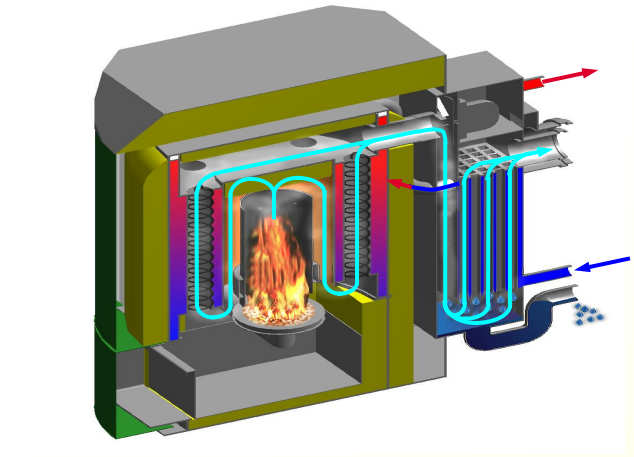
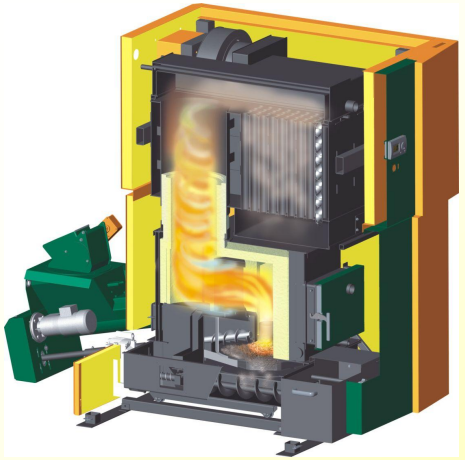
State-of-the-art of small-scale biomass combustion in boilers

Prof. Ingwald Obernberger





process & particle engineering

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- Technologies for small-scale biomass boilers
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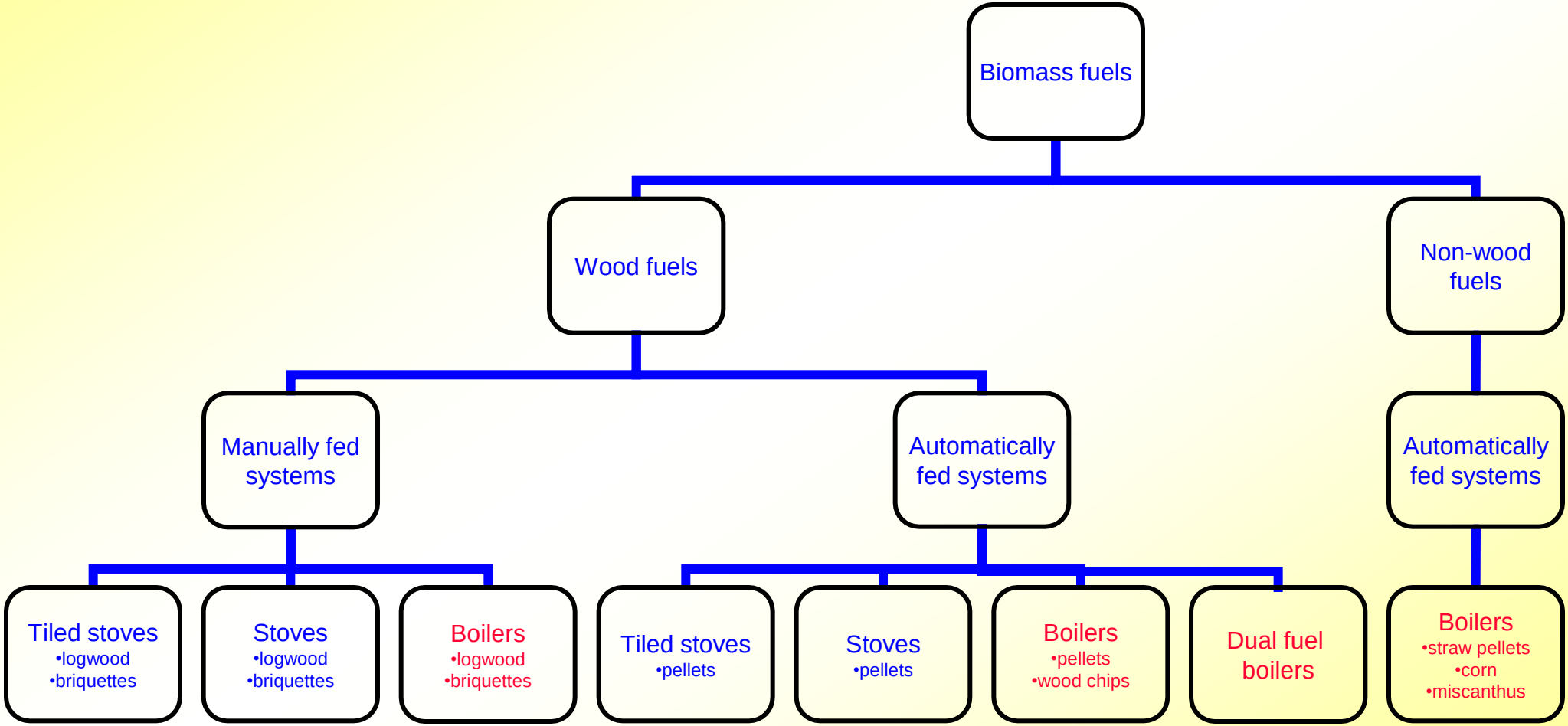
- Emissions from small-scale biomass boilers
- CFD based combustion design
- Summary and conclusions

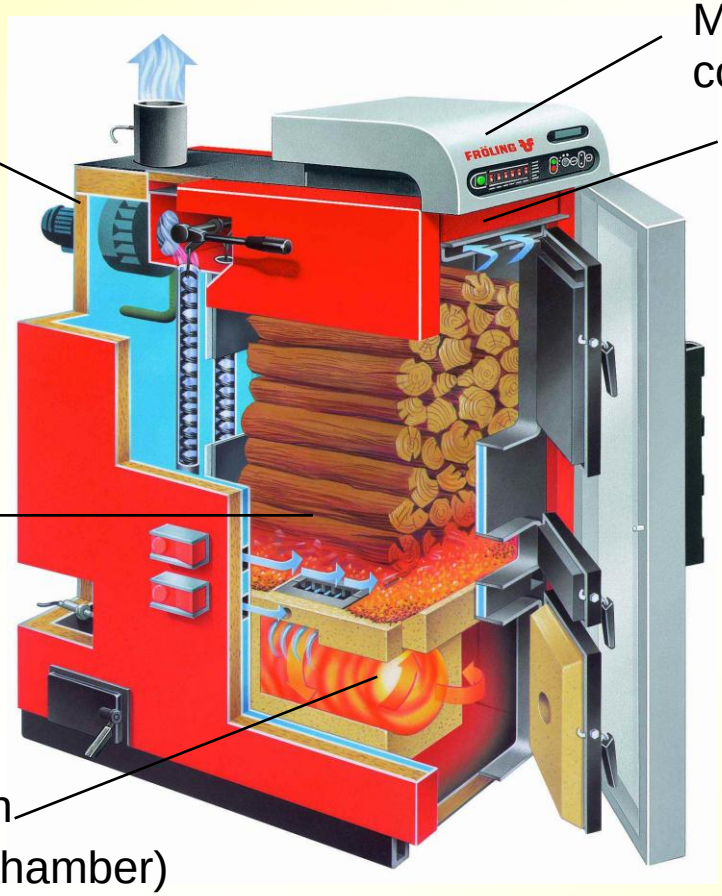
Classification of different small-scale biomass combustion system



Manually fed boilers for log wood (1)

- **State-of-the-art:**
  - Downdraft boilers
    (show a more stable combustion than in over-fire boilers (old technology))
- **Capacity range:**
  - Usually 15 to 70 kW
- **Fuels used:**
  - Wood logs with 33 or 50 cm length
  - Use of wood briquettes possible (not usual)
- **Features:**
  - Manual fuel loading, automatic operation during combustion batches
  - Air staging (primary and secondary combustion zone with separate air feed)

Manually fed boilers for log wood (2)



Types:

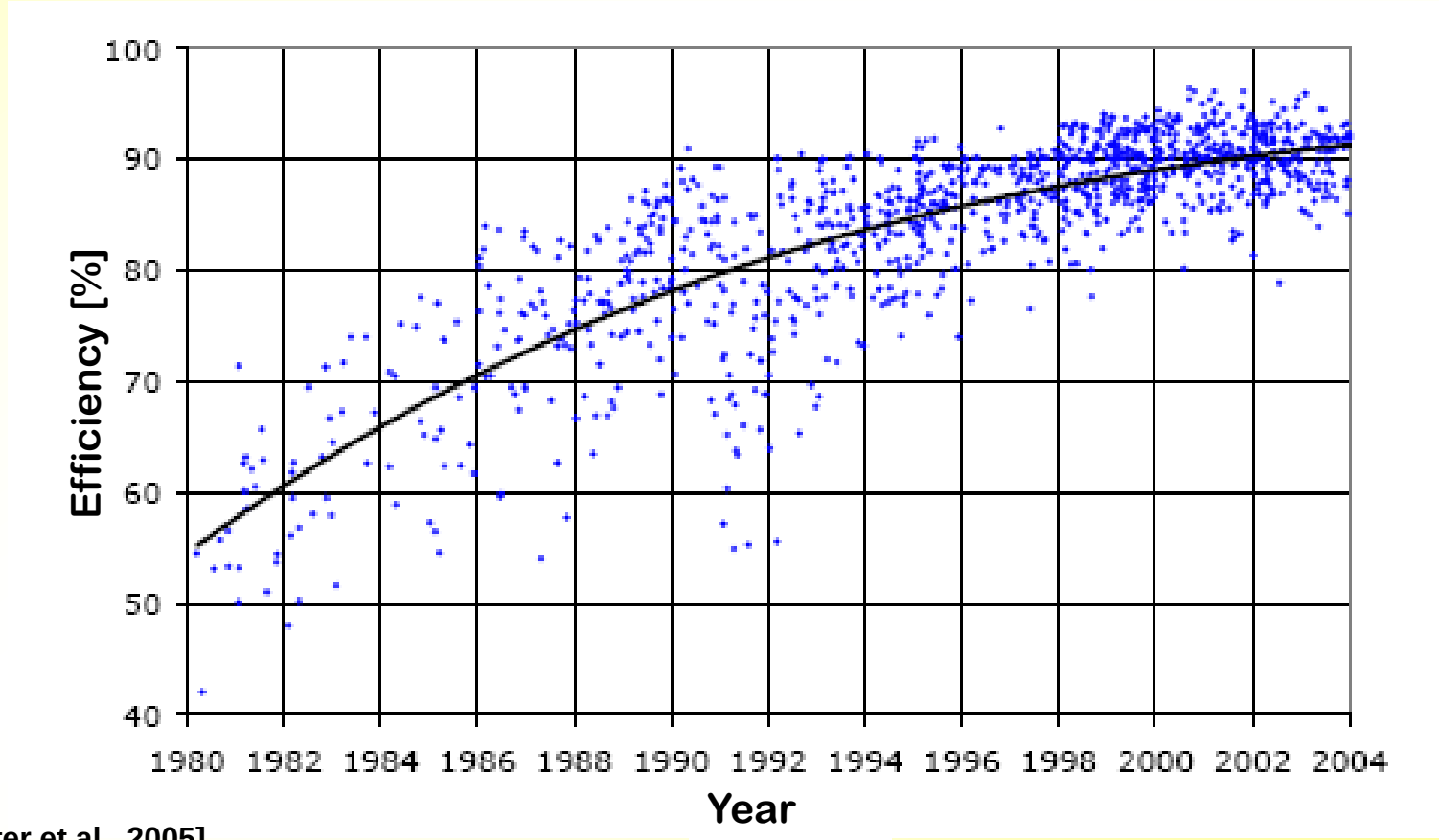
- Draught regulation by combustion air fan
- Very low emissions (improved mixing)
- Automatic control – typically with lambda (O_2) sensor

Source: [Fröling GmbH (A)]

Downdraft boiler

Manually fed boilers for log wood (3)

Performance data: modern log wood boilers achieve efficiencies of more than 90% (compared to approximately 55% in the early 1980´s)



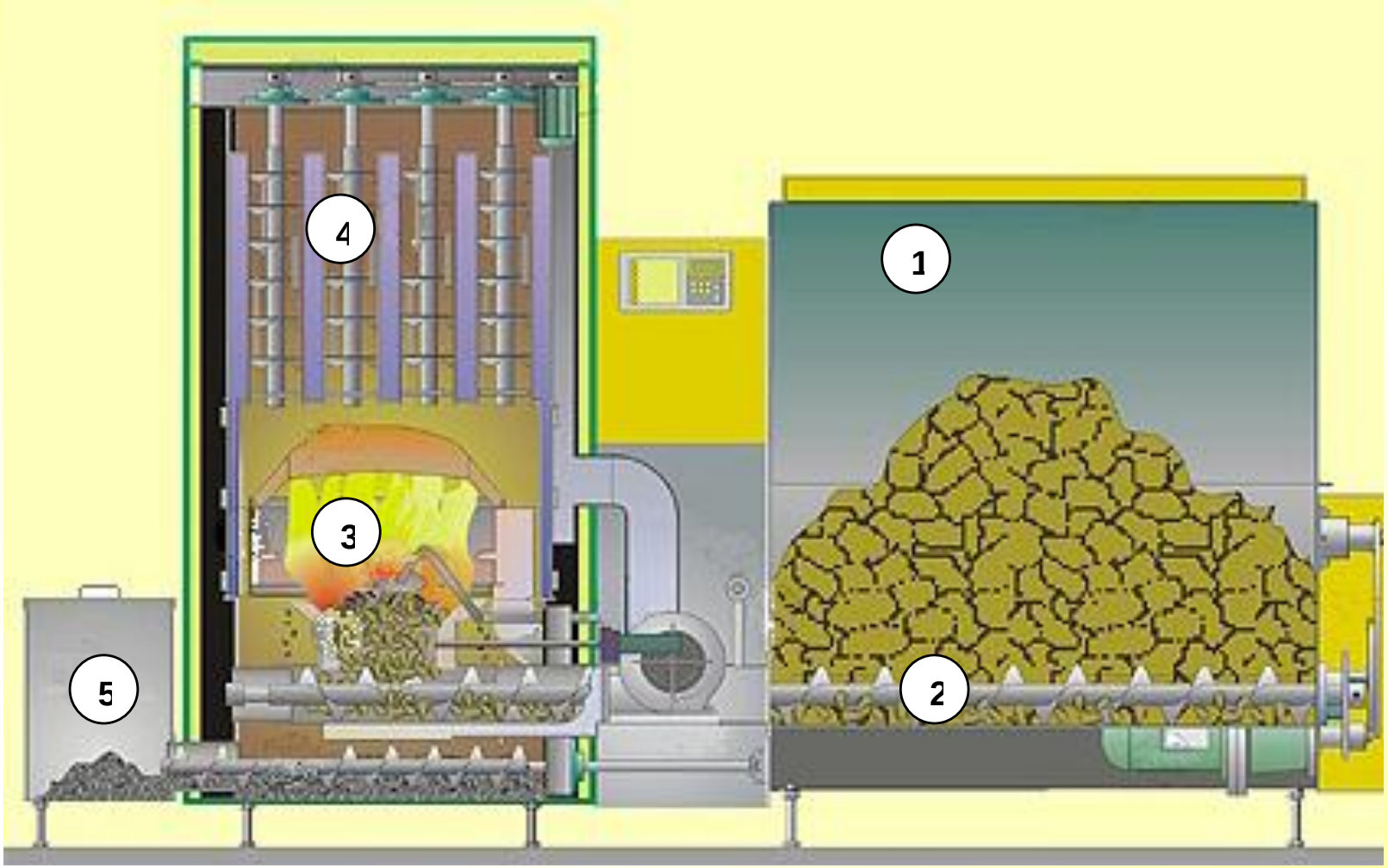
Source: [Wörgetter et al., 2005]

Automatically fed boilers for wood chips (1)

- **State-of-the-art:**
  - Fully automatic operation (only ash box emptying needed)
  - Micro-processor controlled
    (load and combustion control similar to pellet boilers)
  - Proven automatic fuel feeding (screw conveyors, agitators) with burn-back protection
  - Application in residential heating and micro grids
  - Air staging (primary and secondary combustion zone with separate air feed)
  - Typically vertical fire tube boilers with automatic or semi-automatic boiler cleaning (with a clear tendency towards automatic boiler cleaning systems)
  - Flue gas condensation partly applied

Automatically fed boilers for wood chips (2)

Automatically underfed wood chip stoker burner (50-100 kW_{th})



Explanations:

1… storage container
2… feeding screw
3… combustion chamber with radiation plate
4… heat exchanger with turbolators and cleaning system
5… ash container

Source: [KWB (A)]

Automatically fed boilers for wood chips (3)

- **Capacity range: >15 up to several 100 kW**
- **Fuels used: wood chips according to EN 14961 – Part 4**
- **Types: underfed burners, horizontally fed burners, moving grate systems**
- **Performance data [Wörgetter et al., 2005]:**
  - Efficiencies of wood chips boilers in the early 1980´s: around 70%
  - Average efficiency of modern wood chips boilers: 91%

Automatically fed boilers for wood pellets (1)

State-of-the-art:

- Fully automatic operation (only ash box emptying once or twice a year)
- Micro-processor controlled (load and combustion control)
  - Load control by regulation of the fuel and primary air feed guided by the feed water temperature
  - Combustion control by regulation of the secondary air feed usually guided by the O_2 concentration in the flue gas (lambda sensors)
- Proven automatic fuel feeding (flexible or inflexible screw conveyors, pneumatic systems, agitators or combinations) with burn-back protection
- Air staging (primary and secondary combustion zone with separate air feed)

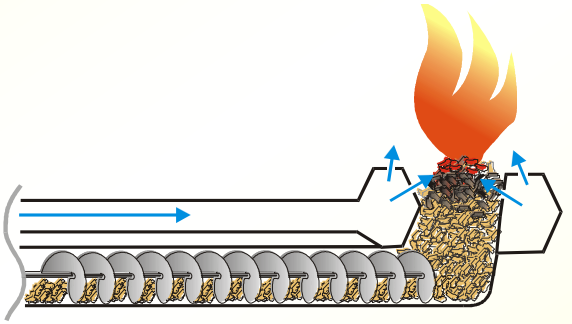
Automatically fed boilers for wood pellets (2)

- **State-of-the-art (continued):**
  - Typically vertical fire tube boilers with automatic or semi-automatic boiler cleaning (with a clear tendency towards automatic boiler cleaning systems)
  - Pellet boilers with flue gas condensation units already available
- **Capacity range: 6 to 300 kW (usual capacities in Austria)**
- **Fuels used: wood pellets according to EN14961-2**

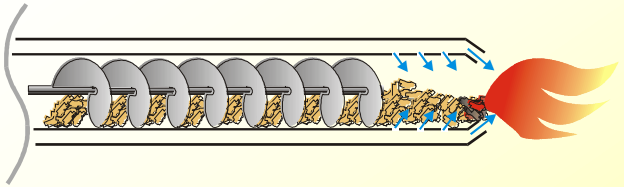
Automatically fed boilers for wood pellets (3)

Types of pellet burners depending on the fuel feeding system:

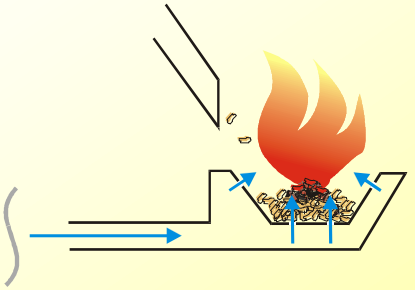
Underfed burners



Horizontally fed burners



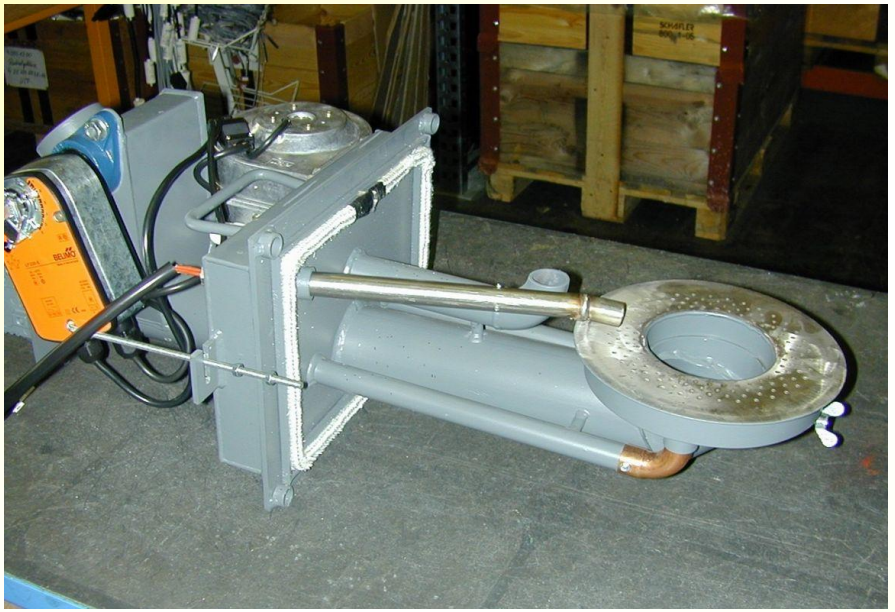
Overfed burners



Source: [Van Loo et al., 2002]

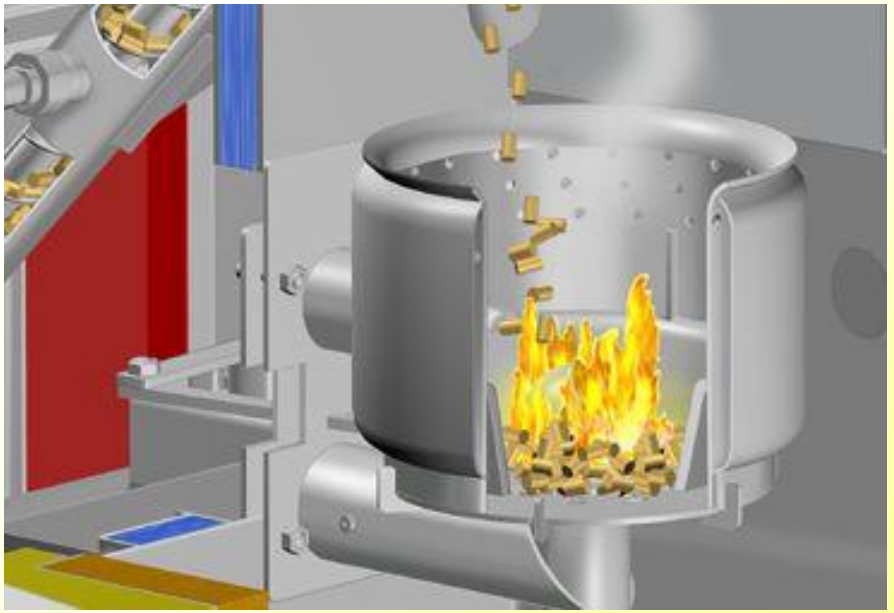
Automatically fed boilers for wood pellets (4) - basic designs

Retort furnaces
(only in combination with underfed burners)



Source: [KWB Kraft und Wärme aus Biomasse GmbH, Austria]

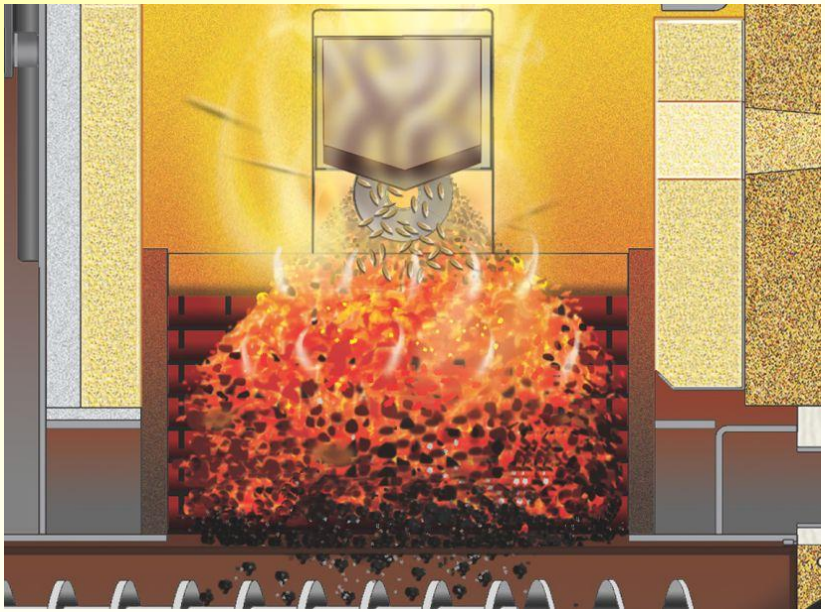
Grate furnaces
(only in combination with horizontally or overfed burners)



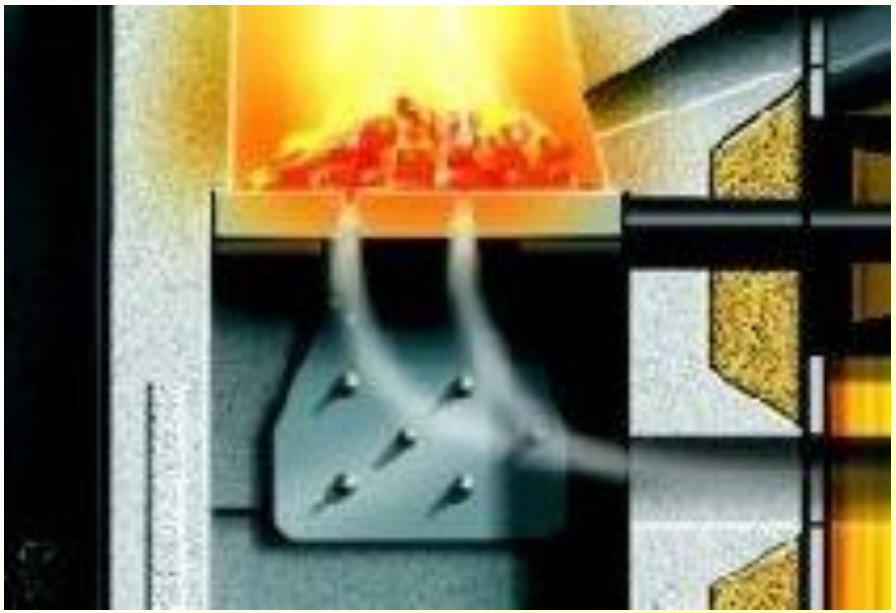
Source: [Windhager Zentralheizung GmbH, Austria]

Fixed grate

Automatically fed boilers for wood pellets (5) - basic designs



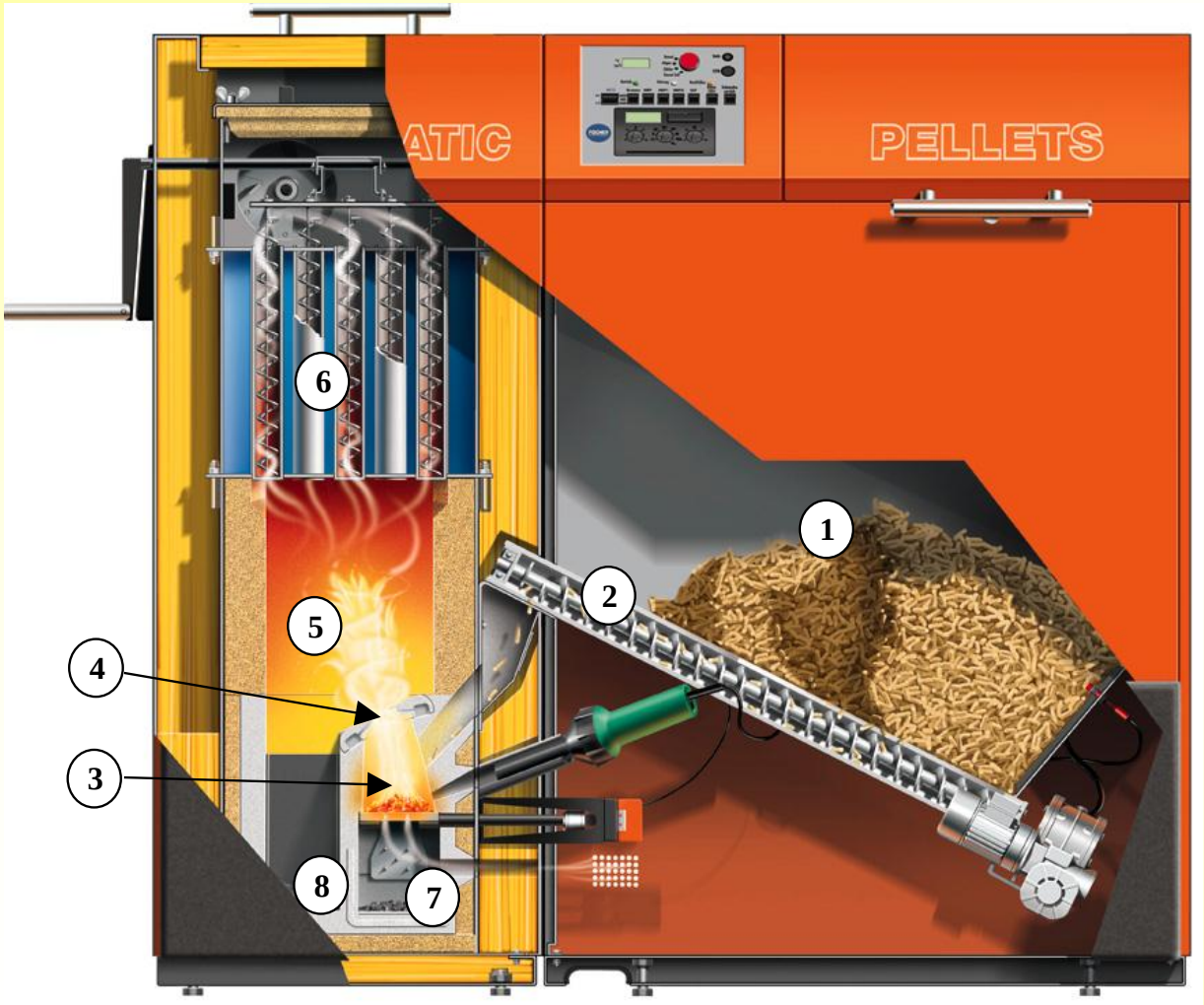
Step grate



Hinged grate

Source: [GUNTAMATIC Heiztechnik GmbH, Austria]

Automatically fed boilers for wood pellets (6) – overfed pellet boiler

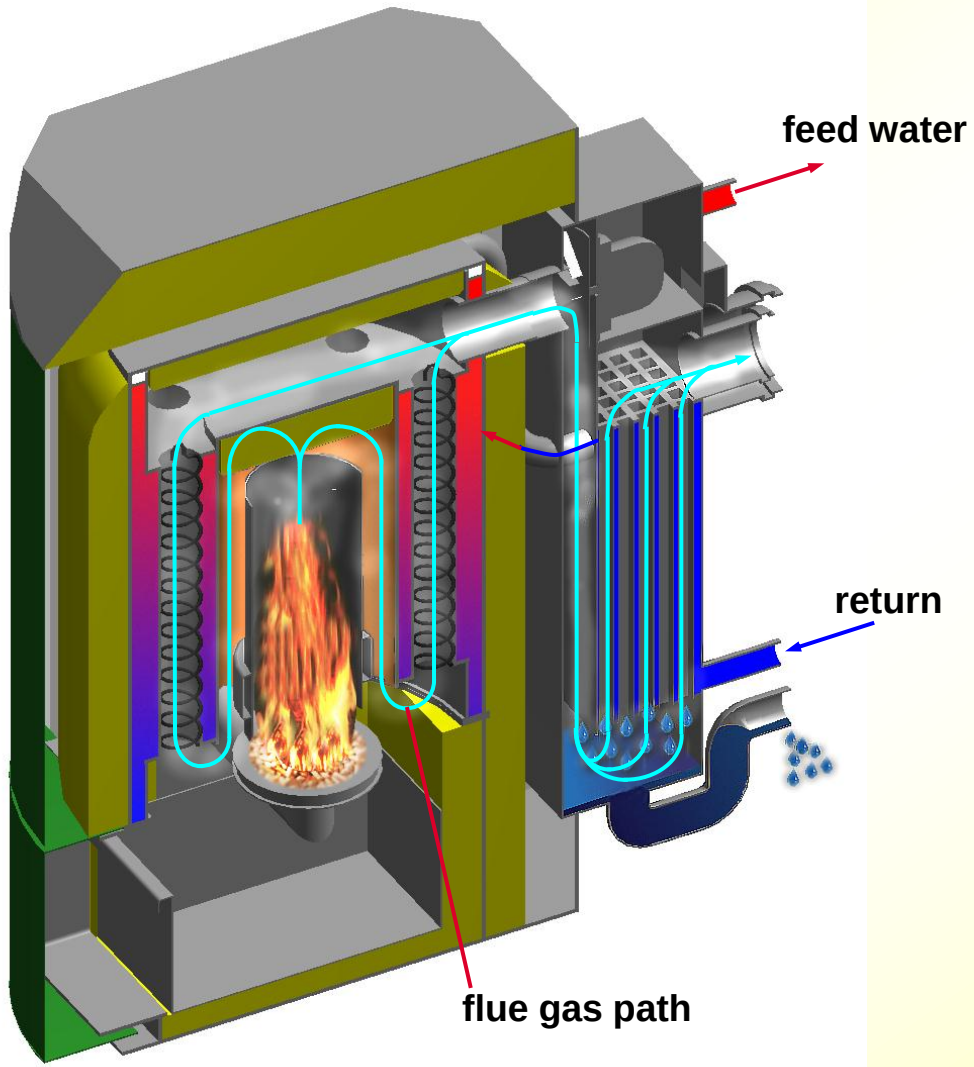


Explanations:

1 …. fuel container
2 …. stoker screw
3 …. primary combustion chamber with primary air addition
4 .... secondary air addition
5 …. secondary combustion chamber
6 …. heat exchanger with cleaning device
7 …. bottom ash container
8 …. fly ash container

Source: [Fischer Guntamatic (A)]

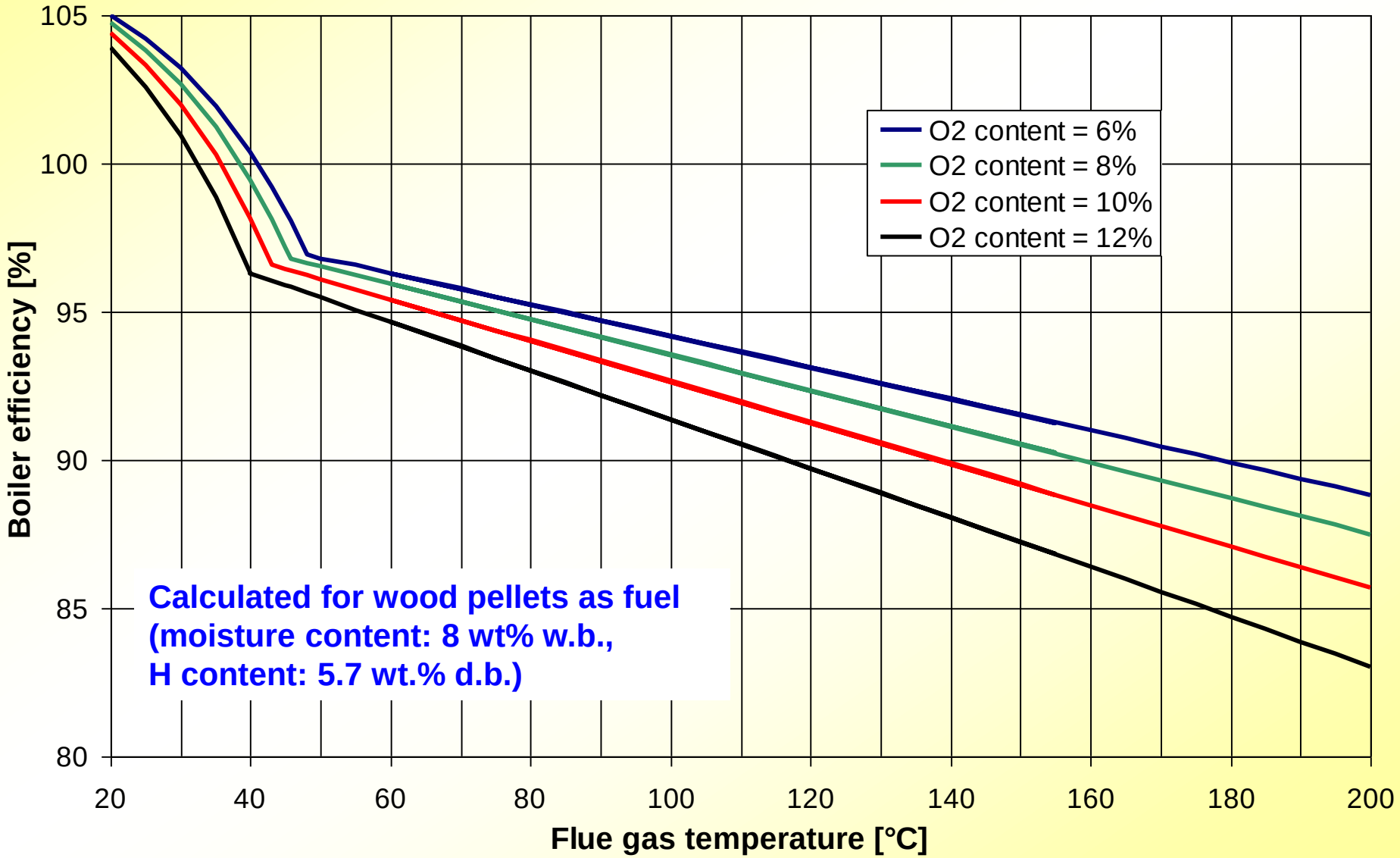
Automatically fed boilers for wood pellets with integrated flue gas condensation



Source: [ÖkoFEN, Austria, 2004]

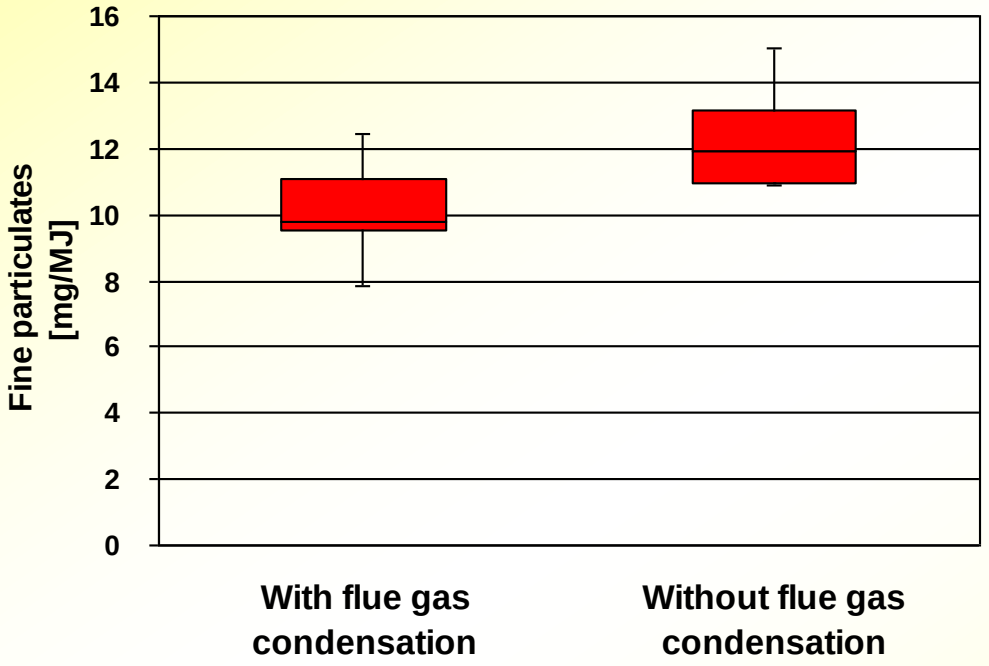
- First pellet boiler with integrated flue gas condensation
- Market introduction: 2004
- Efficiency: up to 103% (according to type test by BLT Wieselburg) depends on return temperature and excess O_2
- Nominal capacities: 8, 10, 15 and 20 kW

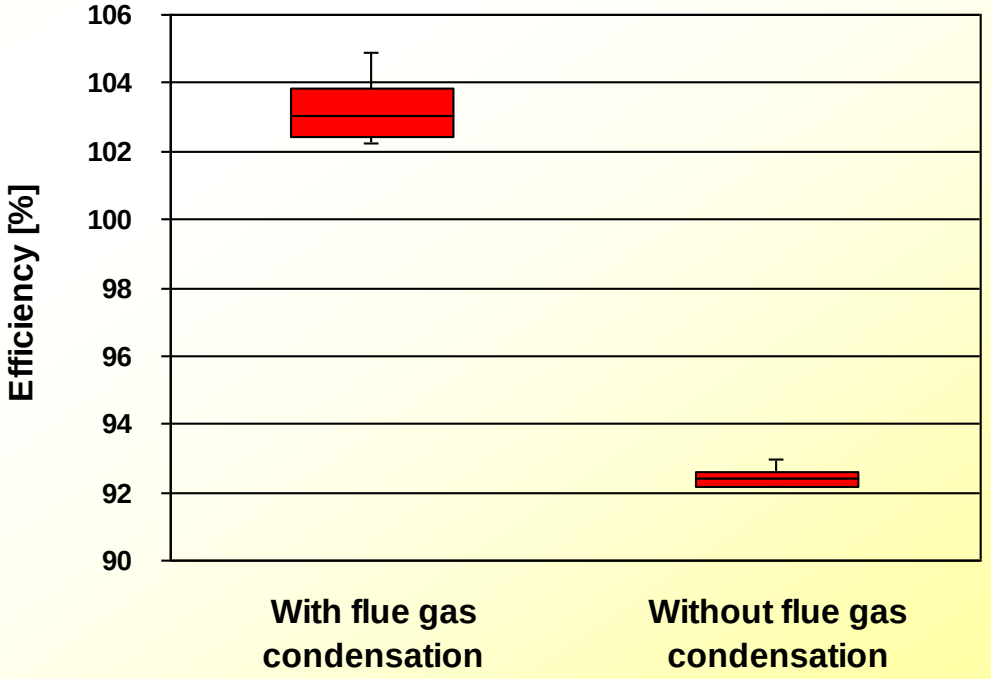
Boiler efficiency as a function of flue gas temperature and O_2 concentration in the flue gas



Source: [BIOS BIOENERGIESYSTEME GmbH, Austria, 2002]

Fine particulate emissions and efficiencies of pellet boilers with and without flue gas condensation





Source: [Obernberger et al., 2006]

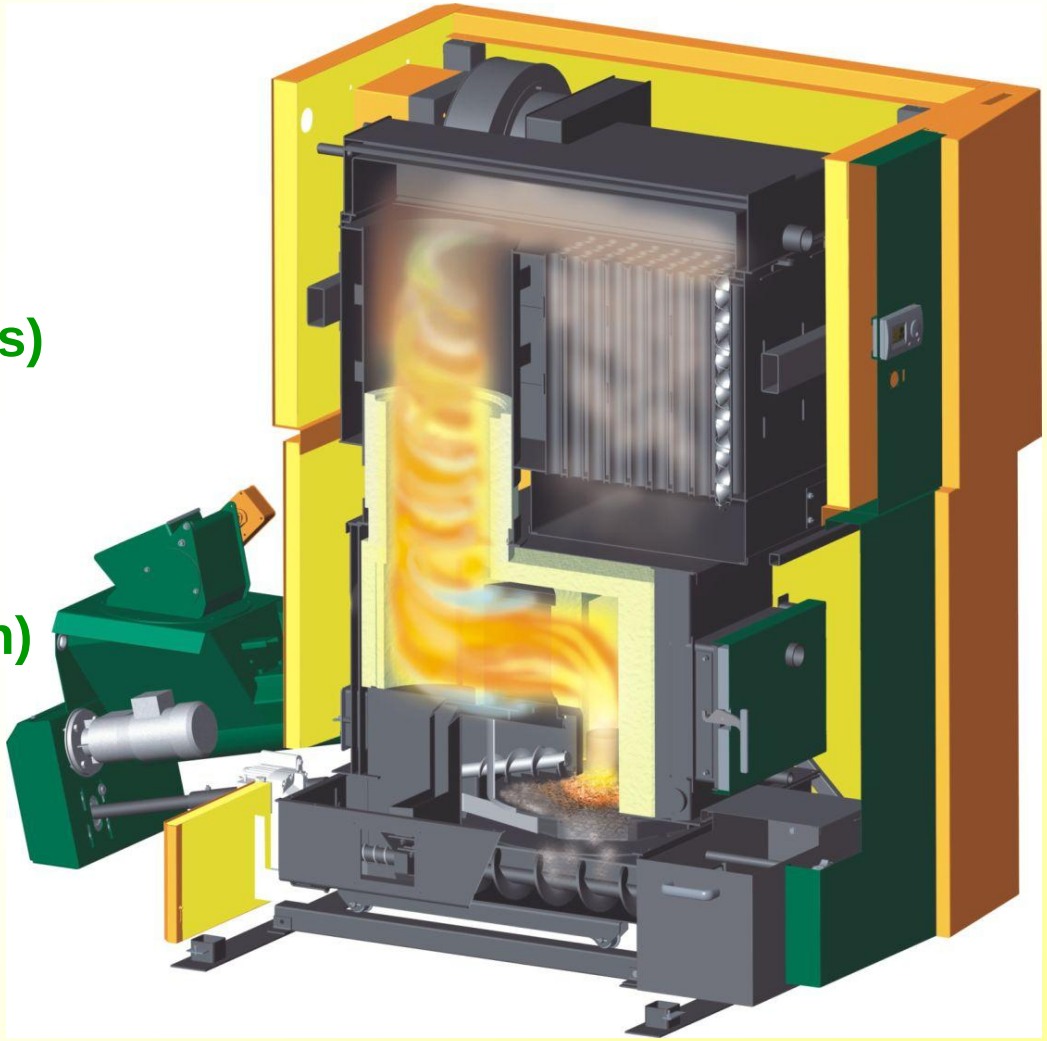
Explanations: operating conditions for furnace with flue gas condensation: load 20 kW; flue gas temperature 33.7°C; return temperature 22.4°C; O_2 concentration in the flue gas 8.3 vol.% dry flue gas; box plots based on 9 measurements; operating conditions for furnace without flue gas condensation: load 18.2 kW, flue gas temperature 144 °C, return 59.8 °C, O_2 concentration in the flue gas 8.6 vol.% dry flue gas, box plots based on 5 measurements

Dual-fuel boilers (1)

- **Proven concepts are already available on the market**
  - **Wood pellets / wood chips combinations (automatic operation for both fuels)**
  - **Wood pellets / firewood combinations (different levels of automation depending on the type):**
    - **Simple boiler concepts have to be adjusted and operated manually in case of operation with firewood**
    - **Sophisticated boilers identify the fuel automatically**
    - **For both boiler types several applications are available**

Dual-fuel boilers (2) - Boiler for wood pellets / wood chips operation

- **Nominal thermal capacity: 15 - 300 kW**
- **Innovative rotary grate furnace (robust, calm bed of embers, optimised gasification conditions)**
- **Innovative cyclone combustion chamber (optimised by CFD simulations, efficient fly ash separation, flue gas recirculation)**
- **Fuels: wood chips (up to w50) and wood pellets**
- **Automatic operation for all fuels**



Source: [KWB – Kraft und Wärme aus Biomasse GmbH, Austria]

Dual-fuel boilers (3) - Boiler for wood pellets / firewood operation

- **Nominal thermal capacity: 15 – 40 kW**
- **Fuels: wood pellets and firewood**
- **Automatic fuel identification**
- **No manual adaptations needed**
- **Automatic operation for all fuels (ignition of firewood with the pellets burner)**

Explanations:

1 process control system

2 fan

3 chamotte

4 combustion chamber for firewood

5 pellet burner

6 isolation

7 secondary combustion chamber

Source: [Fröling Heizkessel- und Behälterbau Ges.m.b.H, Austria]

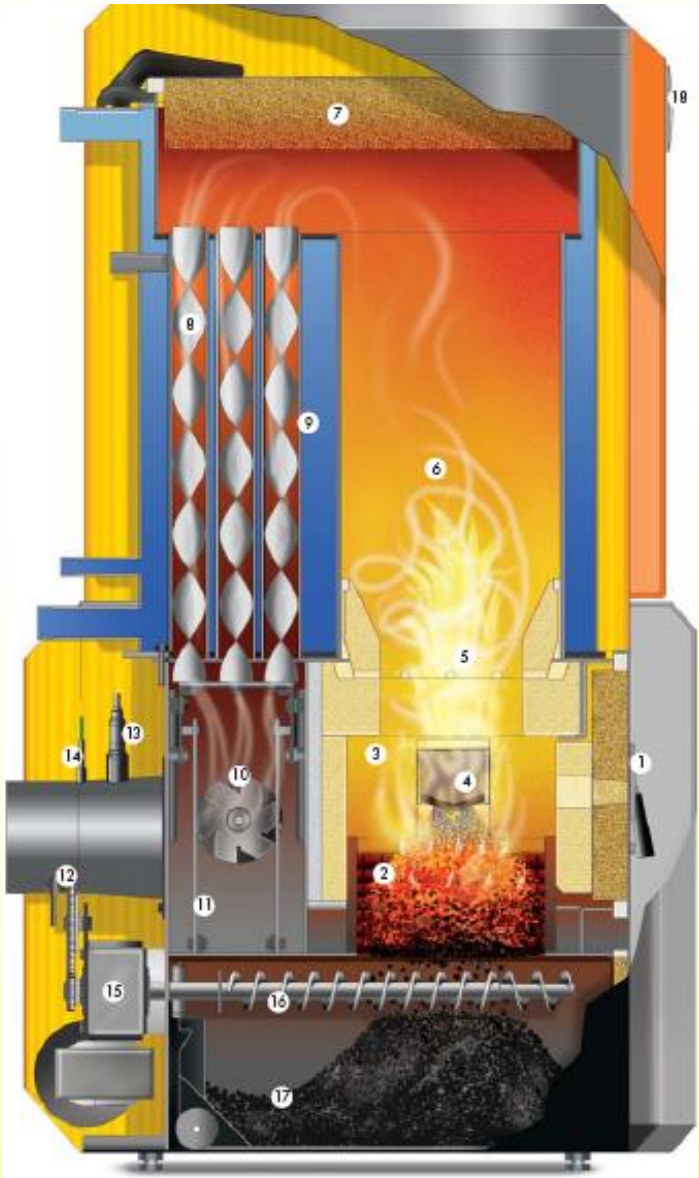
Automatically fed boilers for non-wood fuels (1)

- **State-of-the-art:**
  - Guntamatic Powercorn: for corn and pellets, nominal thermal capacity: 30, 50 and 75 kW [Guntamatic, Austria, 2011]
  - Hargassner Agrofire: for corn, straw pellets, miscanthus, wood chips and pellets, nominal thermal capacity: 25 and 40 kW [Hargassner, Austria, 2011]
  - Ökotherm Compactanlage: for corn, straw pellets, miscanthus, rapeseed cake and wood chips, nominal thermal capacity: 30 – 800 kW [Ökotherm, Germany, 2011]
  - Heizomat RHK-AK: for miscanthus, corn, rape straw, maize cobs, pellets and wood chips, nominal thermal capacity: 30 – 1,000 kW [Heizomat, Germany, 2011]
- **The potential for further development is rather high due to the novelty of these technologies**
- **The gaseous as well as particulate emissions are considerably higher in comparison to wood fuels**

Automatically fed boilers for non-wood fuels (2)

Guntamatic POWERCORN

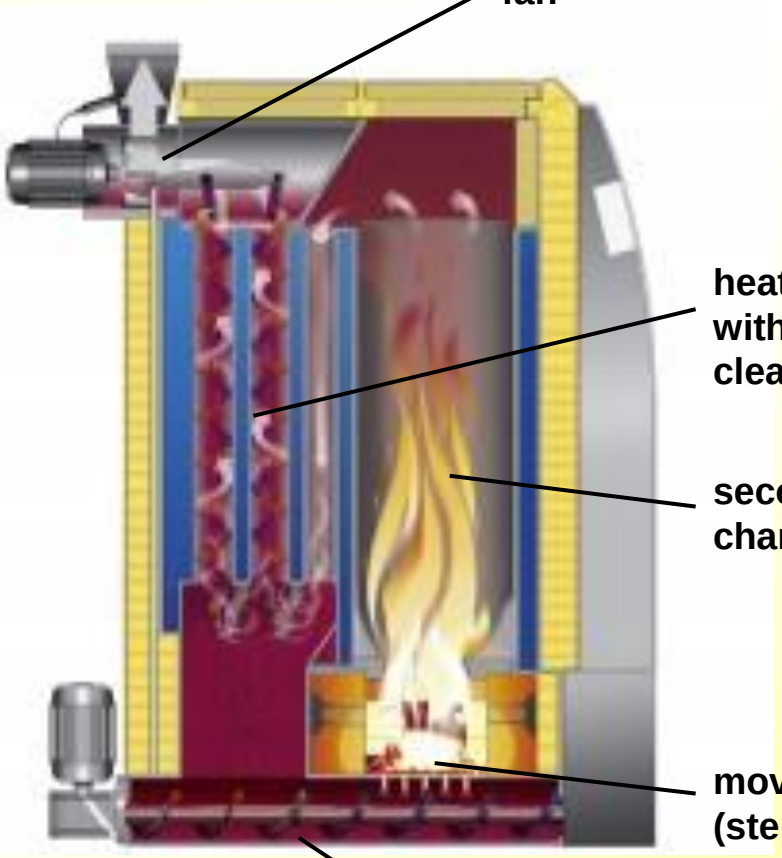
1. Furnace doors
2. Step grate – primary air
3. Combustion chamber
4. Fill level indicator
5. Spiral jet – secondary air
6. Reaction pipe
7. Cleaning cover
8. Vibrating mechanism
9. Tube bundle heat exchanger
10. Induced draught fan
11. Cleaning of heat exchanger
12. Smoke pipe
13. Lambda probe
14. Flue gas sensor
15. Cleaning/ grate drive
16. Ash auger
17. Removable ash container
18. Menu-guided control



Source: [Guntamatic Heiztechnik GmbH (A)]

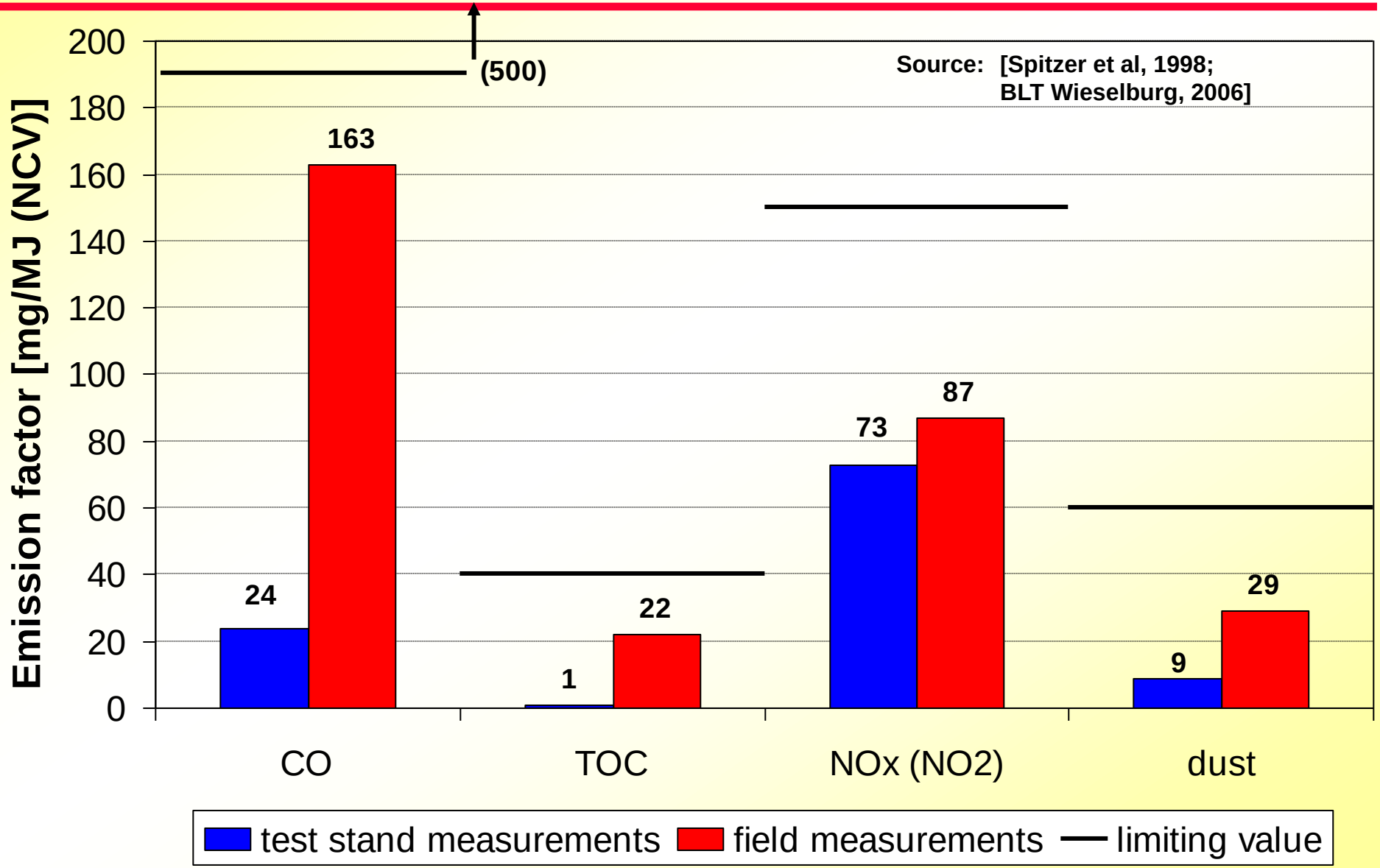
Automatically fed boilers for non-wood fuels (3)

Hargassner AgroFire:

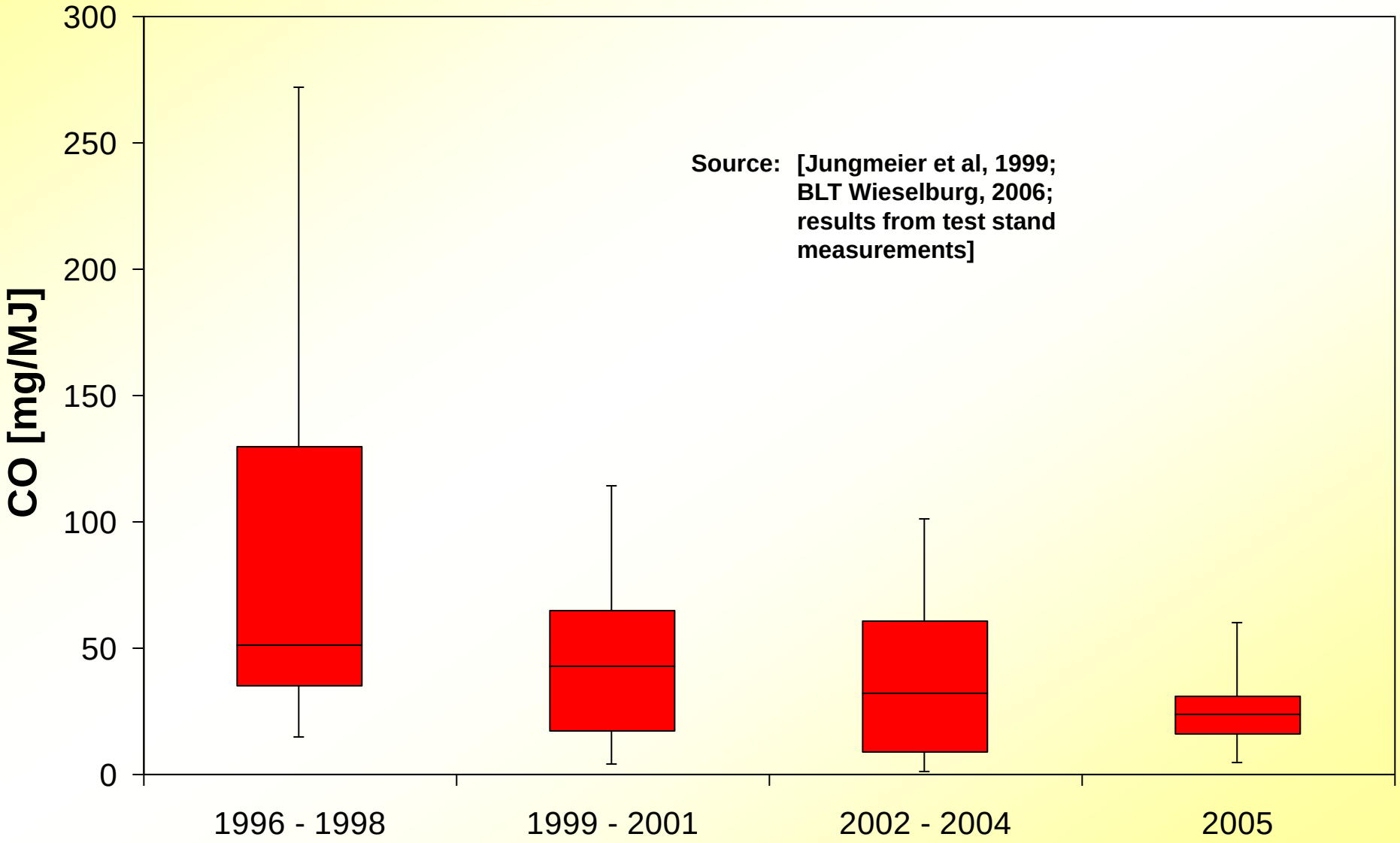


Source: [Hargassner GesmbH (A)]

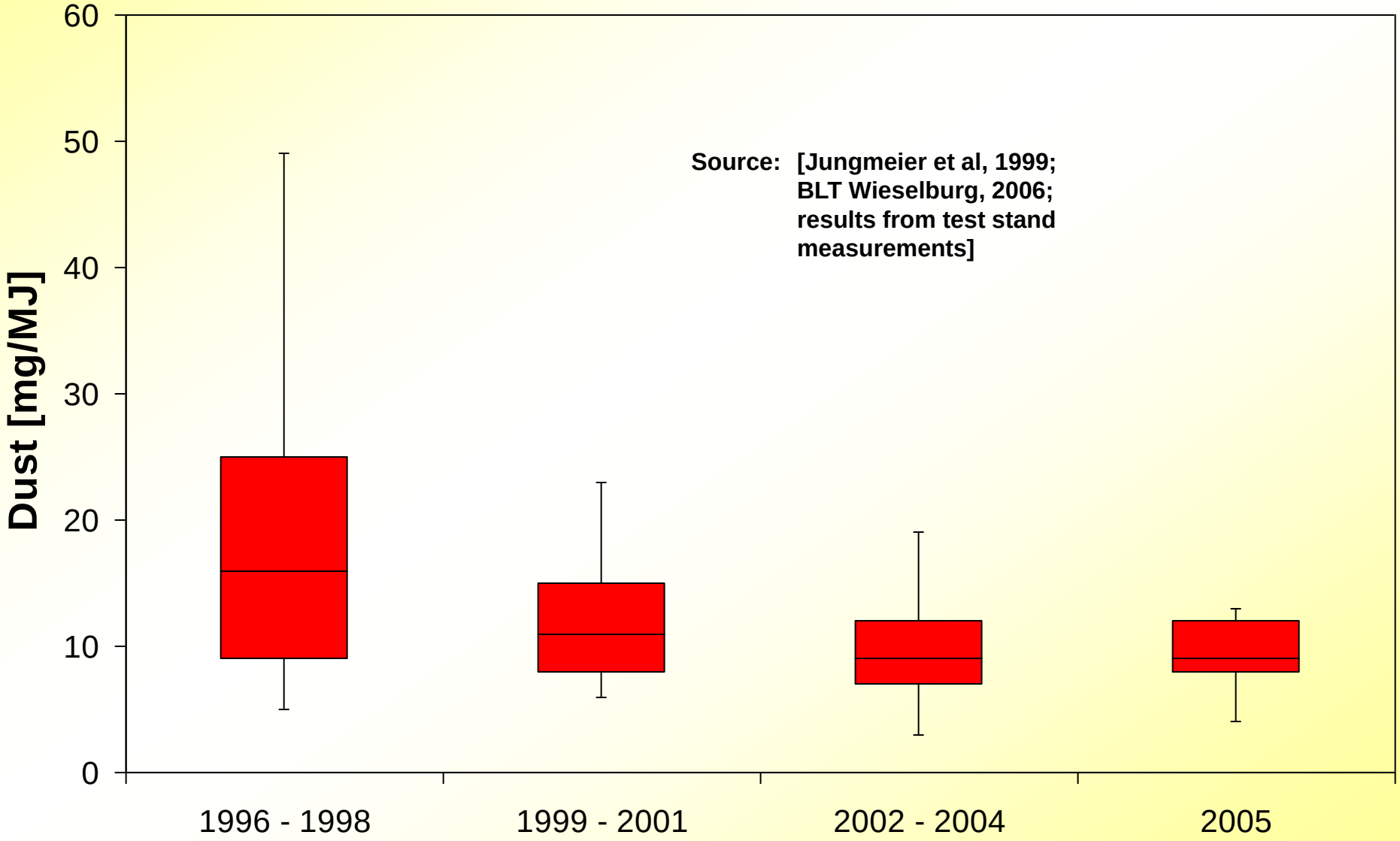
Emissions - overview



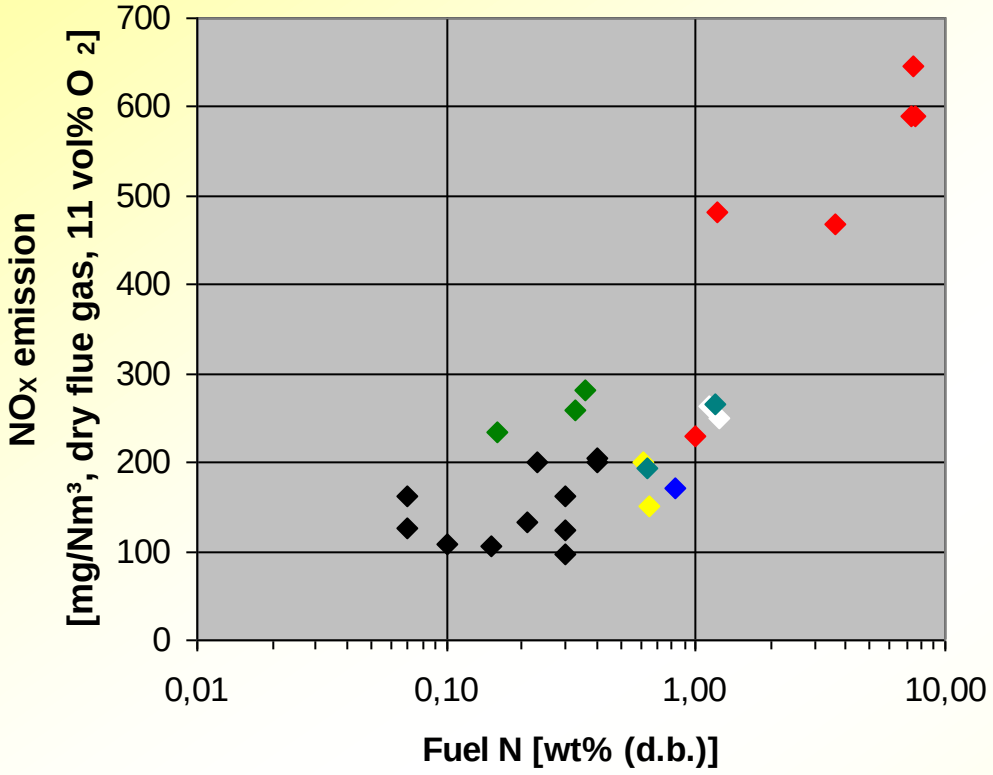
CO emissions – comparison between old and new pellet furnaces

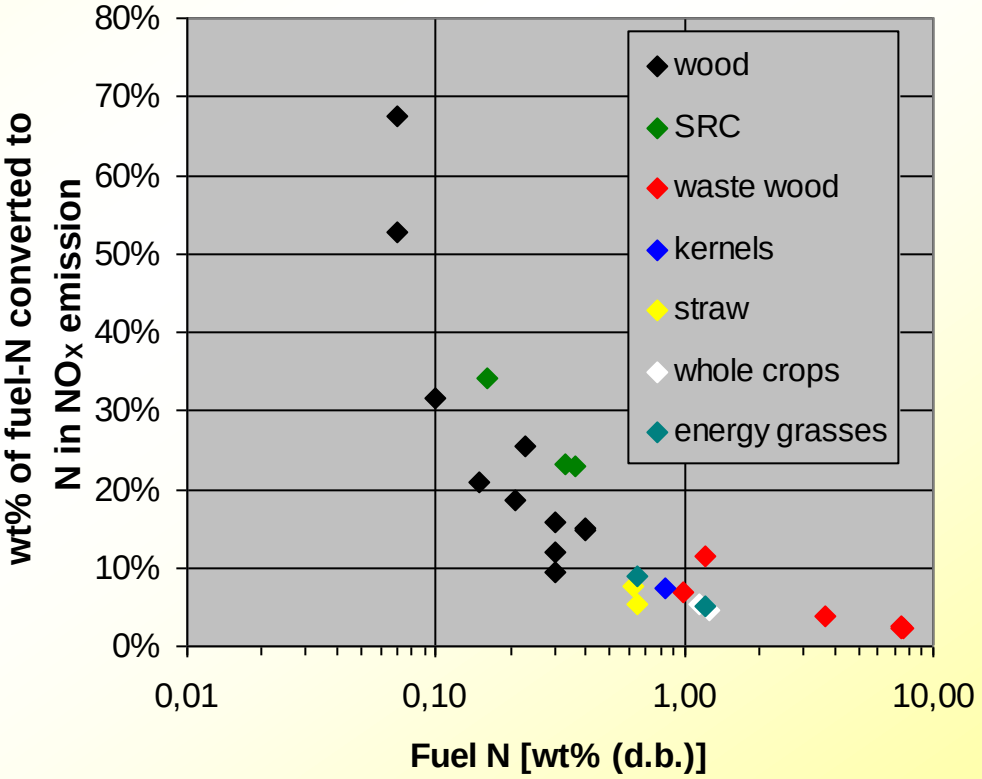


Dust emissions – comparison between old and new pellet furnaces



NO_x emissions and N conversion versus N content in the fuel

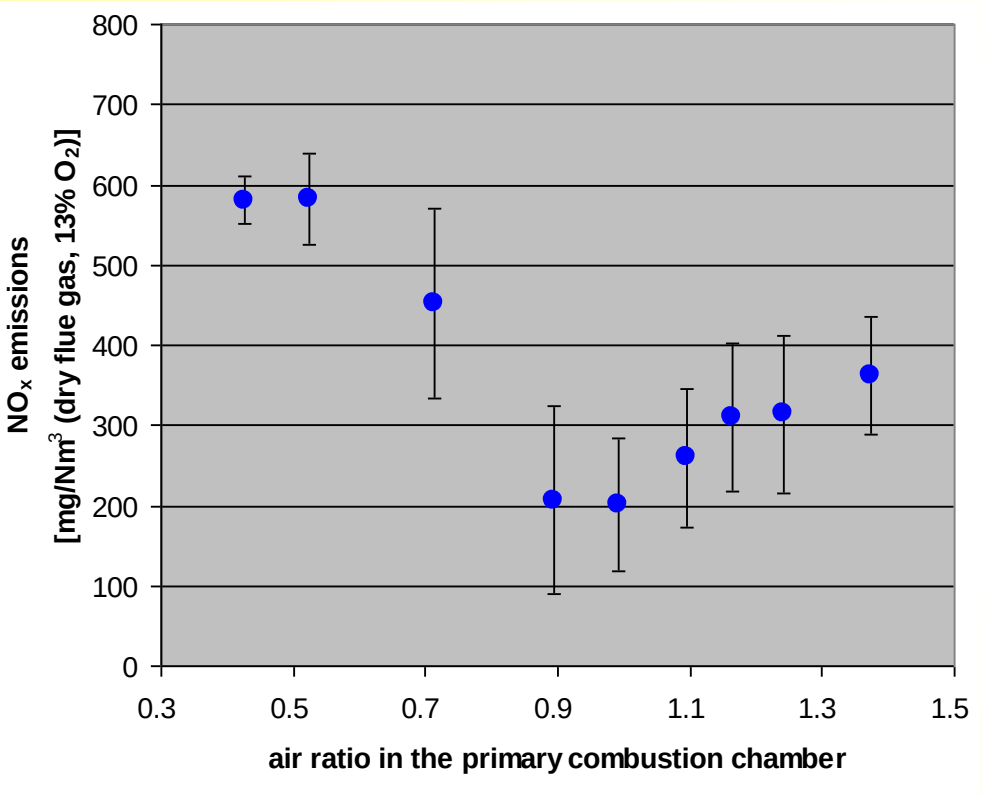




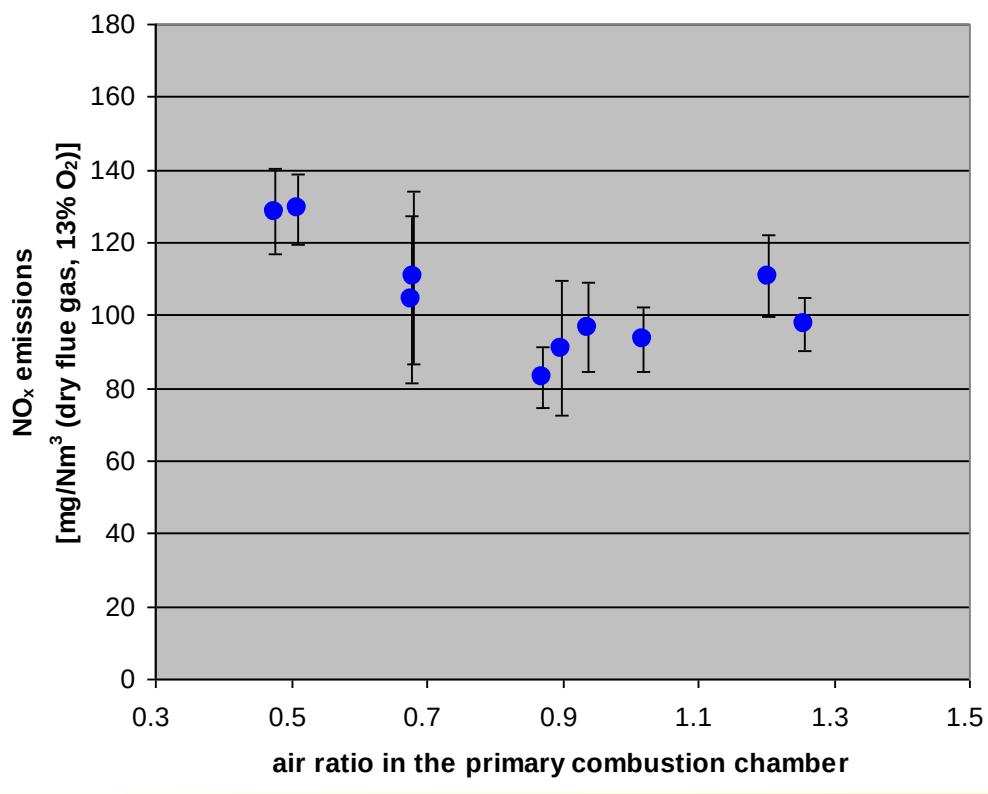
- Fuel selection relevant
- Primary measures especially relevant
- Combination of primary and secondary measures if needed

NO_x emissions versus air ratio in the primary combustion chamber

Fuel: chipboard
N content: 3.7 wt% (d.b.)

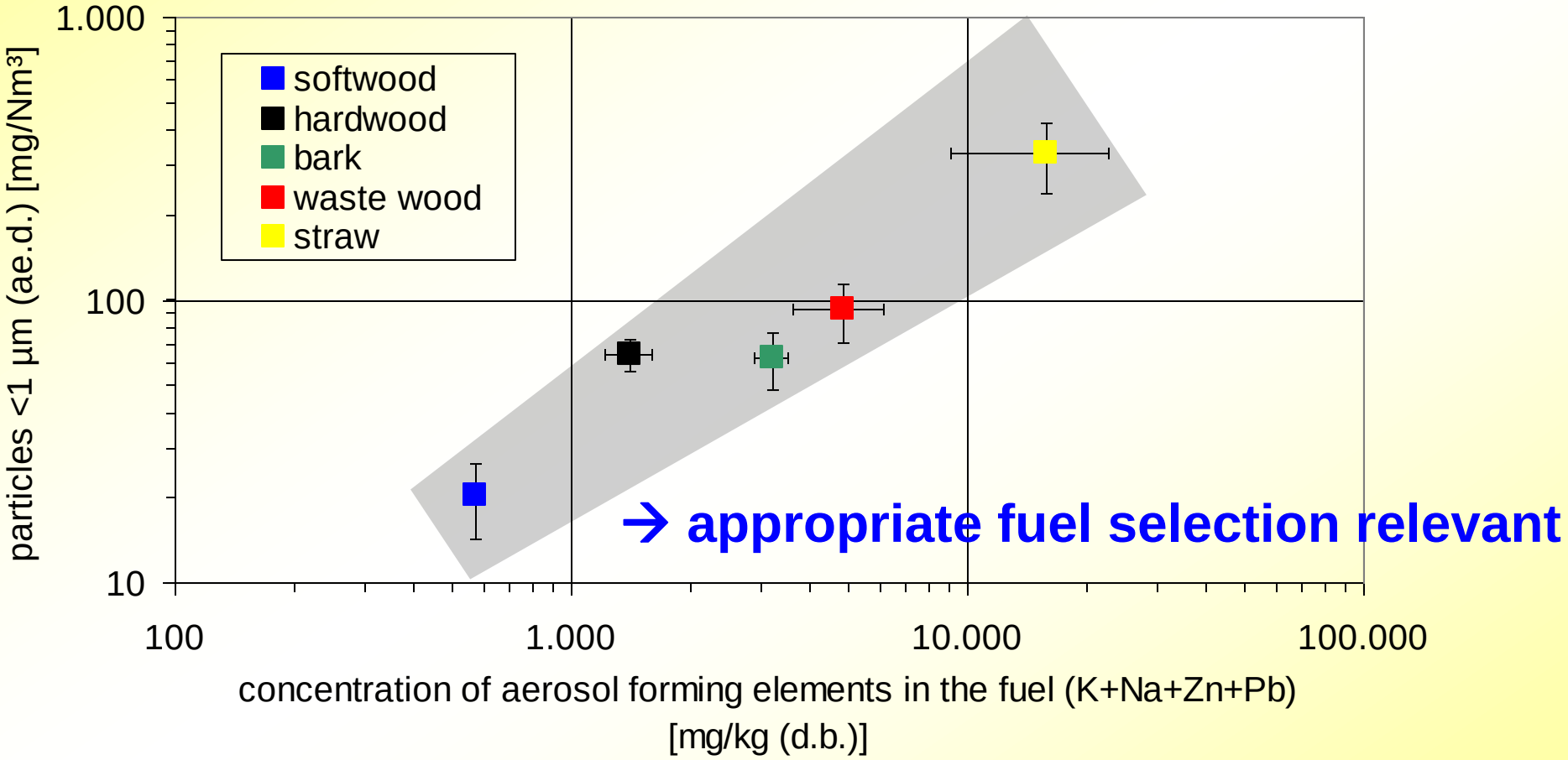


Fuel: wood chips (spruce)
N content: 0.09 wt% (d.b.)



Explanations: Source: [Hesch et.al., 2011, Hesch et.al., 2011 (submitted)], measurements performed in a moving grate furnace (nominal boiler capacity: 150 kW_{th}), air staging and flue gas recirculation above grate applied, temperature in the primary combustion chamber for all tests: 1,000 °C

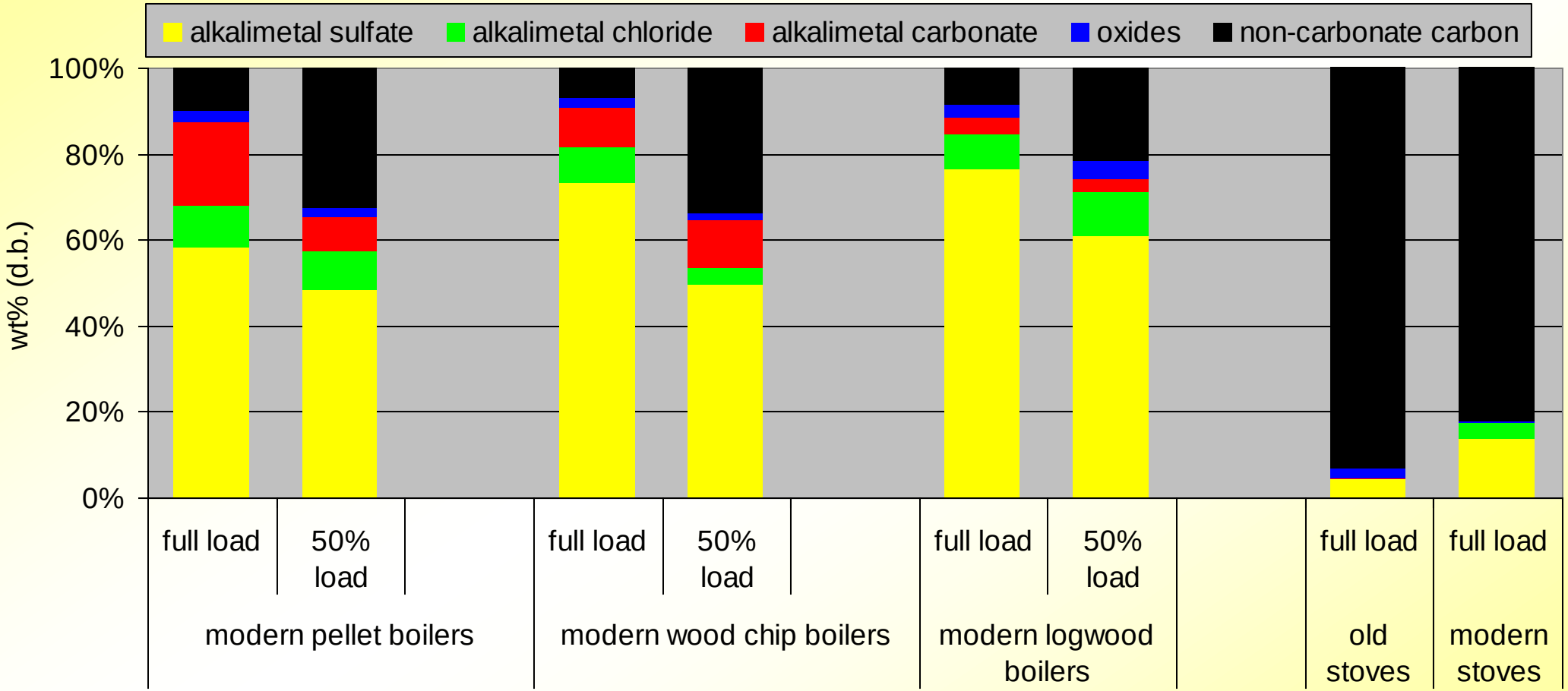
Influence of the fuel used on the mass of aerosols formed



→ **appropriate fuel selection relevant**

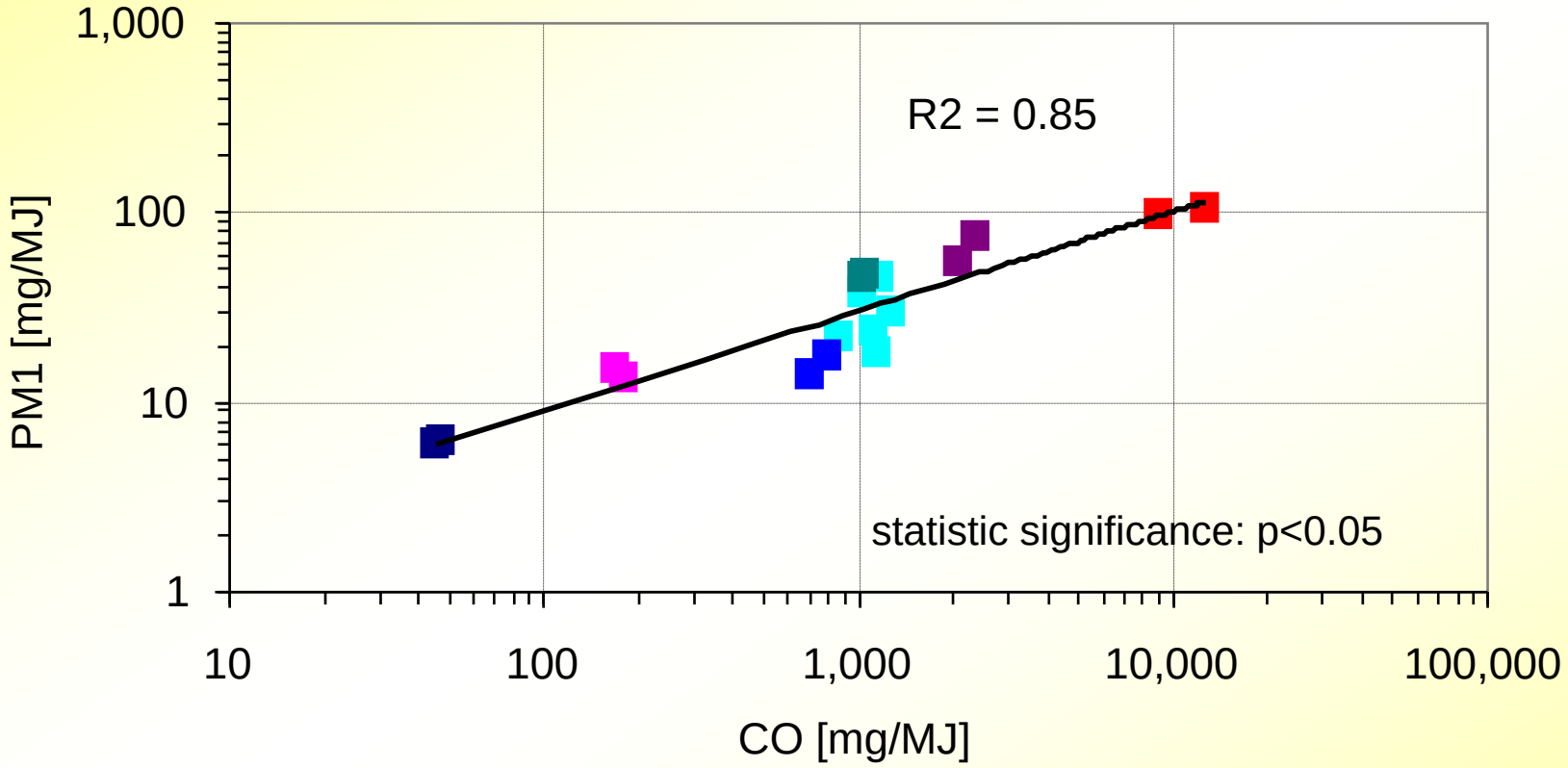
- Emissions at boiler outlet
- Particle emissions related to dry flue gas and 13 vol% O_2

Average chemical compositions of aerosols from small-scale biomass boilers and stoves



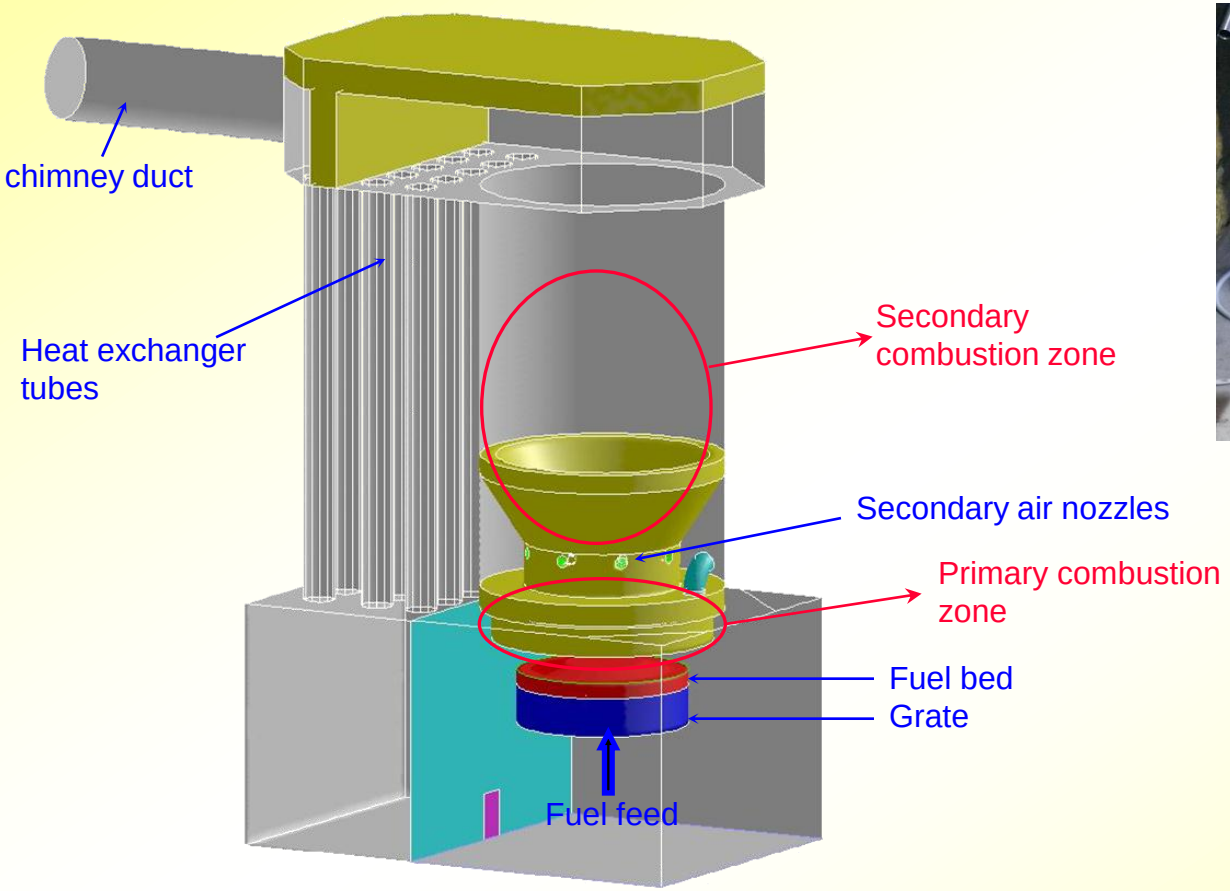
- **Primary measures of great relevance (complete combustion, optimisation of partload operation, reduction of the release of ash vapours)**

Factors influencing aerosol formation – burnout quality

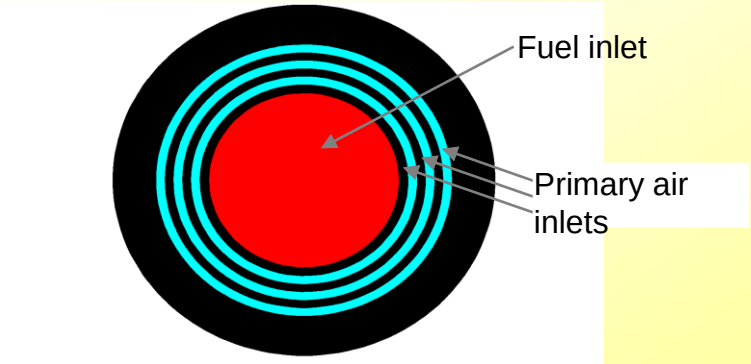


Explanations: mean values from test runs performed with different old and modern residential heating systems (modern pellet boiler, modern wood chip boiler, modern logwood boiler, old logwood boiler, modern stove, old stove, modern tiled stove)

CFD based combustion design (1) - modelling of a biomass fired underfeed stoker grate furnace (20 kW)

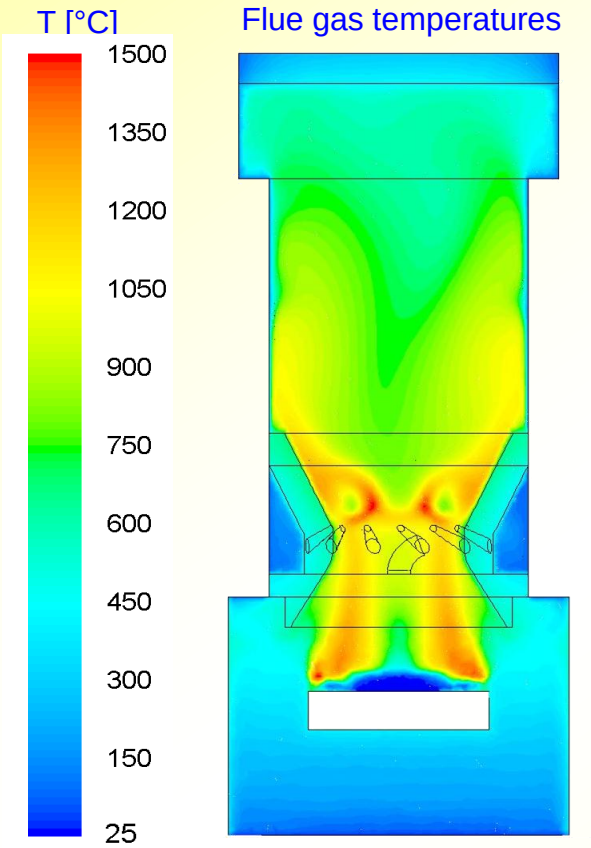


Picture of the grate

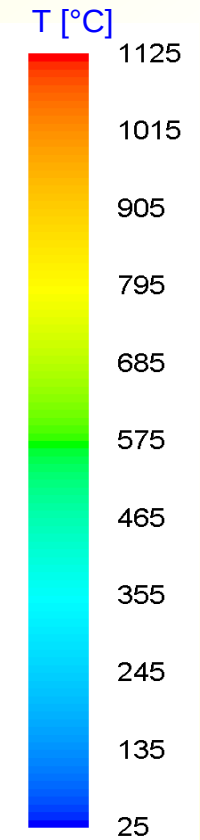


Scheme of the grate used for simulations

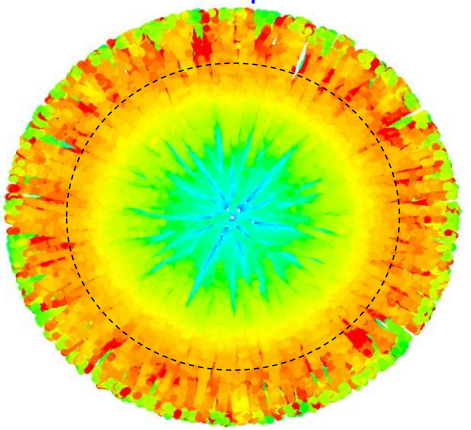
CFD based combustion design (2) - particle and flue gas temperatures [°C]



Flue gas temperatures



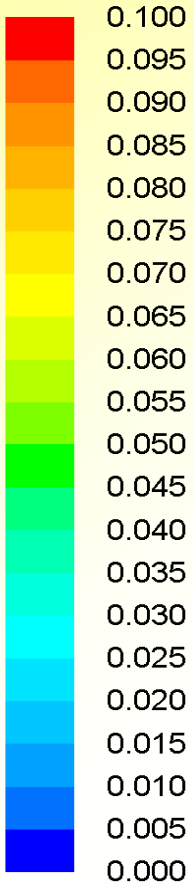
Particle temperatures

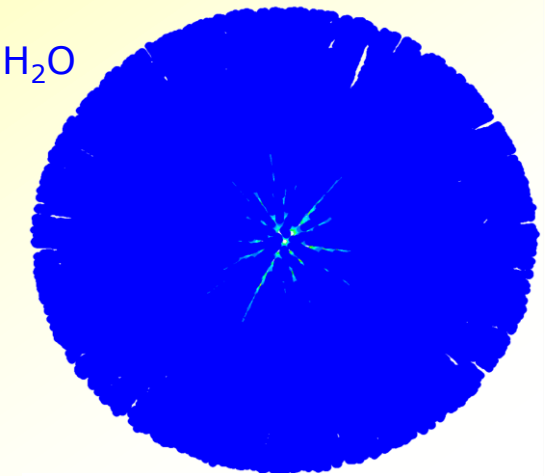


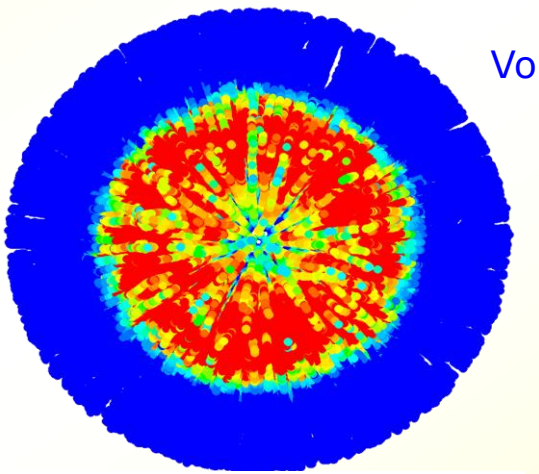
Visual observation

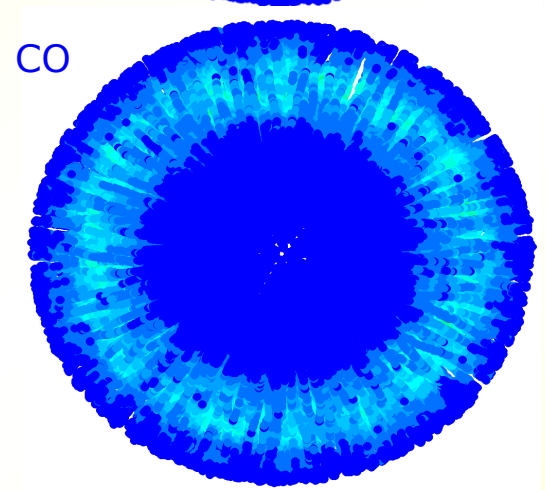
Explanations: Biomass fuel: softwood pellets;
Moisture content= 8.12 wt.% (wet base); λ_{total}= 1.58; λ_{prim}= 0. 64, no flue gas recirculation

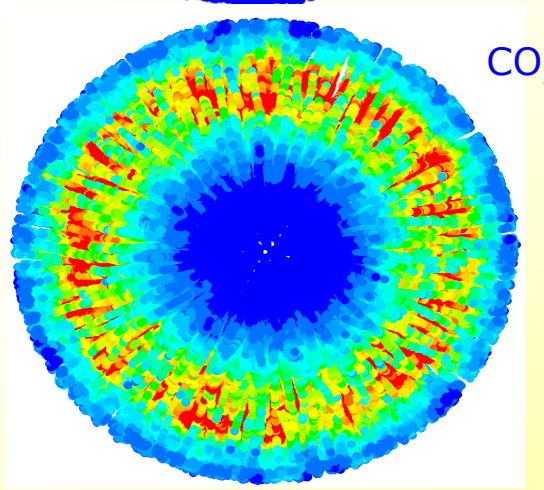
CFD based combustion design (3) - particle tracks coloured by release rates [mg/s]



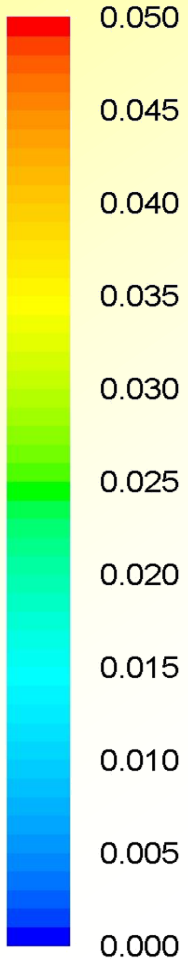


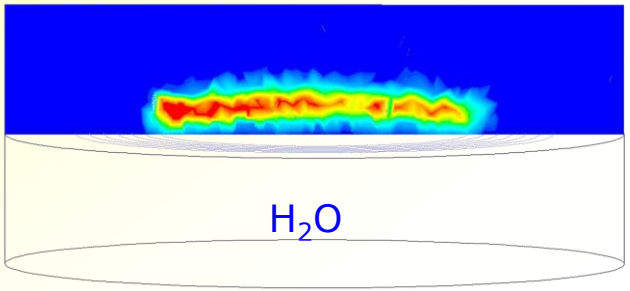


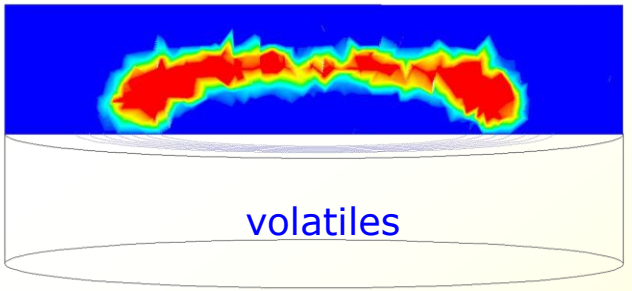


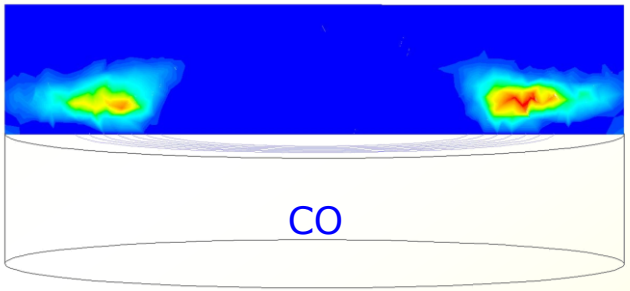


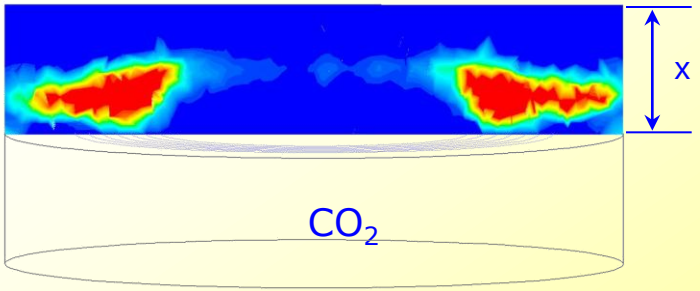
CFD based combustion design (4) - contours of release rates [mg/s]











Contours of release rates at a vertical cross section through the grate axis; x= 5cm

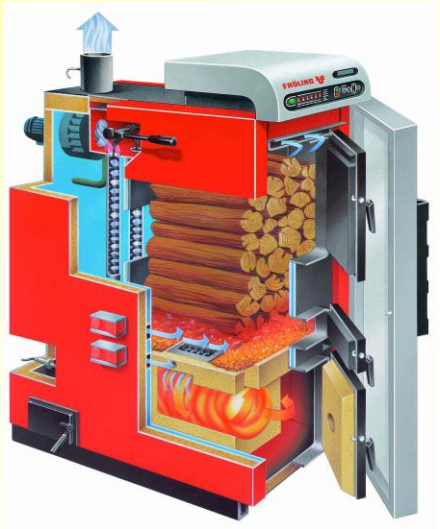
Summary and conclusions (1)

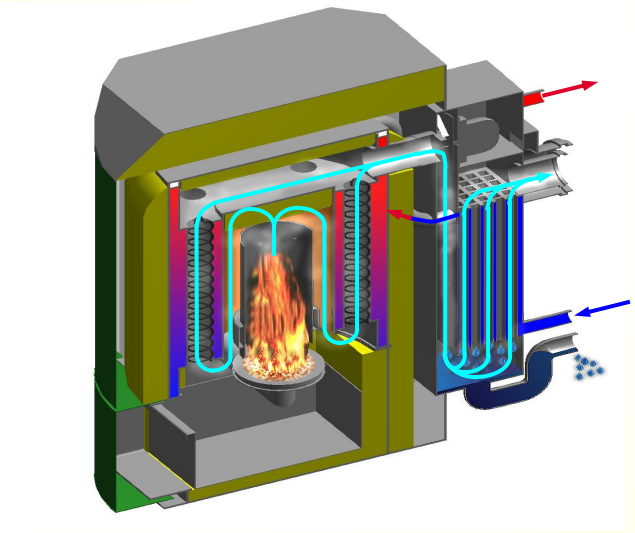
- **The following market-proven small-scale boiler technologies are available for wood fuels**
  - **Manually fed boilers for log wood**
  - **Automatically fed boilers for wood chips**
  - **Automatically fed boilers for wood pellets**
  - **Dual-fuel boilers (wood pellets / wood chips and wood pellets / firewood)**
- **For non-wood fuels only a few manufacturers offer solutions but they are available on the market. Emissions and ash related problems are generally higher for non-wood fuels**
- **Flue gas condensation units offer a potential to increase efficiency. Over 100% (related to the NCV of the fuel) compared to approx. 90% for conventional technology. Flue gas condensation is especially interesting for wet fuels and / or requires low return temperature (30 – 40 °C) to work efficiently**

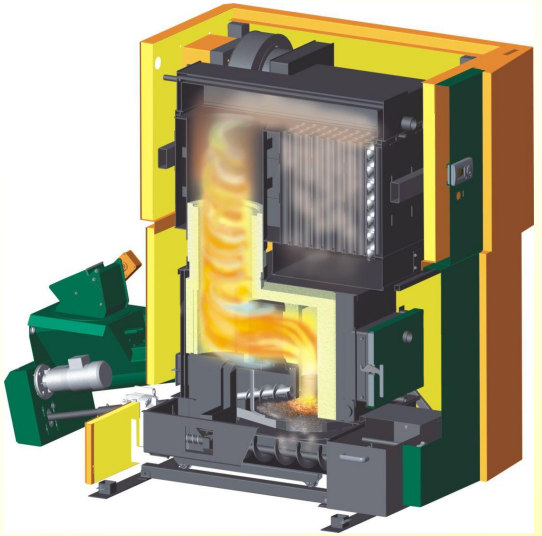
Summary and conclusions (2)

- Small-scale boiler technologies have considerably improved in the last two decades regarding CO, TOC and dust emission reduction
- Further improvements are possible regarding the reduction of NO_x and PM_1 emissions
  - Regarding primary measures an efficient air staging strategy is very important
  - The influence of the fuel itself (N, ash and alkali metal contents vary) is of great relevance → the technologies have to be adapted to the fuels used
- Regarding partial load operation, load changes and the process control system a considerable potential for improvements still exists
- CFD simulations show increasing importance as an efficient design tool for small-scale combustion systems

Thank you for your attention







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