO, PAH and a representative alkene. Ageing phenomena are thermal ageing, pore plugging by coke, poisoning by S, ash and other poisoning compounds present. The real life time of a catalyst will be determined. The catalyst will be prepared as metallic monoliths with washcoat and active phase. The catalyst will be tested by combustion of simulated and real emissions from wood-stoves.

ongoing studies Partikelemissioner vid biobränsleförbränning - förstudie	*English title* Particle emissions from biomass combustion	
Författare/ author Claes Tullin, Johan Johansson, Mathias Johansson, Pernilla Svedberg	*Organisation* SP Swedish National Testing and research Institute	
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2.6	*Fax* 033-13 19 79	*Summary (pages)* 1 (1)

SUMMARY

Air-borne particles occur naturally but are also a result of anthropogenic activities such as combustion. Particles of 10 gm or less can be inhaled and the particle size is important for possible health effects. This study discuss the knowledge concerning particle emissions from combustion with special emphasis on small scale biomass combustion. Particle measurements from some preliminary tests are also reported.

ongoing studies Utveckling av fältmetod för utvärdering av emissioner från villapannor och lokaleldstäder	*English title* Methods for approximate determination of emissions from wood-fired domestic boilers and stoves	
Författare/ author Lennart Gustavsson, Mattias Viktorsson, Mathias Johansson	*Organisation* SP Swedish National Testing and research Institute	
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2.7	*Fax* +46 33 13 19 79	*Summary (pages)* 1 (1)

SUMMARY

Methods for approximate determination of emissions from wood-fired domestic boilers and stoves have been evaluated. The purpose is firstly to approximately quantify emission levels from boilers/stoves which has not been laboratory tested and secondly to indicate if there are shortcomings in installation or use in a case where the appliance have been proven to fulfil emission requirements in laboratory tests.

Three possible measurands and equipment's have been evaluated: soot number, total hydro carbon content (THC) and carbon monoxide content (CO). Of these, CO was deemed to be most appropriate. Equipment which is used by chimney sweepers in Germany for measurements on small solid fuel appliances have been evaluated. The equipment has been deemed as
adapted to field conditions and this method is therefore recommended for use also in Sweden.

ongoing studies Förbränning av pellets: en experimentell studie av olika parametrars betydelse för förbränning och emissioner	*English title* Combustion of pellets: Experimental study	
Författare/ author Claes Tullin, Jörgen Andréasson och Henrik Persson	*Organisation* SP Swedish National Testing and research Institute	
Address Box 857; SE-501 15 Borås	*Telephone* 033-16 50 00	*E-mail* claes.tullin@sp.se
2.8	*Fax* 033-13 19 79	*Summary (pages)* 1 (1)

SUMMARY

The objective with this project is to perform well defined laboratory experiments in order to investigate the behaviour of a refined fuel particle during drying, pyrolysis/devolatilisation and simultaneous combustion under various combustion conditions. For this purpose, an experimental equipment has been developed and taken into operation. Experimental methods have been developed, for instance for the determination of the time resolved tar evolution. The conversion of fuel nitrogen to nitrogen oxides (NO_x) passes over intermediates such as ammonia () and hydrogen cyanide (HCN). The nitrogen chemistry will be studied in detail by means of a high performance FTIR-spectrometer. Preliminary measurements indicate that both NH_3, and HCN form during the pyrolysis/devolatilisation. The final NOx emissions are probably governed by both the concentrations and ratio of NH_3, and HCN.

ongoing studies Färbränningsförlopp i en bädd av biobränsle	*English title* Combustion process in a biomass fuel bed	
Författare/ author Monica Axell, Marie Rönnbäck, Lennart Gustavsson, Henrik Persson Bo Leckner	*Organisation* SP-Swedish National Testing and Research Institute Dep of Energy Conversion, Chalmers University of Technology	
Address Box 857, SE-501 15 Borås CTH, SE-412 96 Göteborg	*Telephone* +46 33-165000 +46 31 772 14	*E-mail* monica.axell@sp.se, marie.ronnback@sp.se energy.conversion@entek.chalmers.se
2.9	*Fax* +46 33-131979	*Summary (pages)* 1 (1)

SUMMARY

The aim of the project is to develop the understanding of the combustion process in a biomass fuel bed. The report gives a short description of performed and planned activities. The main focus of the project is on experimental studies. A test rig has been constructed and taken into operation. Measurement techniques have been developed, for instance a oil-cooled dilution probe for gas analysis. Tests are performed as parameter studies where the influence of primary air flow and size of the fuel particles is studied. The results show how the local stoichiometry affects the gas composition after the bed and the temperatures in and after the bed for a given particle size. The results form a general description of the combustion process in a fuel bed

ongoing studies Rosterförbränning av biobränslen	*English title* Solid-fuel combustion systems	
Författare/ author Rasmus Friberg	*Organisation* Institutionen för Metallurgi, Avd för Värme- och ugnsteknik, Royal Institute of Technology	
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2.10	*Fax* 08-205 204	*Summary (pages)* 1 (1)

SUMMARY

This project is on its fourth year and shall result in a PhD for Rasmus Friberg, doctoral student. The project consists of five stages: 1) Develop a new system theory for conventional solid-fuel combustion systems, 2) Mathematical modelling of a measurement method to quantify a target variable defined in stage 1, 3) Construct the experimental system and verify the measurement method, 4) Experimental serie, and 5) Write the PhD-thesis. Stage one and two are reported and the third stage is more than half-way through. Stage three should be reported in the end of August-99, according to time plan. Lot of problems have arised in stage three. It is measuring devices which have not function according to specification, which has implied that the measurement method needed to be modified with delays around one year as a consequence.

A new system theory called the three-step model was developed in stage one. Some interesting dimensionless variables have been defined, which are measurable quantities, whose aim is to give information about the environmental performance and thermal efficiency. The long term goal is that this theory should result in improved knowledge in the design of more efficient small scale biofuel fired systems.

ongoing studies Modellering av enstaka biobränslepartiklar för förbränning i småskaliga eldstäder	*English title* Modelling of single fuel particles for use in small-scale combustors	
Författare/ author Bo Leckner	*Organisation* Dep of Energy Conversion, Chalmers University of Technology	
Address SE-412 96 Göteborg	*Telephone* +46 31-772 14 31	*E-mail* energy.conversion@entek. .chalmers.se
2.11	*Fax* +46 31 772 3592	*Summary (pages)* 1 (1)

SUMMARY

This work deals with modelling of drying, devolatilazion and combustion of single fuel particles for use in small-scale combustors «10 MW_{th}). The fuel models treat spheres, cylinders and slabs of sizes varying from pellets to wood logs. Initially models of different complexities have been compared with measurements showing good agreement. Seemingly simple quantities, such as thermal conductivity and specific heat, are not sufficiently well specified in literature, which, together with some other factors, causes a minor uncertainly in the results.

ongoing studies CFD-modellering av mindre biobränslepannor	*English title* CFD modelling in small-scale biomass-fired boilers	
Författare/ author Anders Lönnermark	*Organisation* SP Swedish National Testing and research Institute	
Address Box 857, SE-501 15 BORÅS	*Telephone* +46 33 - 165691	*E-mail* anders.lonnermark@sp.se
2.12	*Fax* + 46 33 - 417759	*Summary (pages)* 1 (1)

SUMMARY

The objective of the present investigation is to gain knowledge about the parameters affecting the processes in the gas phase in a small-scale biomass-fired boiler. CFD modelling is used to study the influence of the boiler design and the addition of air on the temperature distribution, the flow pattern, the mixing processes, and the combustion taking place in the gas phase. The knowledge gained will constitute a foundation for decreasing emissions of nitrogen oxides and other substances injurious to health or harmful to the environment from small biomass-fired boilers. Especially the influence of the variation in boundary conditions at the grate is studied. So far, particularly the temperature distribution and the flow pattern have been studied.

ongoing studies	*English title* Simulation of Biomass Combustion in a Furnace	
Författare/ author N Griselin X S Bai L Fuchs	*Organisation* Division ofFluid Méchanics, Department of Heat and Power Engineering, Lund Institute of Technology	
Address SE-221 00 Lund, Sweden	*Telephone*	*E-mail* nico@ ms.vok.ith.se bai@ ms.vok.ith.se lf@ms.vok.ith.se
2.13	*Fax*	*Summary (pages)* 1 (1)

SUMMARY

This report summarises our recent work on biomass combustion modelling. First a brief review of different processes of biomass combustion in furnaces is provided. These basic processes include: (1) devolatilization, pyrolysis and gasification of biomass fuels (wood chips) in the bed; (2) mixing of the gas phase fuel and secondary air as well as heat transfer in the furnaces; (3) combustion of gas phase fuels with secondary air in the furnace; and (4) solid phase particle emission and combustion in the furnace, etc. We report here the model development in our group on the gas phase mixing, combustion and heat transfer in the furnace combustion chamber and the particle tracking and combustion. These models are applied to a small-scale biomass furnace and a 'larger' scale biomass furnace (40 MW) where the experimental data is available

ongoing studies	*English title* Computerised design tools for more environmentally friendly biomass boilers and stove	
Författare/ author Magnus Lundqvist Roger Hermansson	*Organisation* Division of Energy Engineering, Department of Mechanical Engineering, LuleåUniversity of Technology,	
Address SE-971 87 Luleå, SWED EN	*Telephone*	*E-mail* magnusl@mt.luth.se roger.hermansson@mt.luth.se
2.14	*Fax* +46 920 91047	*Summary (pages)* 1 (1)

SUMMARY

The commercial computer code CFX has been evaluated as a tool for designing future furnaces and stoves. Optimisation of a cylindrical secondary combustion chamber for a wood stove has been used as an illustrative example. The results of the calculations show that CFX is an excellent tool for simulating combusting flows in complex geometry's like those found in furnaces and stoves. In short time it is possible to evaluate how different configurations will affect the combustion process. In practical research for development of improved designs, the use of this tool, even in the present fairly primitive form, can save considerable time and money that would otherwise be spent on trial and error experiments. By using a chemical model it is possible to estimate the emissions of different species. For better modelling a complete list of combustible gases and their reaction paths to form products should be included.

ongoing studies Eldstadsrummets inverkan påemissioner från småpelletsbrännare	*English title* Influence of the furnace on the emission from small pellet burners	
Författare/ author Jenny Larfeldt	*Organisation* Termiska Processer AB	
Address Studsvik, SE-611 82 Nyköping	*Telephone* 0155-221308	*E-mail* jenny.larfeldt@tps.se
2.15	*Fax* fax: 0155-221398	*Summary (pages)* 1 (1)

SUMMARY

The influence of the furnace on the emission from two pellet burners have been tested in a small scale boiler for house heating. The boiler is representative for the Swedish households and the burners, upwards and forward burning, are commercially available on the Swedish market. The forward burning burner is shown to be less influenced by the furnace design compared to the upward burning burner. The upward burning burner showed comparatively high emissions of unburnt. However, it was possible to reduce the emissions from the burner using ceramic insulation of the furnace.

ongoing studies Eldningstester med olika pelletskvalitéer - Betydelsen av diametern på bränslepellets vid eldning i småskaliga anläggningar	*English title* The pellet size influences of the combustion in small scale burners and stoves	
Författare/ author Albert Bachs	*Organisation* ENVIVE AB	
Address Box 8006, SE-650 08 Karlstad	*Telephone* 054 533350	*E-mail* ab@envive.se *www.envive.se*
2.16	*Fax*	*Summary (pages)* 1 (1)

SUMMARY

Eight different pellet qualities with diameters of 6, 8 and 10 mm where studied by firing tests in three pellet burners and two pellet 4toves. In total 78 tests were carried out. The objective was to study how the pellet size influences the combustion and the emissions of hydrocarbons, carbon monoxide and nitrogen oxides.

The study shows that the size does not have any general influence on the emissions. The emission variations are big between the "best" and the "worst'" burners and stoves. The differences in hydro carbon emissions are a factor 2,2 between "best" and "worst" firing technologies. Looking at pellet fuel the difference between the "best" and "worst" fuel is even more drastic. A factor 25 differ the "best" from the "worst" pellet fuel.

ongoing studies Pyrolysmodell	*English title* Pyrolysis Model	
Författare/ author Michel Belais Truls Liljedahl, Krister Sjöström	*Organisation* KTH Royal Institute of Technology	
Address Institutionen för kemiteknik/Kemisk teknologi, SE-100 44 Stockholm	*Telephone* +46 8 7906602 +46 8 7908777 +46 8 7908248	*E-mail* michel@ket.kth.se truls@ket.kth.se krister@ket.kth.se
2.17	*Fax* +46 8 108579	*Summary (pages)* 1 (1)

SUMMARY

The aim of the Pyrolysis Model project is to develop a reliable pyrolysis kinetics model for large biomass particles for application in combustion. An additional aim is to determine the limits for the utilisation of thermobalance data with respect to studying pyrolysis kinetics. The model should account for the impact of particle size and surface temperature. It should also account for the char residue and the gas composition over time. Focus until now has been on surveying the literature and on the modelling of large particle pyrolysis. This implies the development of a preliminary one dimensional model based on the work by Gronli (1996). Experiments have been conducted in a thermobalance and in the single particle pyrolysis reactor developed by Physical Chemistry at Gothenburg University. In this latter reactor the weight loss and the gas composition can be monitored simultaneously and continuously

ongoing studies Konsekvenser av föreslagen CEN-Standard för braskamminer i fråga om utsläpp	*English title* Comparative tests of wood stoves according to a proposed CEN-standard and Swedish regulations	
Författare/ author Lennart Gustavsson Mattias Viktorsson	*Organisation* SP Swedish National Testing and research Institute	
Address Box 857, SE-501 15 BORÅS	*Telephone* +46 33-16 55 23	*E-mail* lennart.gustavsson@sp.se
2.18	*Fax* +46 33-13 19 79	*Summary (pages)* 1 (1)

SUMMARY

The project concerns comparative tests of wood stoves according to a proposed CEN-standard and Swedish regulations now in force. The comparison specially deals with emission of CO and unburnt hydrocarbons. The project has been postponed due to an ongoing revision of the standard proposal

ongoing studies Utvärdering av utsläpp från traditionella kakelugnar	*English title* Emissions of organic bound carbon (OGC) from typical traditional tiled stoves	
Författare/ author Lennart Gustavsson Mattias Viktorsson	*Organisation* SP Swedish National Testing and research Institute	
Address Box 857, SE-501 15 BORÅS	*Telephone* +46 33-16 55 23	*E-mail* lennart.gustavsson@sp.se
2.19	*Fax* +46 33-13 19 79	*Summary (pages)* 1 (1)

SUMMARY

The aim of the project is to determine the emissions of organic bound carbon (OGC) from typical traditional tiled stoves. Through defining the combustion related design, tests of a few types of tiled stoves with different exterios design. Test results from two tiled stoves, one circular and one rectangular, show that these well fulfil the emission requirements now in force.

ongoing studies Metoder för att mäta småråkgasflöden	*English title* Methods for measuring small flue gas flows	
Författare/ author Lennart Gustavsson, Magnus Jönsson, Henrik Persson	*Organisation* SP Swedish National Testing and research Institute	
Address Box 857, SE-501 15 BORÅS	*Telephone* +46 33-16 55 23	*E-mail* lennart.gustavsson@sp.se
2.20	*Fax* +46 33-13 19 79	*Summary (pages)* 1 (1)

SUMMARY

SUMMARY

Methods for measuring small flue gas flows (velocity 0,5 - 1 m/s) are studied. Possible alternatives are ultrasonic methods and trace gas methods. Conventional pressure difference methods are not possible because of the small pressure drops which can be achieved. Comparative tests with the ultrasonic method, the trace gas method and theoretical calculation of the flue gas flow have been made with a number of pellet burners at continuous and intermittent operation. The ultrasonic method requires relatively expensive equipment but is easy to use and facilitate continuous measurement. The correspondence with calculated values is acceptable in most cases. The feasibility of the trace gas method has not yet been fully evaluated.

ongoing studies P-märkning för fliseldningsutrustningar	*English title* P-marking, quality marking system, for small wood chip combustion equipment	
Författare/ author Lennart Gustavsson, Henrik Persson	*Organisation* SP Swedish National Testing and research Institute	
Address Box 857, SE-501 15 BORÅS	*Telephone* 033-16 55 23	*E-mail* lennart.gustavsson@sp.se
2.21	*Fax* 033-13 19 79	*Summary (pages)* 1 (1)

SUMMARY

A quality marking system, P-marking, for small wood chip combustion equipment is developed. The marking system should guarantees the safety of the equipment as well as minimum levels concerning emissions, efficiency and operational reliability. The P-marking system is developed with the corresponding system for pellet burners as a guidance. The system is developed in co-operation with manufacturers, users, insurance companies, the chimney sweepers as well as the authorities concerned.

ongoing studies Deltagande i International Energy Agency (IEA)	*English title* Swedish participation in International Energy Agency (IEA) - Biomass Combustion	
Författare/ author Claes Tullin Lennart Gustavsson	*Organisation* SP Swedish National Testing and research Institute	
Address Box 857; SE-501 15 Borås	*Telephone* +46 33-16 50 00	*E-mail* claes.tullin@sp.se
2.22	*Fax* +46 33-13 19 79	*Summary (pages)* 1 (1)

SUMMARY

On behalf of the Swedish National Energy Administration, SP participates in IEA Task 19-Biomass Combustion. The objective is to stimulate the utilisation of biomass by compiling and disseminate information regarding ongoing activities in the member countries. A work program has been initiated within Task 19 with the following projects: ash related problems during combustion, ash handling, classification of biomass fuels, compilation of ongoing mathematical modelling activities, combined heat and power production and state-of-the-art technology for biomass combustion. A national network is being formed and the information is communicated via internet.

ongoing studies	*English title*	
Författare/ author	*Organisation*	
Address	*Telephone*	*E-mail*
42	*Fax*	*Summary (pages)* 1 (1)

SUMMARY

ongoing studies	*English title*	
Författare/ author	*Organisation*	
Address	*Telephone*	*E-mail*
42	*Fax*	*Summary (pages)* 1 (1)

SUMMARY