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State-of-the-art concerning particle precipitation devices for residential biomass combustion systems

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Introduction (I)

- Particle precipitation devices for medium and large-scale biomass combustion plants are already state-of-the-art.
- During last years strong interest has arisen in the use of filters for small-scale biomass combustion systems, especially for residential biomass boilers and stoves, as it is already well known that in several European countries residential biomass combustion contributes with more than 80% to the total PM emissions of the residential heating sector.
- Up to now only a small number of particle precipitation devices (e.g. ESP) for small-scale biomass combustion systems has been introduced into the market.
- A considerable number of devices is presently under development and is expected to be demonstrated soon.

Introduction (II)

- **Common disadvantages of these systems are:**
  - **investment costs are relatively high compared to the costs of furnaces/stoves**
  - **most of the filters are developed and tested under good or acceptable combustion conditions**
  - **the operation behaviour of filters under poor combustion conditions is not sufficiently tested**

- **Up to now detailed studies concerning applications of different particle precipitation devices in small-scale combustion systems are scarce.**

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Objectives (I)

- **Within the ERANET FutureBioTec project a survey on the present state-of-the-art of particle precipitation devices for residential biomass combustion systems (nominal boiler capacity $<50\ kW_{th}$) in Europe has been performed in co-operation with IEA Bioenergy Task32.**

- **The work mainly focused on technologies which are already available on the market or which are close to market introduction with an emphasis on dry and wet ESP systems or a combination of ESP with scrubber/condensing systems. Ceramic filters and catalytic converters have also been investigated but are of minor relevance.**

- **The main objectives were:**
  - **collection and compilation of data**
  - **assessment of particle precipitation devices regarding applicability, availability and technical performance**

Objectives (II)

- Information concerning ongoing R&D projects, subsidies and necessary certificates for particle precipitation devices in the partner countries are given.
- Moreover, information concerning standards and specific problems of dust emission measurements are stated.
- Finally, techno-economic evaluations of the filters have been performed.

Methodology

- A literature survey as well as data available from manufacturers, data from the project partners as well as from national and international projects formed the basis of this survey.
- Evaluation of 13 electrostatic precipitators, 2 catalytic converters, 2 ceramic filters and 3 flue gas condenser from Austria, Finland, Germany, Liechtenstein, The Netherlands, Norway and Switzerland.
- In addition, the situation of particulate emissions in general as well as of dust emission limits for residential biomass combustion in the partner countries (Austria, Finland, Germany, Ireland and Sweden) are summarised.

Background – general issues

- The contribution of residential biomass combustion to the total PM emissions of the residential heating sector exceeds in some European countries 80%.
- Intense R&D activities regarding the development of particle precipitation devices are especially ongoing in Austria, Germany and Switzerland at present.
- Significant differences exist regarding the present total dust emission limit values for small-scale combustion systems in the partner countries (from no limits up to quite strict regulations).
- There are no dedicated PM_1 emission limit values existing for biomass fired combustion systems in the partner countries.
- **Stricter emission limits accelerate the technological development and the market introduction of particle precipitation devices.**

Background – dust emission measurements (I)

- There is no common international approach regarding PM emission measurements (usually gravimetric methods, e.g. according to VDI 2066).
- Some of the national regulations on residential combustion which include requirements for maximum particle matter (total dust) emissions do not define or refer to a specific method on how to determine particle matter emissions.
- A common European method to determine PM emissions has started within CEN (standardisation groups CEN/TC 57 and CEN/TC 295) during the last years, but no European Technical Specification or European standard has been achieved so far.
- Moreover, also for the determination of dust precipitation efficiencies of filters no common international approach exists so far. However, standard test method for determining the collecting efficiency of a particle precipitator is currently being elaborated in Germany (VDI Guideline 33999).

Background – dust emission measurements (II)

General aspects regarding measurements at ESP units

- The influence of charged particles on particle losses in sampling lines is not fully understood yet
  → more investigations are needed
- Filters at chimney top cannot be evaluated in the field concerning precipitation efficiency.
  → appropriate test stand tests are needed.
- At test stand measurements the field operation conditions of a specific filter have to be considered:
  - Position of the filter
    (directly coupled to the stove/boiler vs. chimney top)
    → position has strong influence on flue gas temperature and organic aerosol formation

Background – dust emission measurements (III)

General aspects regarding measurements at ESP units (continuation)

- At test stand measurements the field operation conditions of a specific filter have to be considered (continuation):
  - Temperature history between filter inlet/outlet (due to possible condensation of gaseous organic species)
  - Condensation issues if measurements take place after condensers or quench systems where flue gas temperature is at or close to the water dew point
  - Parallel measurements before and after filter

Results of technologies evaluated – electrostatic precipitators (I)

- **The ESP technology seems to be the most promising technological approach. Up to now a few number of ESPs for residential biomass combustion systems have been introduced into the market and some ESPs can be expected to enter the market soon.**

- **Mean total dust precipitation efficiencies of 50 to 90% can be achieved (single measurements between 11% to 92%). The particle precipitation efficiency strongly depends on the fuel utilised and the combustion technology (old/new system).**

- **An efficient and periodic cleaning of the ESP is of relevance - is done automatically (brush, vibration, water spray) or manually (e.g. by the chimney sweep).**

Results of technologies evaluated – electrostatic precipitators (II)

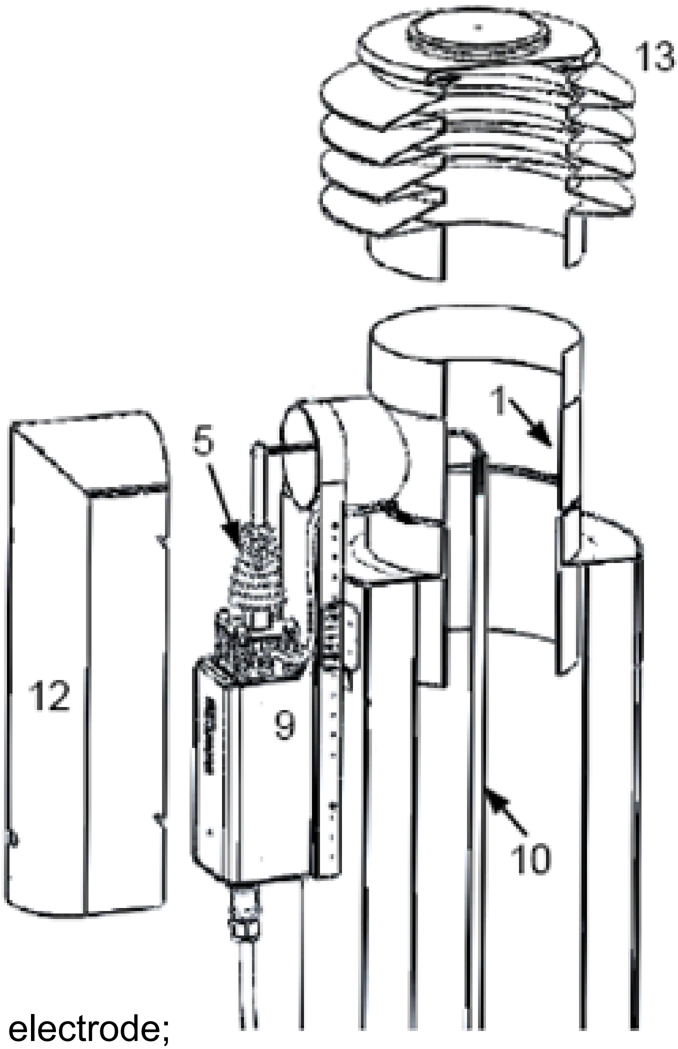
- **The ESP is installed in the flue gas pipe between furnace and chimney (left) or is mounted on top of the chimney (right).**

ESP AL-TOP/Schräder (Germany)

ESP OekoTube/OekoSolve (Liechtenstein)

Results of technologies evaluated – electrostatic precipitators (III)
Ökotube ESP – basic technological data

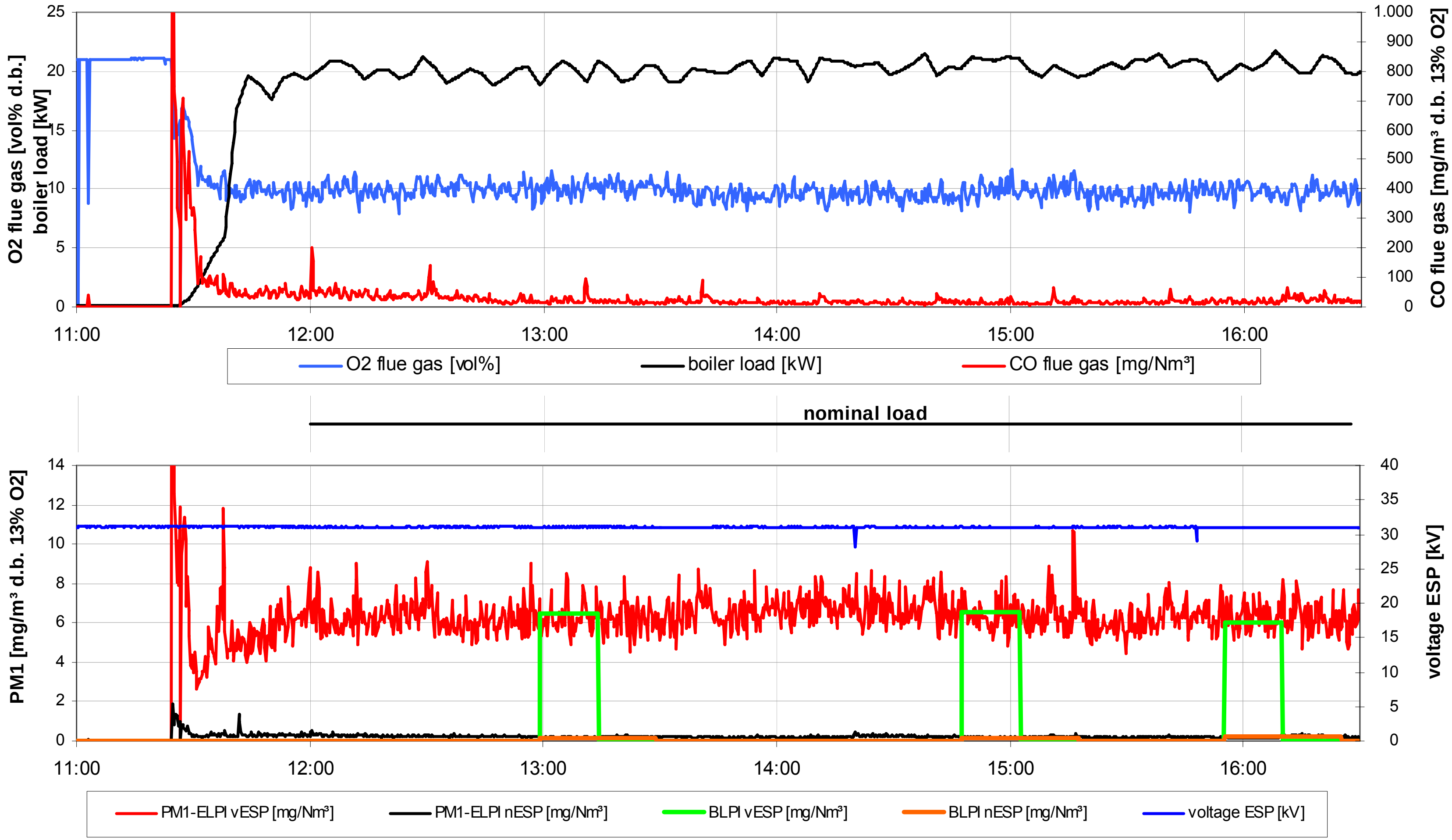
- **Description of technology:**
  - **tube-type electrostatic precipitator**
  - **unit is mounted on top of the chimney**
  - **power consumption: 20-30 W during operation**
  - **voltage of high-voltage power supply depends on depositions on electrode (15-30 kV)**
- **Field of application (according to manufacturer):**
  - **applicable for biomass combustion systems up to 70 kW**



Explanations: 1 ... metal tube; 5 ... insulator; 9 ... electronic circuit; 10 ... electrode; 12 ... ESP cover; 13 ... chimney hood

Results of technologies evaluated – electrostatic precipitators (IV)

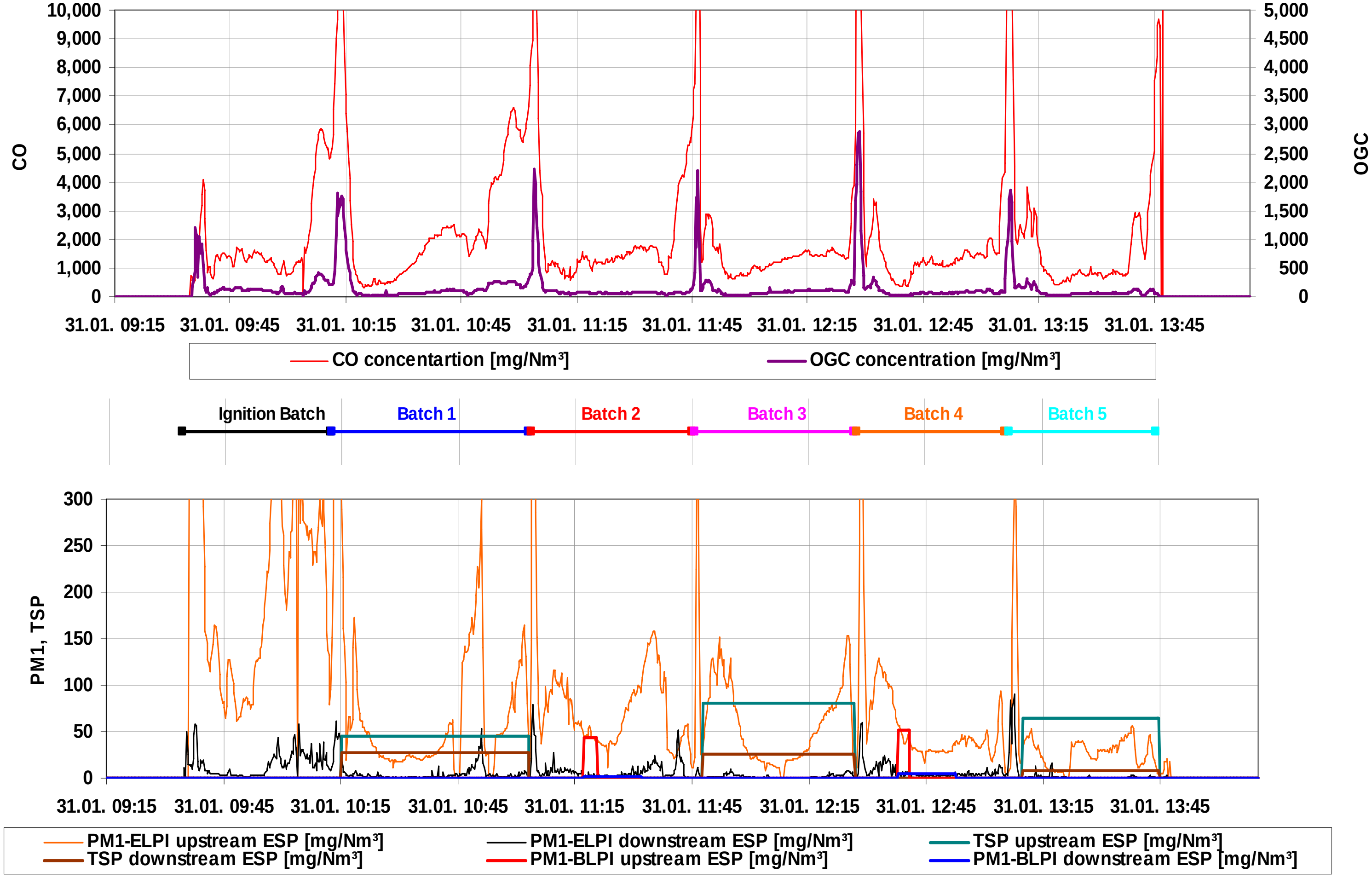
- Results of a test run with the ESP OekoTube – modern pellet boiler



Explanations: emissions related to dry flue gas and 13% O_2; test run with pellet boiler Windhager BioWin 210; ELPI: Electrical low-pressure impactor; BLPI … Berner-type low-pressure impactor; fuel: logwood (beech)

Results of technologies evaluated – electrostatic precipitators (V)

- **Results of a test run with the ESP OekoTube – old stove**



Explanations: emissions related to dry flue gas and 13% O_2; test run with wood stove Wamsler KF 108; ELPI: Electrical low-pressure impactor; BLPI … Berner-type low-pressure impactor; fuel: logwood (beech)

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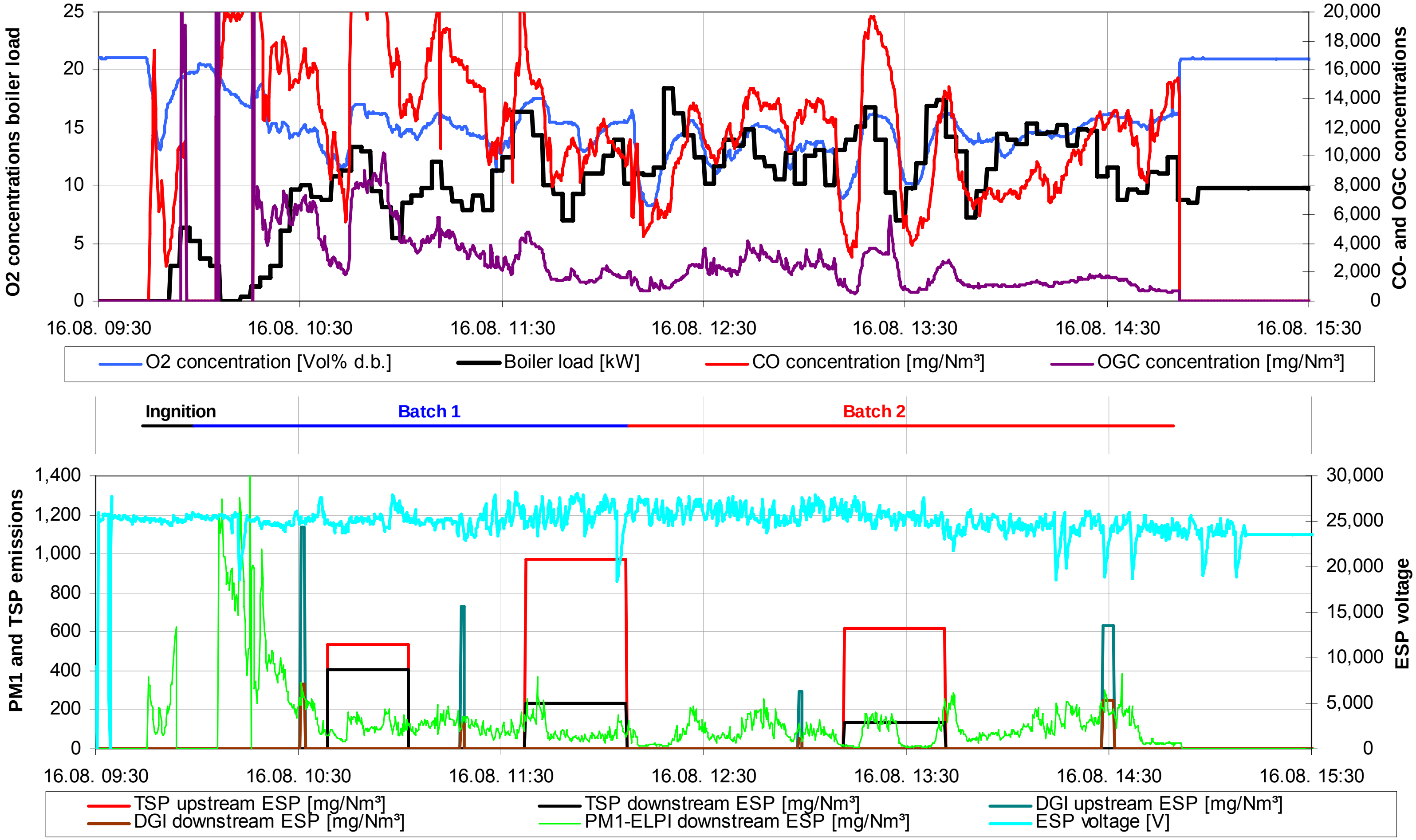
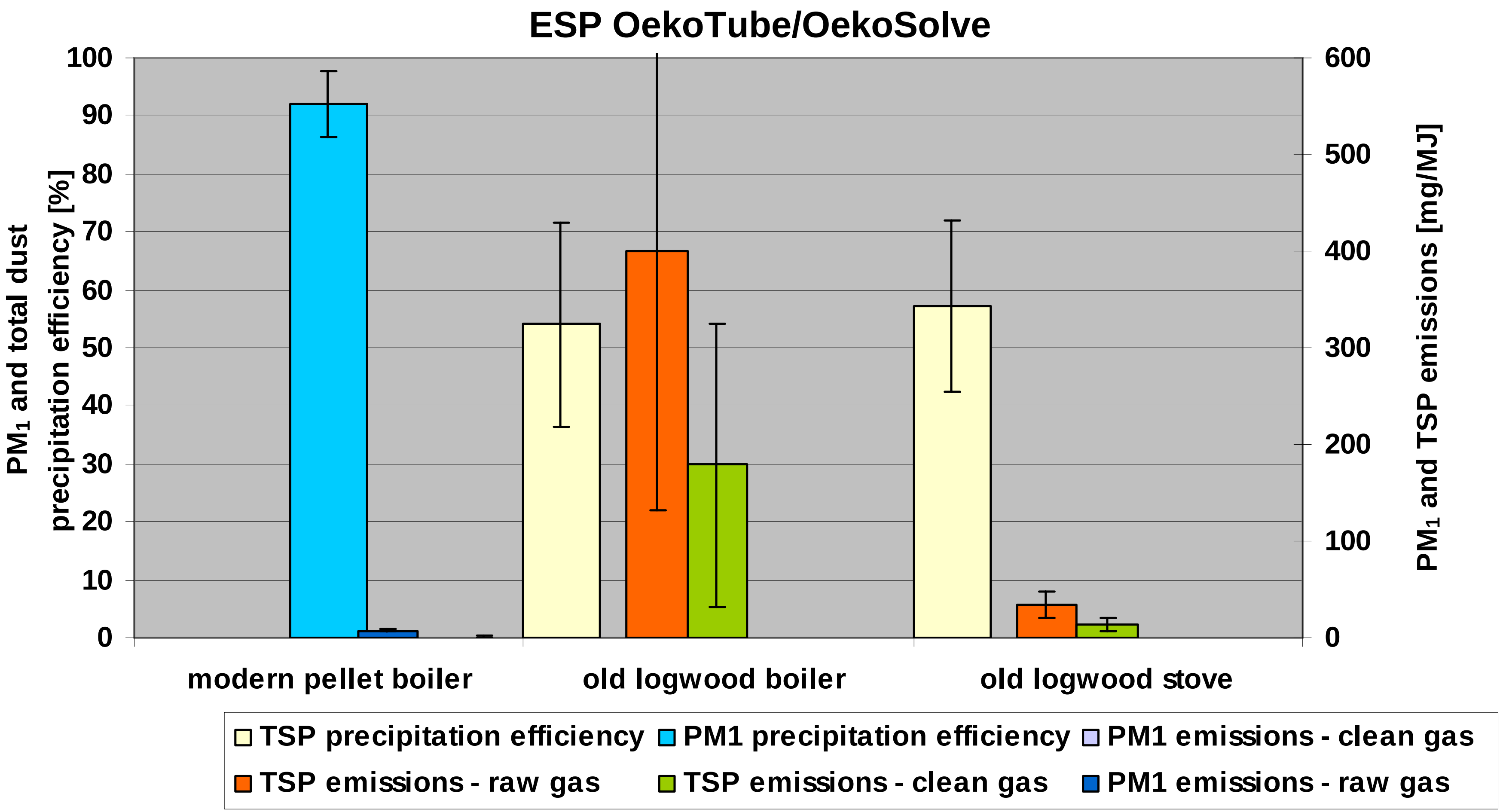
Results of technologies evaluated – electrostatic precipitators (VI)

▪ Results of a test run with the ESP OekoTube – old logwood boiler



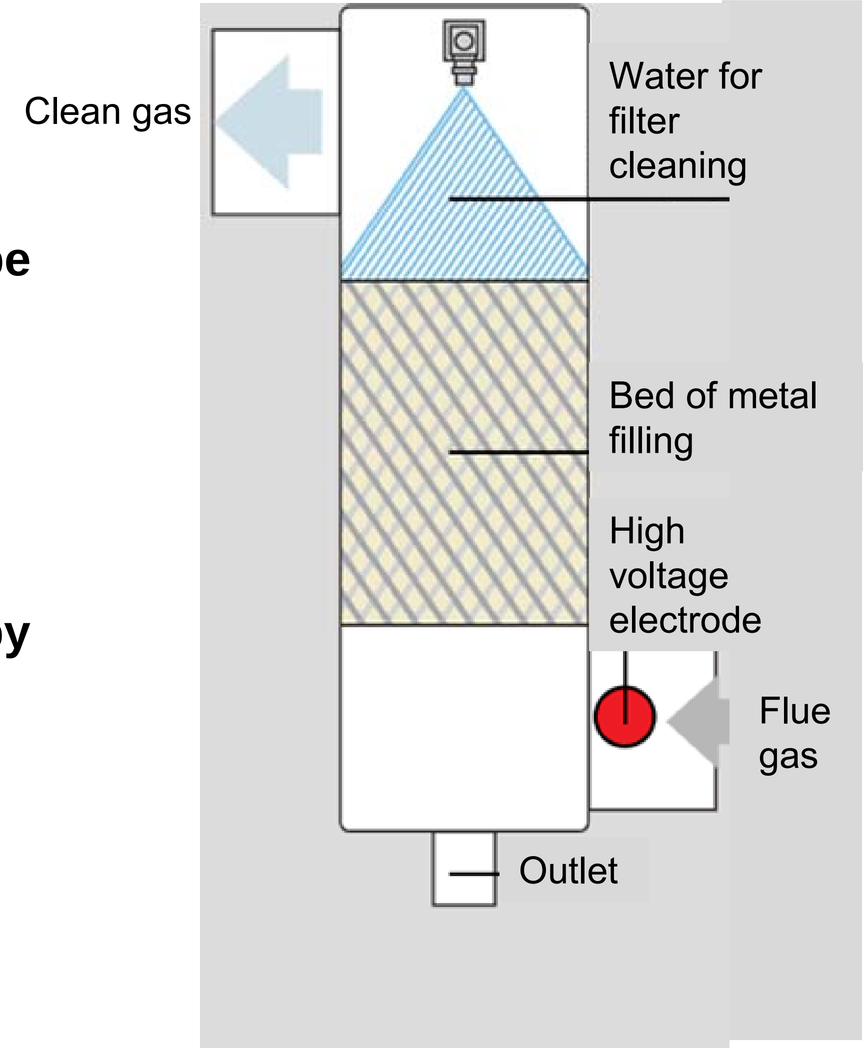
<u>Explanations</u>: emissions related to dry flue gas and 13% O_2; test run with old logwood boiler (Fröling); ELPI: Electrical low-pressure impactor; DGI … Dekati Gravimetric Impactor ; fuel: beech log wood

Results of technologies evaluated – electrostatic precipitators (VII)



Explanations: modern pellet boiler ... Windhager BioWin 210 (mean value of 12 measurements); old logwood boiler … Fröling (mean value of 8 parallel measurements); old logwood stove … Wamsler KF 108 (mean value of 9 parallel measurements); fuel: logwood (beech)

Results of technologies evaluated – electrostatic precipitators (VIII)
Al-Top ESP – basic technological data



- **Description of technology:**
  - **unit is installed in the flue gas pipe between furnace and chimney**
  - **electrostatic precipitator with metal filter bed**
  - **particles are precipitated within metal filter bed**
  - **filter bed is periodically cleaned by means of water spray**
- **Field of application (according to manufacturer):**
  - **for pellet and wood chip boilers from 15-150 kW**

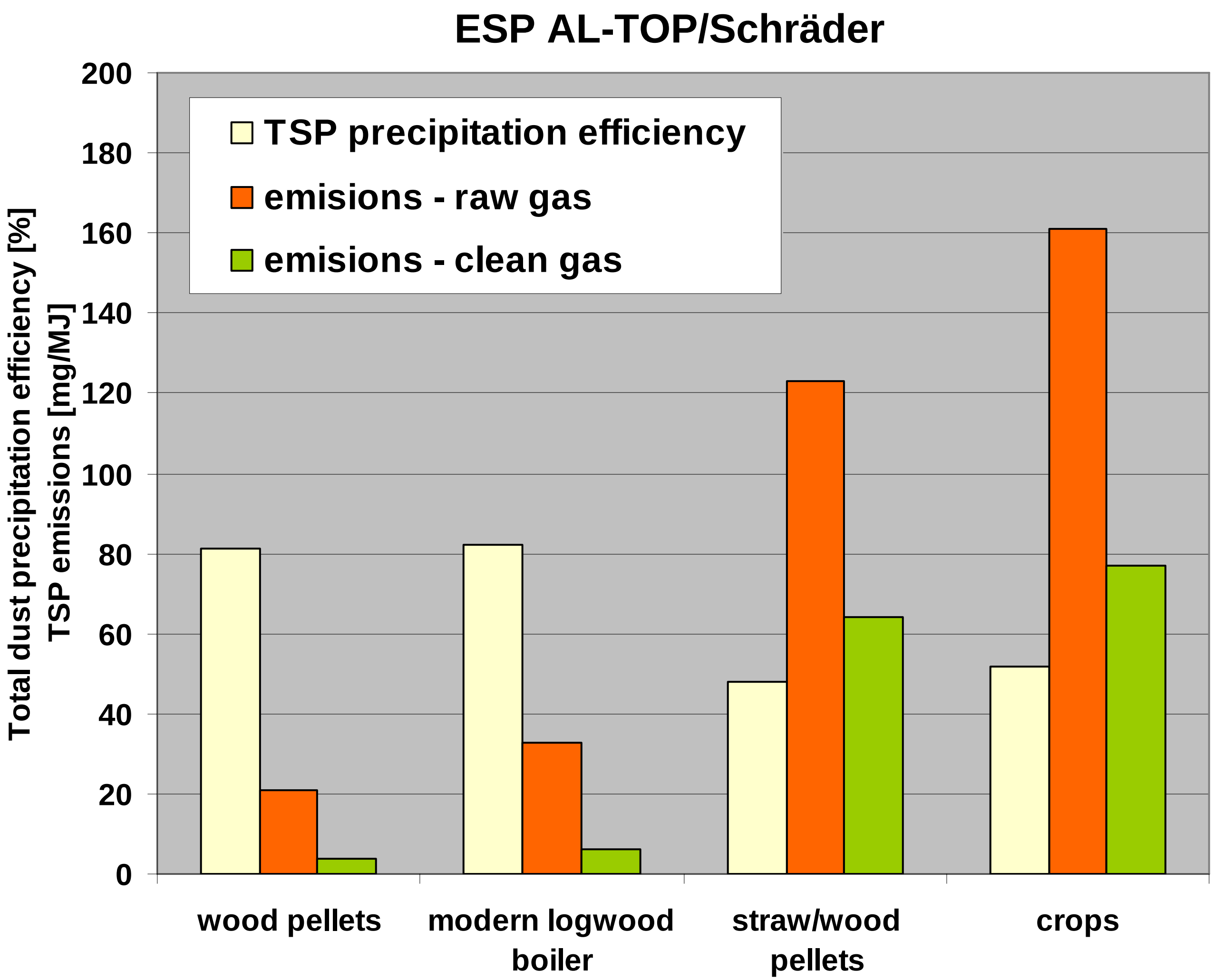
Results of technologies evaluated – electrostatic precipitators (IX)

ESP AL-TOP/Schräder

	PM	Filter OFF emissions [mg/Nm³ 13% O_2 d.b.]	Filter ON emissions [mg/Nm³ 13% O_2 d.b.]	Mean precipitation efficiency [%]	Precipitation efficiency - range [%]
wood pellets					
	PM_1	6.2	0.9	86.3	75 - 89.2
	TSP	7.3	2.0	73.1	65.3 - 76.1
willow chips					
	PM_1	123.4	9.2	92.5	87.8 - 94.9
	TSP	138.9	13.8	90.4	88.2 - 91.9

<u>Explanations</u>: voltage of high voltage electrode: 28 kV; test runs with new electrode at test stand by Teagasc

Results of technologies evaluated – electrostatic precipitators (X)



Explanations: test runs with old electrode at test stand performed by DBFZ Leipzig

Results of technologies evaluated – electrostatic precipitators (XI)

- Power consumption of ESPs: 10 to 100 W (mostly 10-30 W)
- Investment costs of ESPs: 1000 to 3000 €, excl. VAT (mostly 1,200-1,500 €)
- Most of the ESPs have been developed and tested under good or acceptable combustion conditions at test stands. Furthermore, up to now only a few long-term field test runs have been performed.
- The results of the FutureBioTec project show that the performance of the ESP systems evaluated is highest for modern pellet and modern logwood boilers and lower for stoves and old systems with poor burnout conditions as well as for agricultural fuels.
- Ongoing and future projects are focusing on the applicability of filters for old systems as they will be crucial for a broad market introduction of a specific technology.

Results of technologies evaluated – catalytic converters and ceramic filters (I)

- **Up to now no promising results have been achieved with catalytic converters for wood boilers and stoves. Due to the high flue gas temperatures required for catalytic oxidation, these devices are typically not available during start-up where typically the highest emissions occur.**
- **Catalytic converters should preferable be installed in the combustion chamber, where temperatures are sufficiently high to burn absorbed carbonaceous particles.**
- **In general, no information regarding deactivation of catalysts and their cleaning procedure are available.**

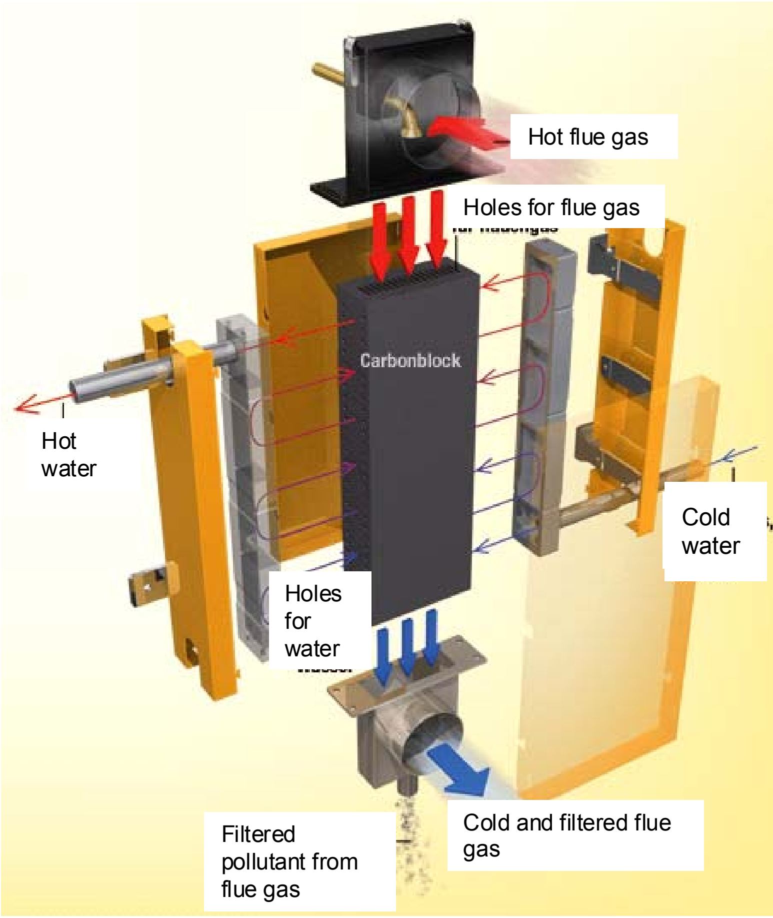
Results of technologies evaluated – catalytic converters and ceramic filters (II)

- The tested ceramic filters are installed in the upper part of the combustion chamber of modern chimney stoves. Thus, an evaluation of the filter itself is not possible. Comparisons with TSP emissions of other modern stoves show no relevant differences regarding TSP emissions. Therefore, the precipitation efficiency seems not to be very high.

- The pressure drop of a ceramic filter or catalytic converter may negatively influence the combustion behaviour of natural draft systems.

Results of technologies evaluated – condensing heat exchangers

- In general, the precipitation efficiency of conventional condensing heat exchangers is rather low (typically 10-20%).
- The main application of these systems is to increase the thermal efficiency of the boiler rather than to reduce particulate emissions.
- A specially developed high temperature condensing heat exchanger (UEF/Finland) can achieve a higher particle precipitation efficiency. The technology is still in the R&D phase.
- No information is provided by the manufacturers regarding the treatment of the waste water. A clear regulation regarding the treatment of the waste water exists only in some countries (e.g. Austria).



flue gas condenser Öko-Carbonizer - Bschor (Germany)

Conclusions and recommendations (I)

- In general particle precipitation devices are secondary measures and therefore could especially be attractive for old systems which show the highest particulate emissions.
- But these systems also show the most difficult framework conditions in terms of PM load, burnout quality of the particles and stickiness of particles.
- Therefore, the applicability of filters for old systems where really great particle reduction potentials are given is a special focus of future work.
- A second possible application for filters are stoves as the burnout quality of batch combustion systems with natural draft is not as good as of continuously operated systems.

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Conclusions and recommendations (II)

- For stoves filters which are directly implemented in the chimney or on top of the chimney are of special interest.
- The ESP technology seems to be the most promising technological approach for residential biomass combustion systems.
- For modern biomass boilers the main focus should be on the reduction of particulate emissions by primary measures.
- There is no common international approach regarding PM emission measurements and a common European method for the determination of filter efficiencies is urgently needed.

Conclusions and recommendations (III)

- In order to really introduce new residential filters in the market, the filters must be well tested and reliable. Furthermore, the filters must operate automatically over a whole heating period and must work efficiently.

- Besides the technological requirements, which still have to be proven for most applications, also legal and financial incentives will be needed to really achieve an effective market introduction.

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Thanks for your attention!

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