bioenergy2020+

# Technological Progress and Innovation of small scale combustion appliances: Impact on PM and Benzo(a)pyren emission reduction

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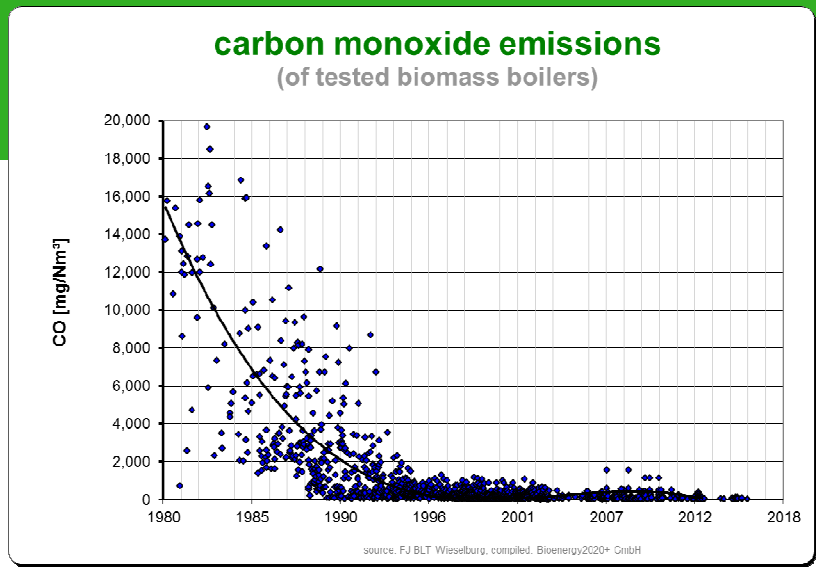
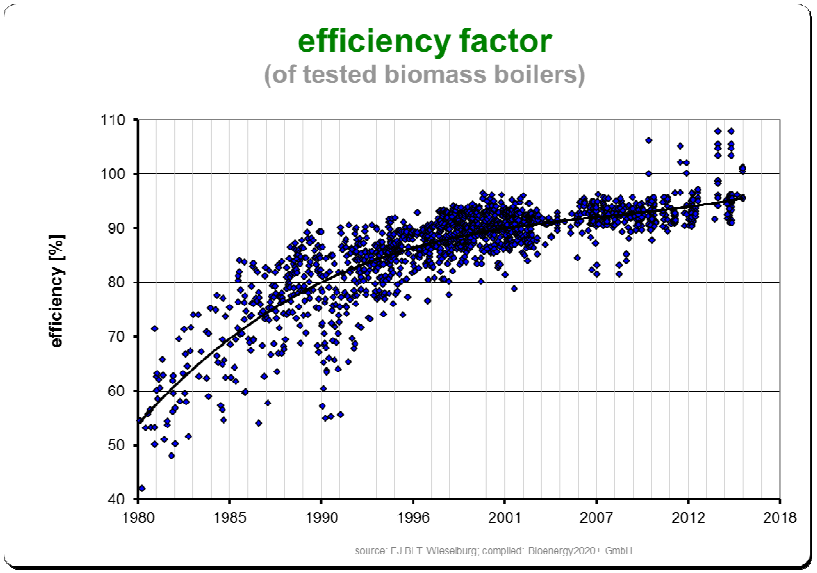
# Outline

- Introduction
- Situation in real life
- PM/TSP and BaP emissions of boilers and stoves
- Comparison with emission factors from inventories
- Current technological progress
- Key (Take-Home) Messages

# Introduction: General

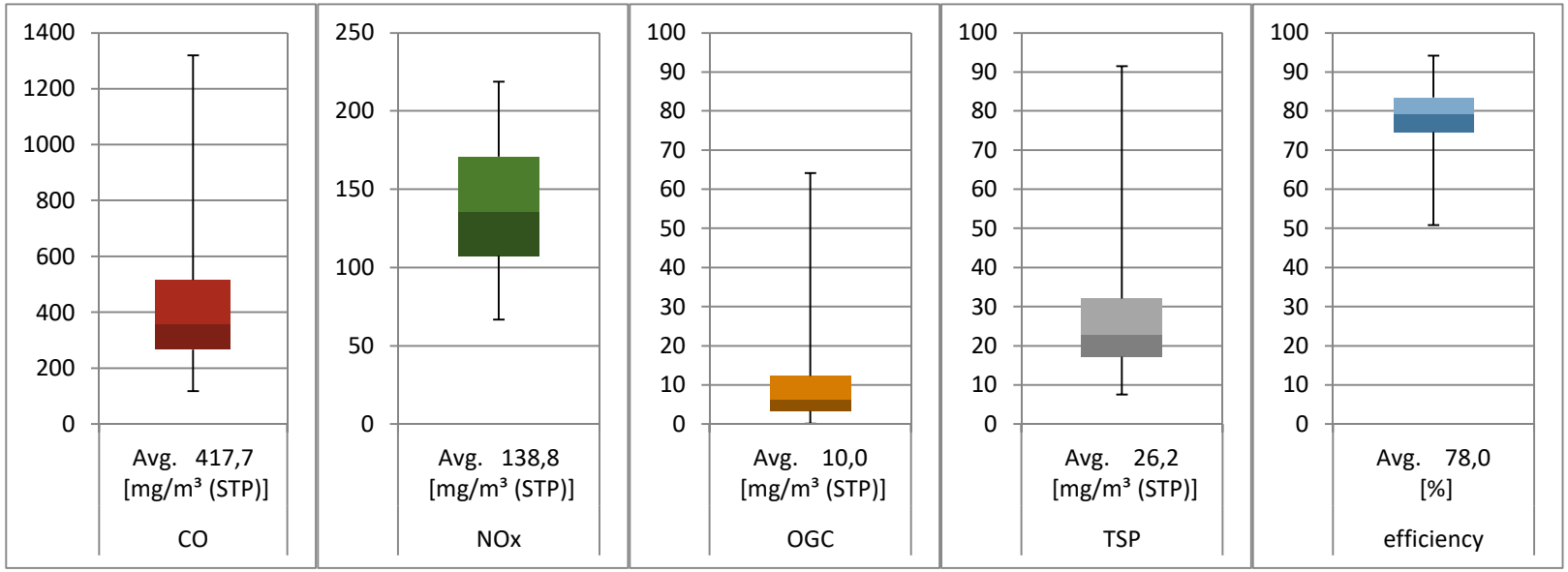
- Biomass Combustion Technology has improved tremendously:
- FJ-BLT Wieselburg Type Testing Averages 2015/16 (n=26):
  - Efficiency = **96%**
  - Carbon Monoxide = **5mg/MJ**
  - Organic gaseous Carbon < **1mg/MJ**
  - **Total suspended Particles = 7mg/MJ**
- Further Improvement Potential?
  - No, or very limited
  - Already complete Combustion
- EN303-5 testing at constant Load Conditions



# What is the situation in the field?

- Real-life (field) emission factors of pellet boiler in modulating operation:



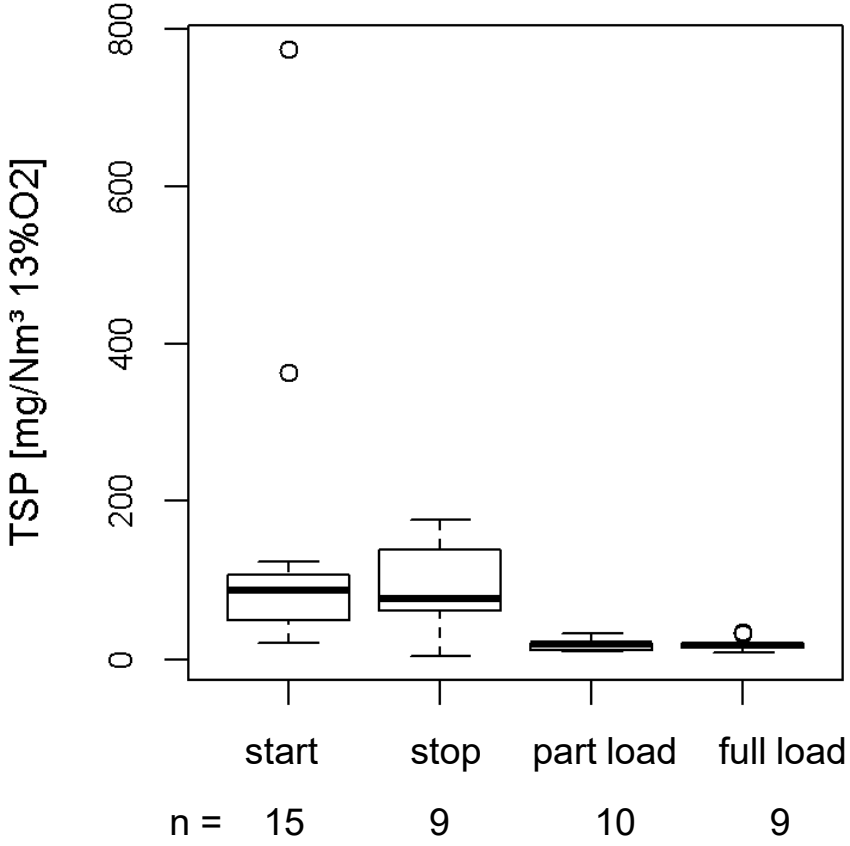

- Variable performance (extremely good – medium)

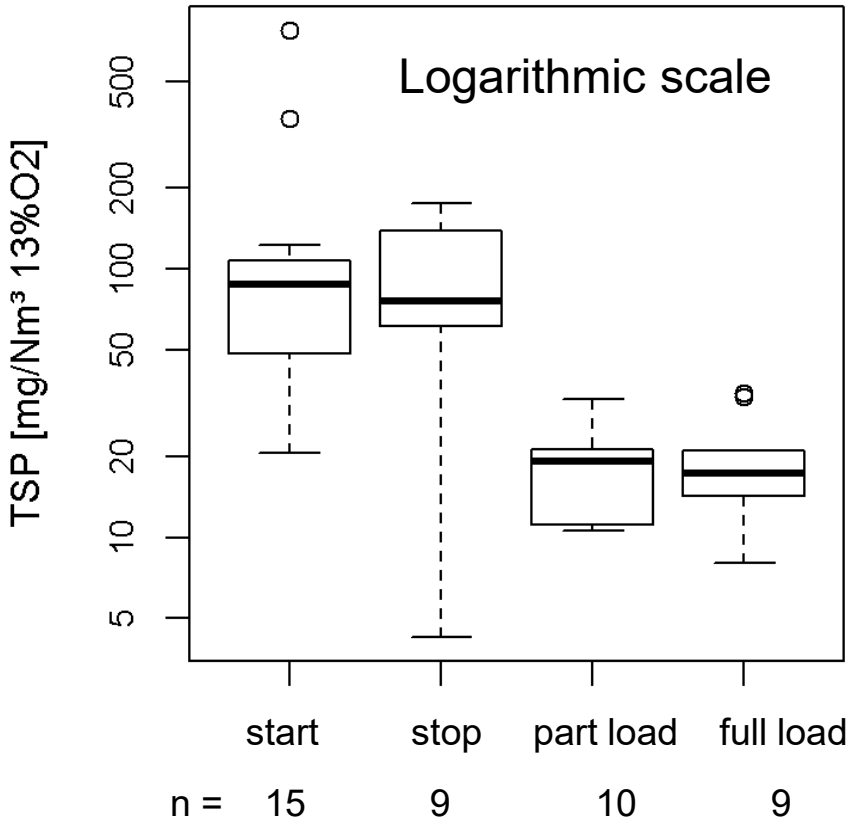


* Data from BioMaxEff project

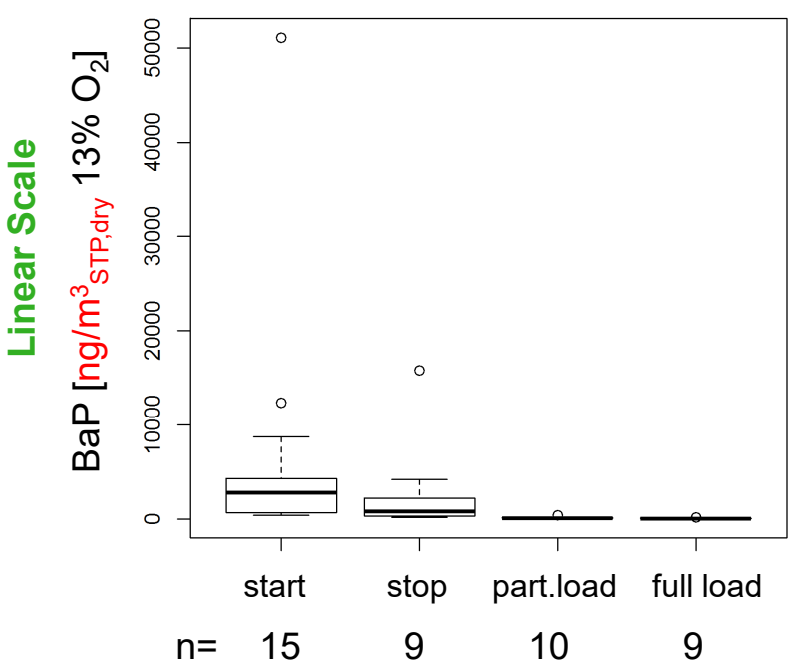
# Main Reason: not only stationary combustion phases in real-life

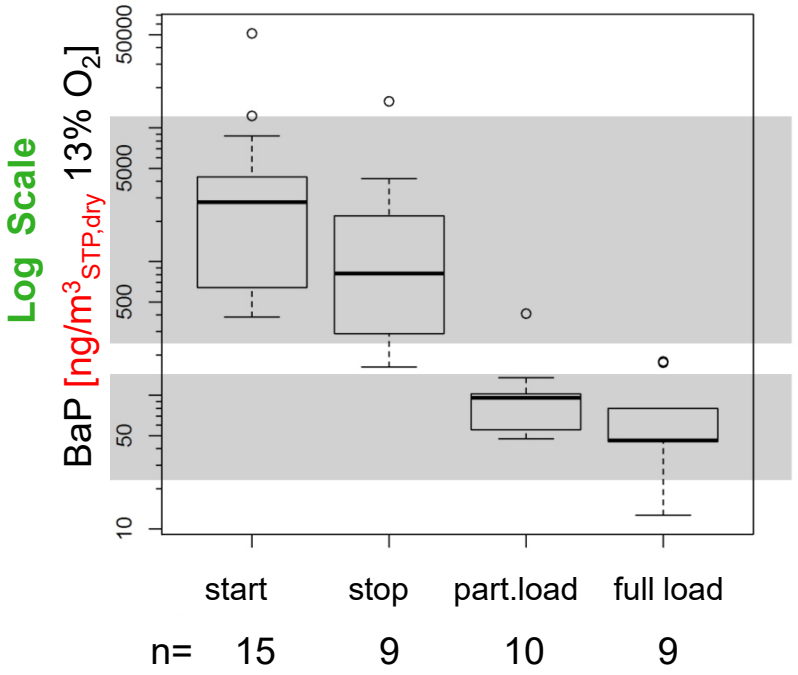
Particle emission concentrations from different biomass boilers



# BaP Emissions – Operation Phases Boilers

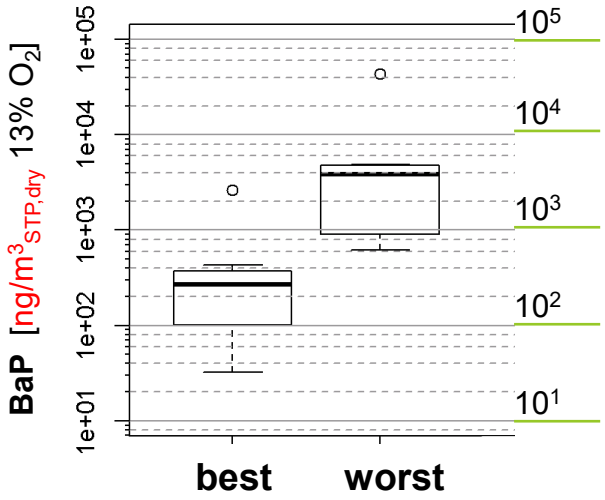



The emissions during start and stop are **1 to 2 orders of magnitude** higher than during continuous operation!

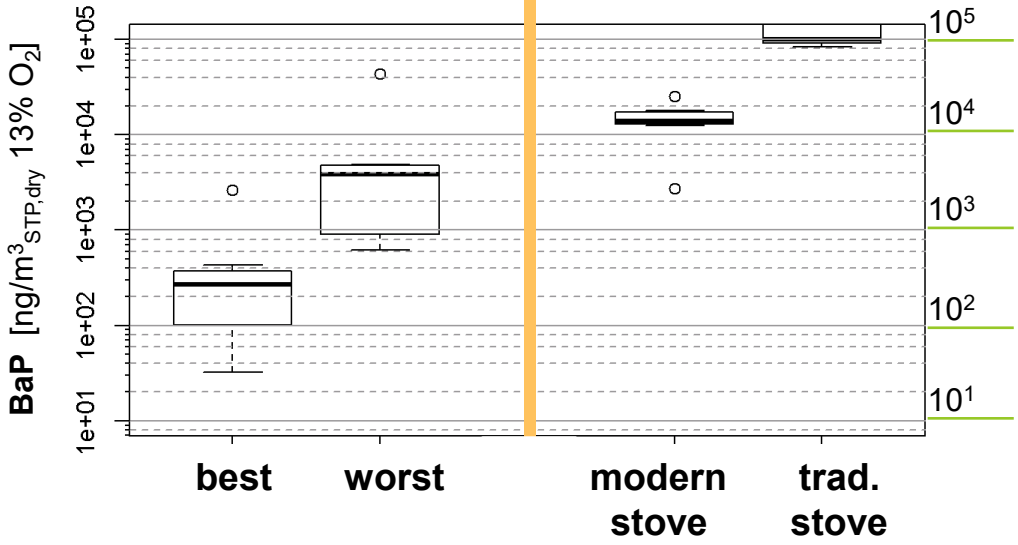
# Comparison with Literature

| Best Case operation | Worst Case operation |
|---|---|
| Automatic boilers | |
| 1x Start and Stop, 8 h full load | Start-Stop-operation |



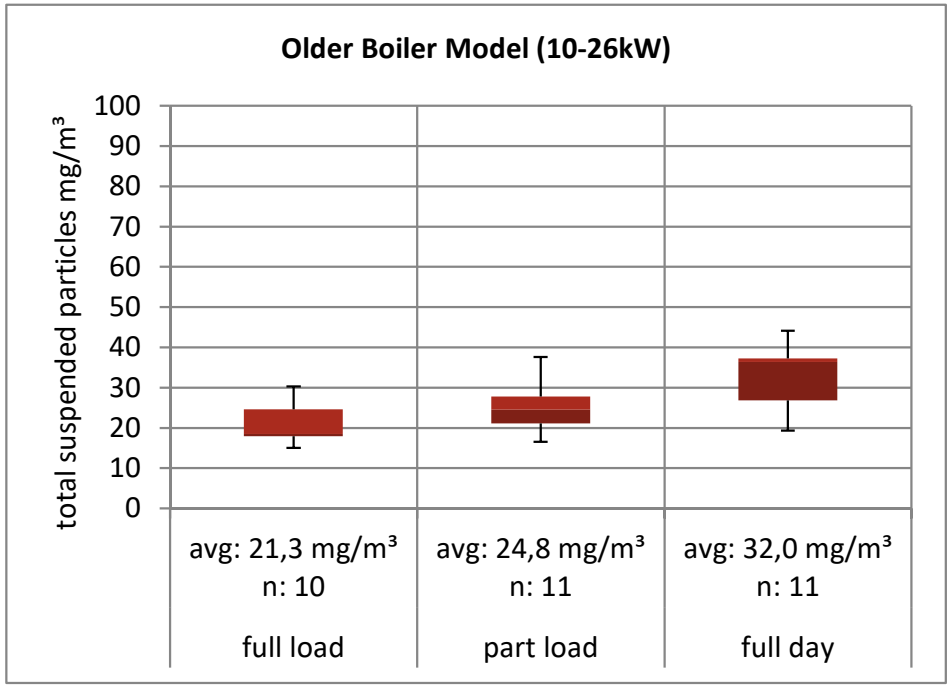
# Comparison with Literature

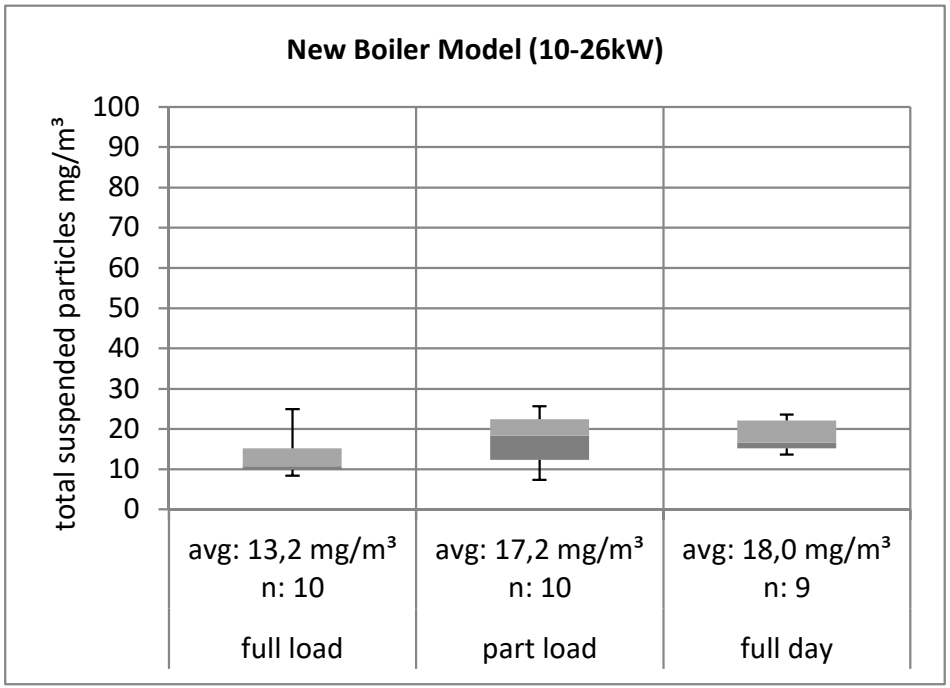
| Best Case operation | Worst Case operation | modern | „traditional“ |
|---|---|---|---|
| Automatic boilers | | Logwood stoves | |
| 1x Start and Stop, 8 h full load | Start-Stop-operation | Primary and secondary air supply (Ozgen et al., 2014) (Kelz et al., 2012) | (Kelz et al., 2012) (Orasche et al., 2012) |




n= 7 7 6 4

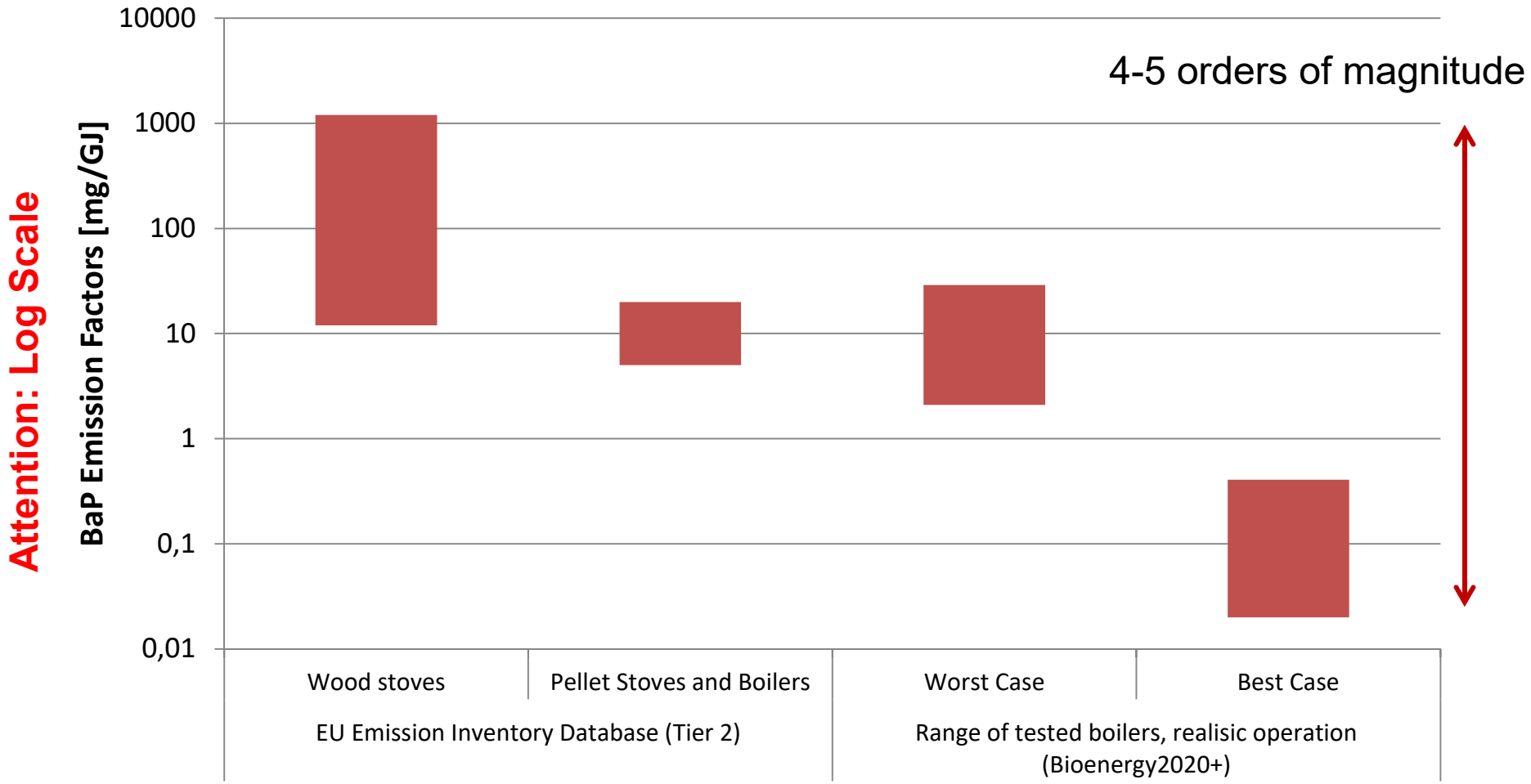
# Best practice in field performance: Pellet Boilers 10-26kW



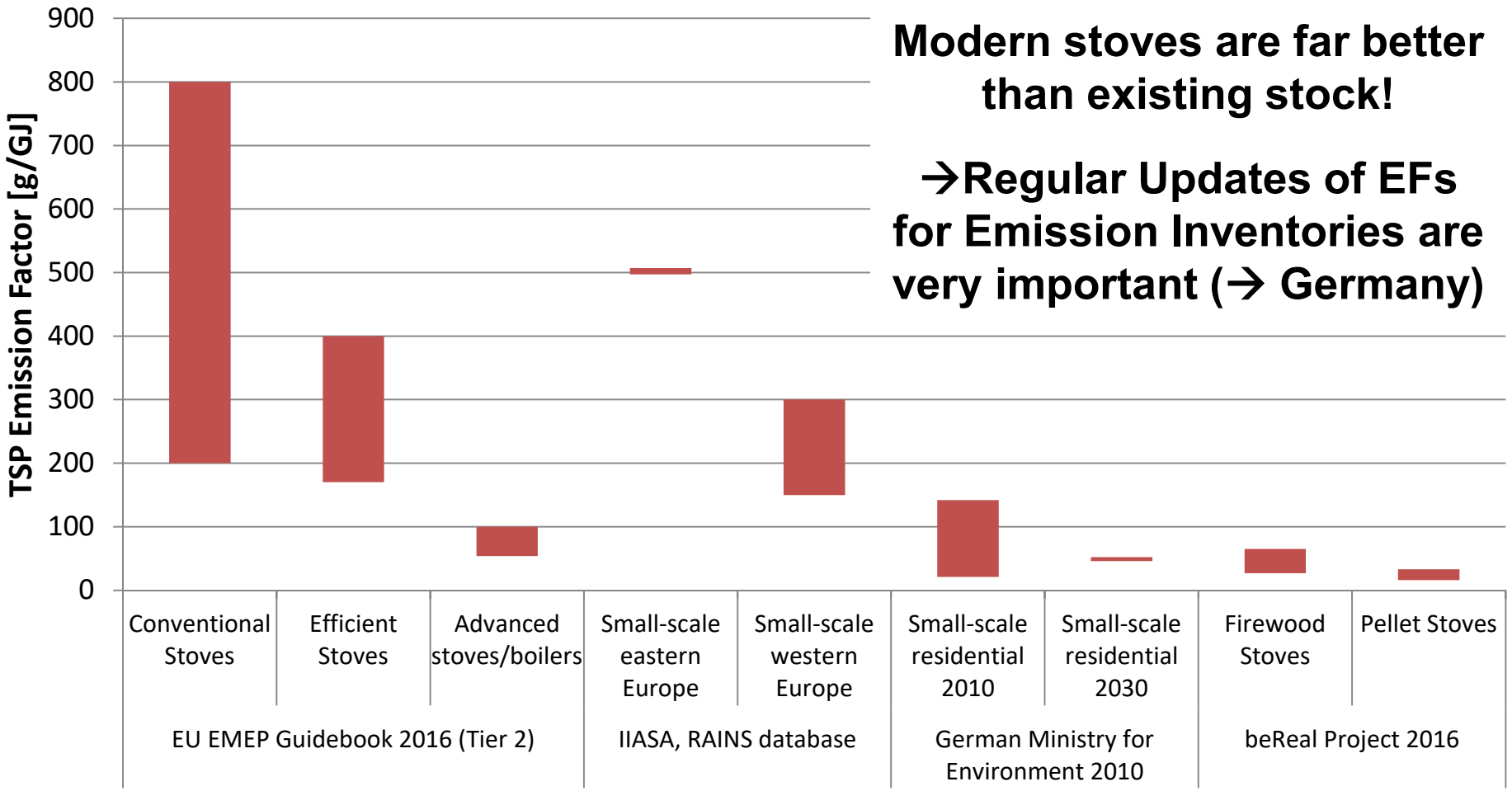




- Improvement of boiler technology is evident
- Narrow distributions → very stable performance even in full day measurements

# Boilers/Pellet Stoves: BaP Emission Factor Comparison



# TSP (Dust): Emission Factor Comparison




**Modern stoves are far better than existing stock!**

**→Regular Updates of EFs for Emission Inventories are very important (→ Germany)**

# Current technological Progress (Examples)

- Intelligent Control Algorithms:
  - E.g. Model based Control Concepts
- New combustion concepts
  - Extreme air staging (for boilers)
  - Candle burning principle (for stoves)
- Integration of secondary abatement systems (e.g. Electrostatic precipitators)
- Real life optimisation and testing methods

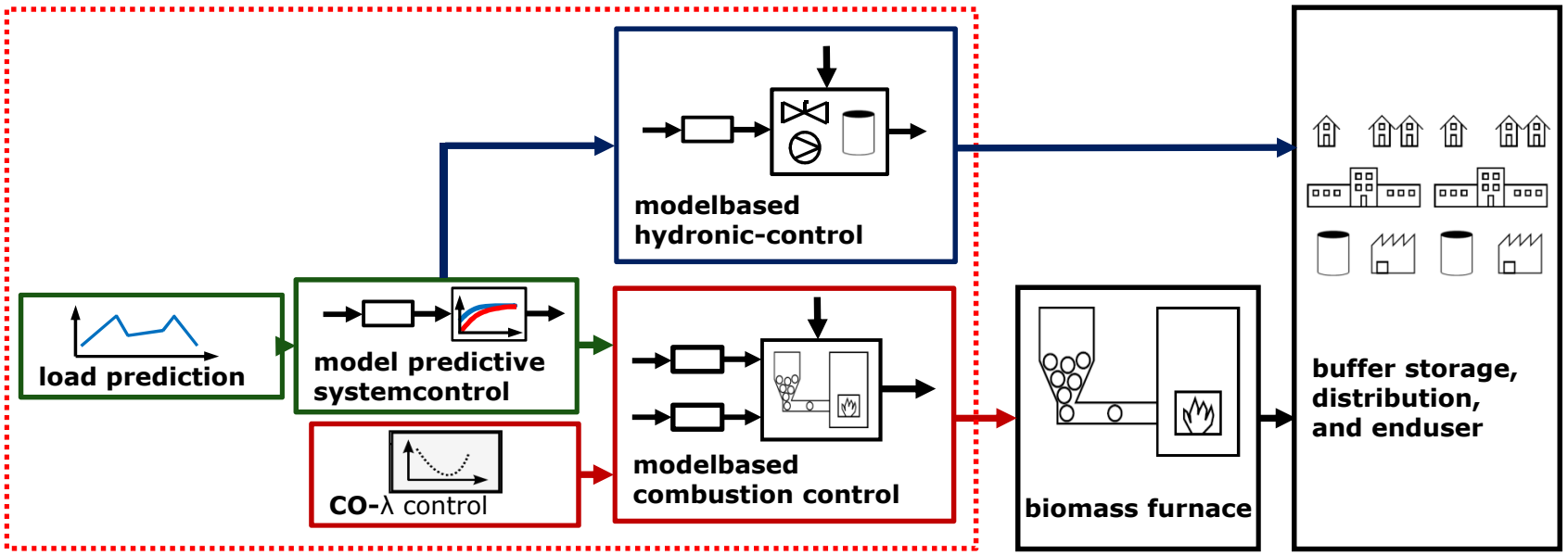
# Innovative Control concepts: Model-based control

- **Automatic adjustment** of control strategy to changing fuel properties (water content, density)
- **Stable load conditions**
  - Faster response to load changes
- **Stable trend of oxygen concentration in all load ranges**
  - Potential for the reduction of $O_2$-concentration → improvement of efficiency
- **Reduced emissions (CO and particulate matter)**

# Intelligent control algorithms

## Optimisation of the operation by model based control – modular approach

independent of range of capacity




Source: Bioenergy2020+ GmbH

# Extreme air staging – Motivation and Concept

- Particle reduction without any additional precipitators
- Additional costs are expected to be lower than standard technologies + filter (suited for lower power levels)
- Synergy effects with $NO_x$ reduction
- Results show - depending on fuel quality – similar or even lower emission values as for (economically feasible) electrostatic precipitators
- Technology is interesting for small- and medium scale starting at around 20kW (to 2 MW)

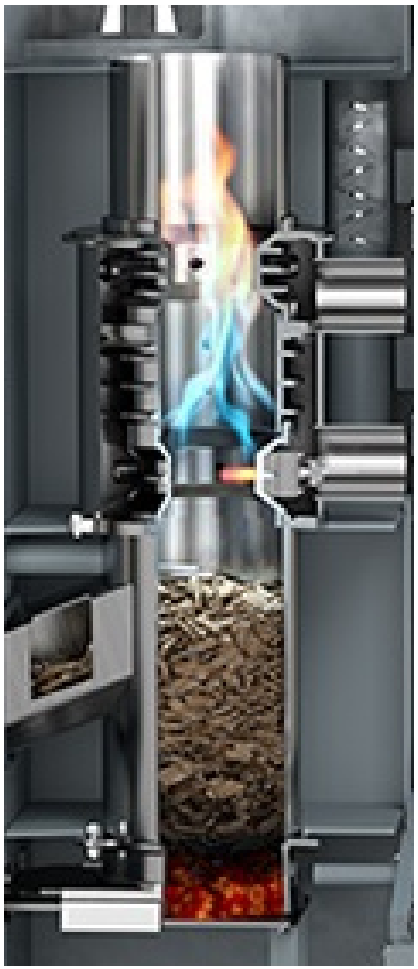
# Extreme staged combustion – Concepts and Development Challenges

Secondary and tertiary air

Gas ignition

Fuel bed

$\lambda_{primary} < 0,5$



- Load modulating operation more difficult
- Material lifetimes
- Secure flame formation (i.p. during start-up
- Emissions during start/stop
- Stable fuel bed (homogeneous flow)
- Tight ash removal system to maintain reducing conditions (avoiding false air)

➢ finding suitable system configuration and control concept

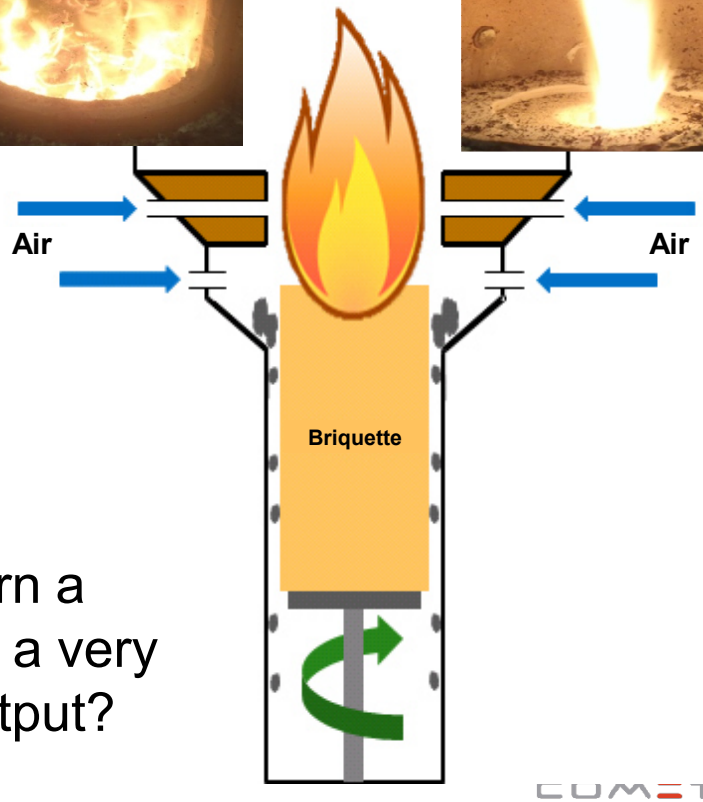
Source: Windhager Zentralheizung Technik GmbH

# New combustion concepts for stoves

**Briquette Candle Burner**
PCT Patented

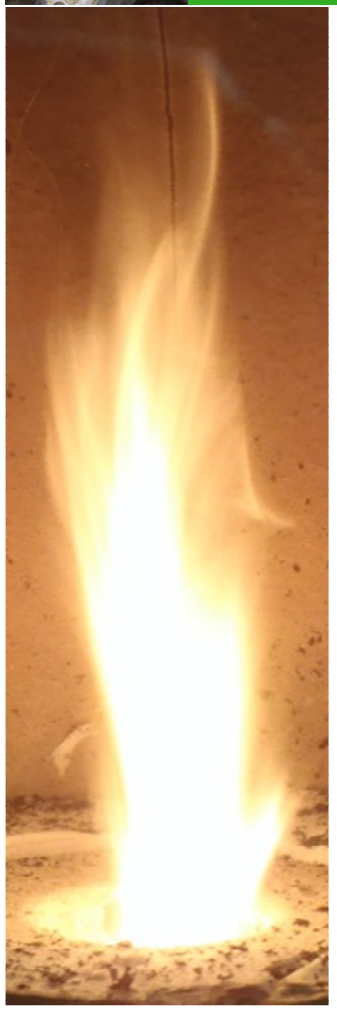
≈

Combustion Chamber

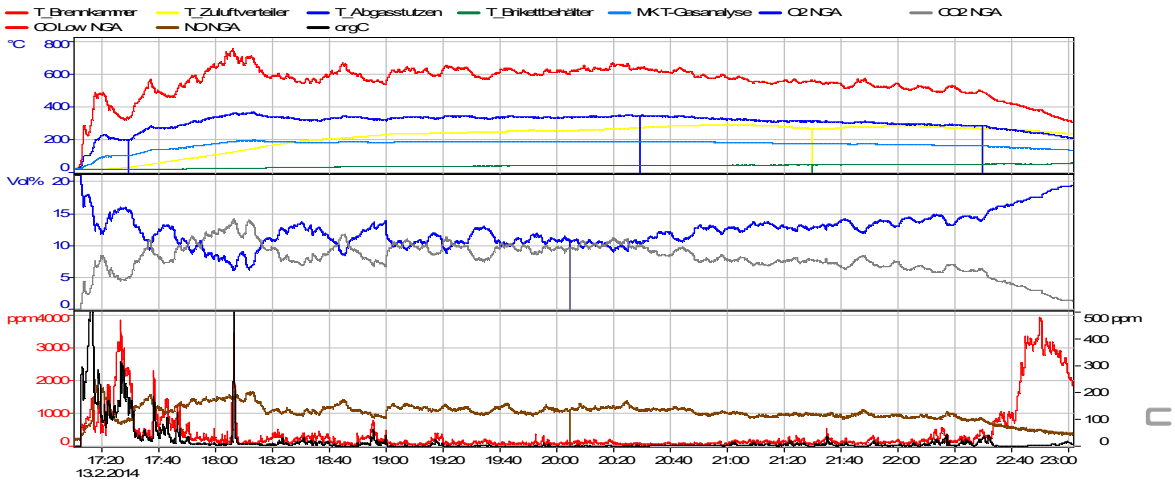



How to burn a briquette with a very low heat output?

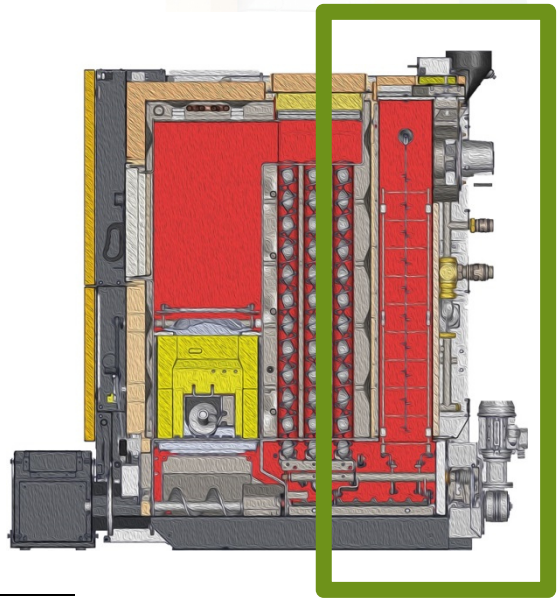
# Candle burning principle – Motivation / Advantages



- Semiautomatic operation with a flame design comparable to a log wood stove
- Comfort: Long burning periods (e.g. 8 hours for 2 briquettes)
- Low loads: Well suited for low energy buildings
- Low emissions also for low loads (1-2 kW)



# Integrated Particle Precipitators

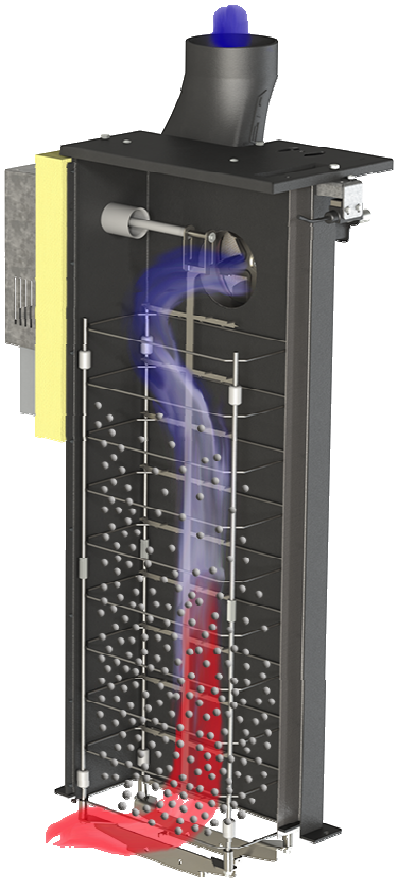



- Conformity and security to stay significantly below limit values
- Compact design provides advantages in space demand and during start up.
- Coupling with cleaning system of heat exchanger effects efficiency
- Combined ash removal and control systems allow a reduction of production costs compared to stand alone solutions.
- Power range > 100 kW



Sources: Eta Heiztechnik GmbH,
KWB Kraft und Wärme aus Biomasse GmbH

# Integrated precipitators - success criteria

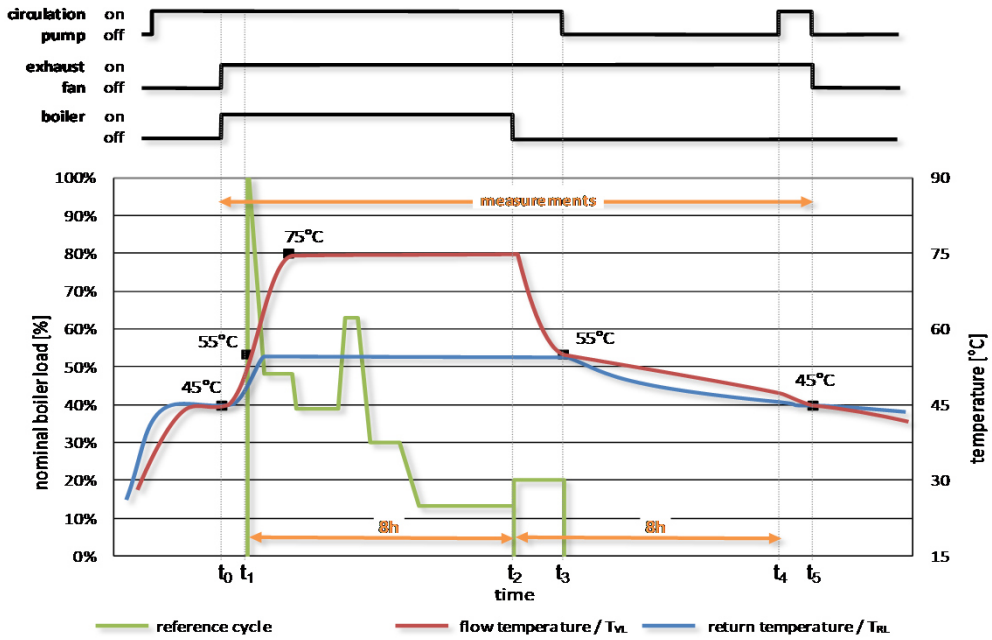


Source: Eta Heiztechnik GmbH

- Modular compact design
- Long-term stability of electrostatic field for sufficient precipitation efficiency
- Cleaning efficiency of electrode and deposit surfaces
- Cost reduction compared to standard boiler + standard filter

# Real-life oriented testing methods

- Testing methods strongly influence technological development
- Real-life oriented testing methods can support / force development into the right direction
- Proposals for such methods are available:
  - Load Cycle Testing of Boilers
  - beReal Tests for Stoves (see separate presentation)







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# Key (Take-Home) Messages 1

1. Modern biomass combustion technology has reached a **very high level of performance** under standardised testing conditions (~ complete combustion in boilers).
2. **Further sharpening of** already very low emission **thresholds** (in regulations or quality labels) will mainly increase the turnover of testing labs (for re-testing) but **will not improve the performance in real life**.
3. The **keys to better air quality** are
   a) **Replacement** of old appliances (factor: 10 – 100(0))
   b) **Development-focus on real-life performance** (supported by **suitable testing methods**)

# Key (Take-Home) Messages 2

4. Innovative solutions for further improvement of the performance of biomass appliances in the field are…
   a) **Advanced control strategies** such as model based control systems for combustion- and load-control (reducing starts and stops)
   b) **New combustion concepts** implementing advanced primary measures for emission reduction (e.g. extreme air staging, candle burning principle)
   c) **Secondary emission abatement** technologies for bigger size boilers (~ > 100kW)

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ideas with a future

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# Supporting Information

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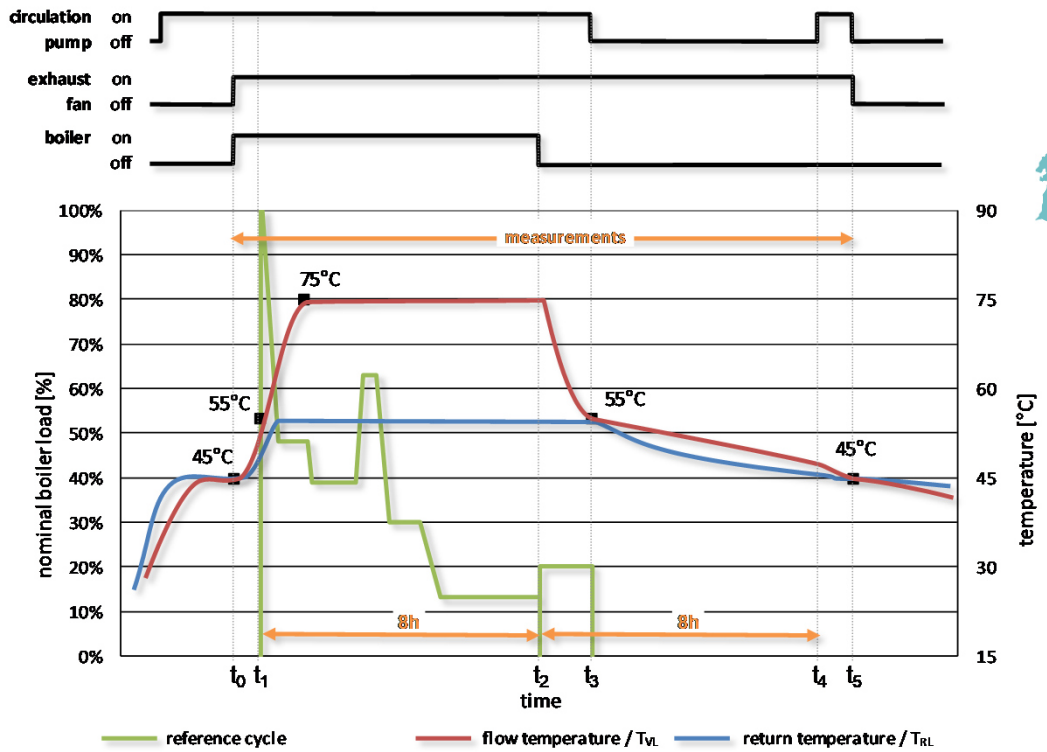
# Methodologies Study 1

- Laboratory: Full Load, Part Load and **Load Cycle Test** (8-hour Modulation)



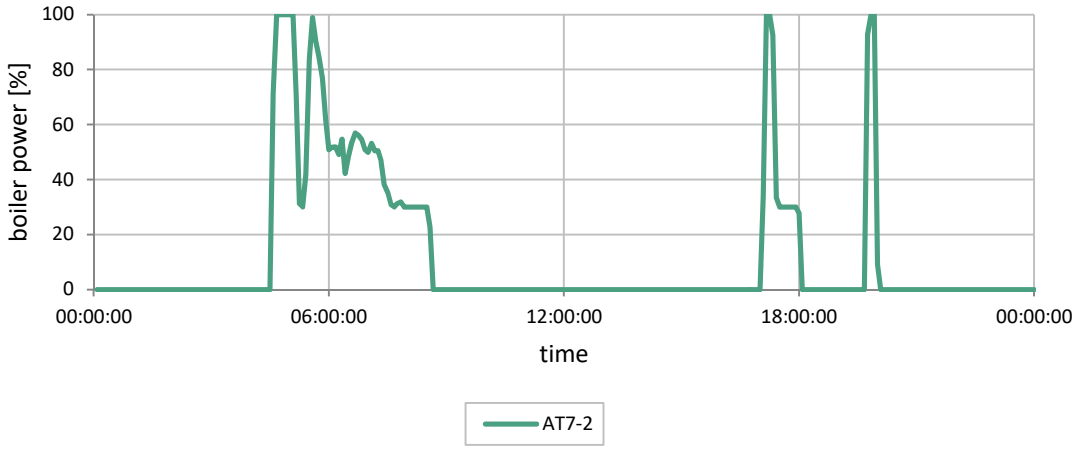




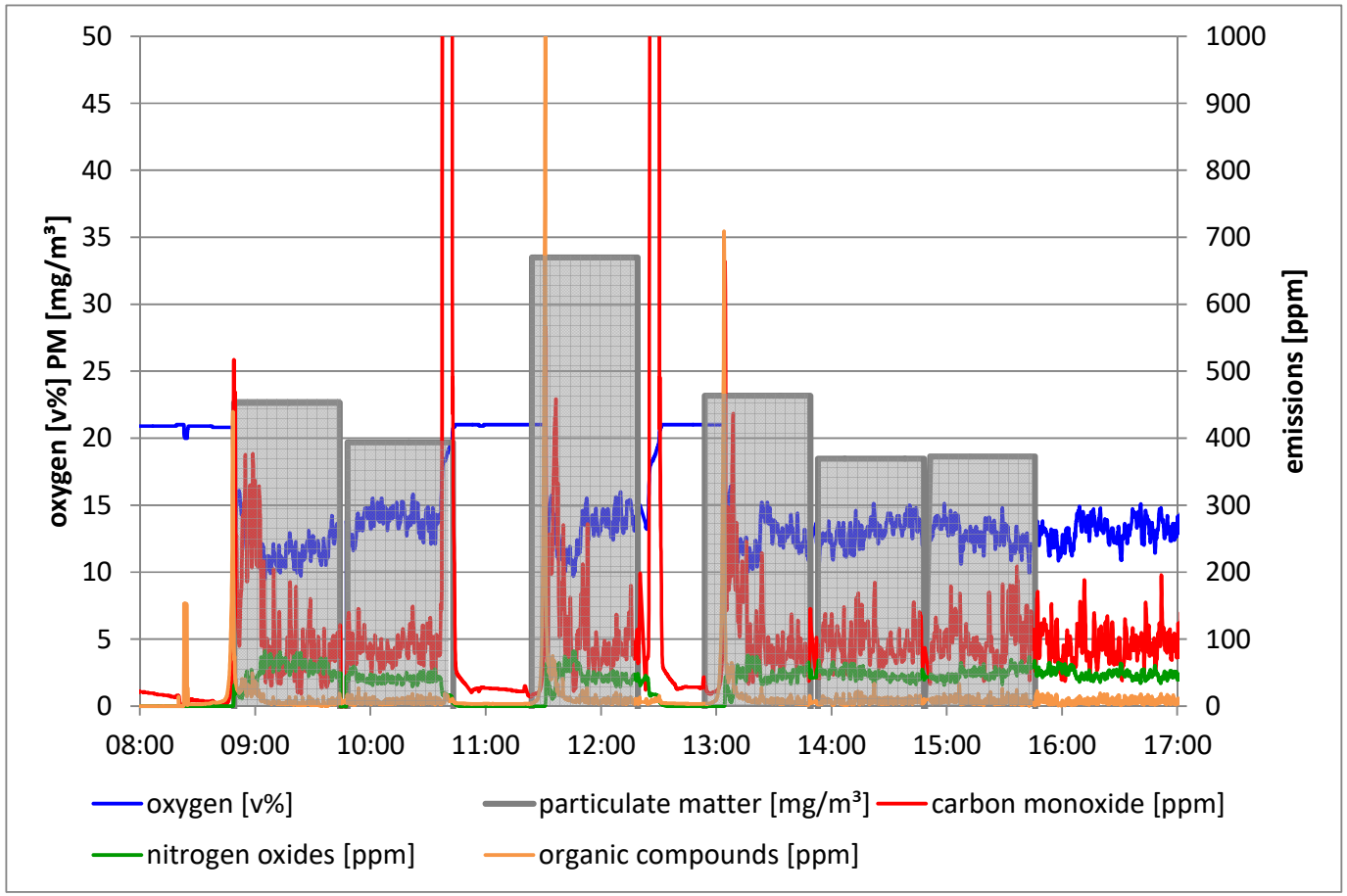
- Field Measurements (n=73):
  - 18 Sites, 3 Building Types (new, refurbished, old)
  - Continuous Efficiency Monitoring over up to 3 years
  - Full Load Test in Field
  - Real Life Operation: 24h Emission testing

# Results Study 1: Field measurements

- What's the real boiler operation behavior?
- Boiler operation behavior depends on
  - boiler type
  - weather
  - building
  - user habits



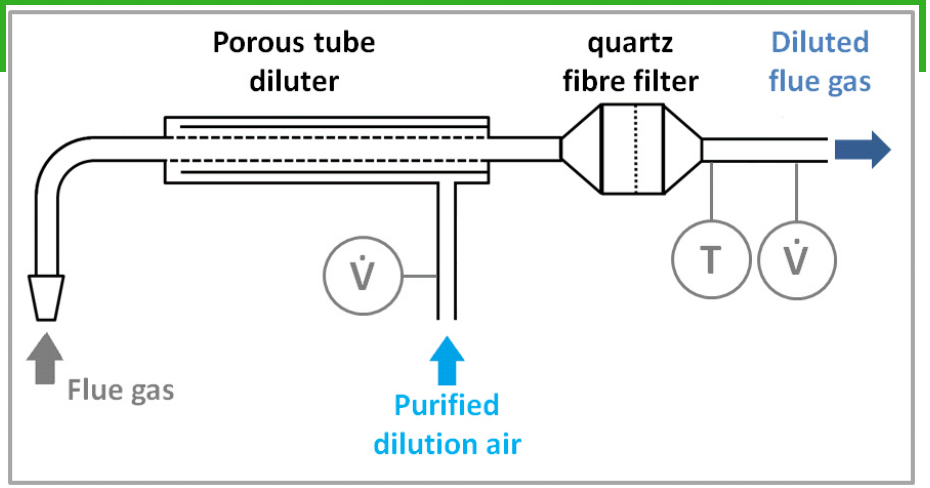
# Example from 24h field emission measurement



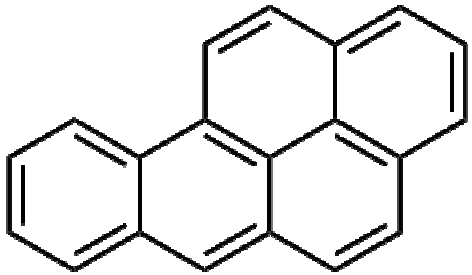
# New testing methods: Comparison Load Cycle Test – Real Life Performance

| | | Pellet Boiler 1 | | Pellet Boiler 2 | | Pellet Boiler 3 | |
|---|---|---|---|---|---|---|---|
| **Parameter** | Unit | Load cycle | Real life | Load cycle | Real life | Load cycle | Real life |
| **CO** | [mg/m$^3_{STP}$] | 272 | 343 | 434 | 358 | 415 | 447 |
| **NOx** | [mg/m$^3_{STP}$] | 110 | 135 | 158 | 151 | 128 | 120 |
| **OGC** | [mg/m$^3_{STP}$] | 9 | 7 | 24 | 7 | 3 | 5 |
| **Dust** | [mg/m$^3_{STP}$] | 37 | 25 | 30 | 32 | 27 | 18 |
| **Efficiency** | % | 78,2 | 75 | 75,2 | 83,6 | 81,1 | 83,2 |
| **Annual Efficiency** | **%** | **-** | **72,4** | **-** | **78,8** | **-** | **81,4** |

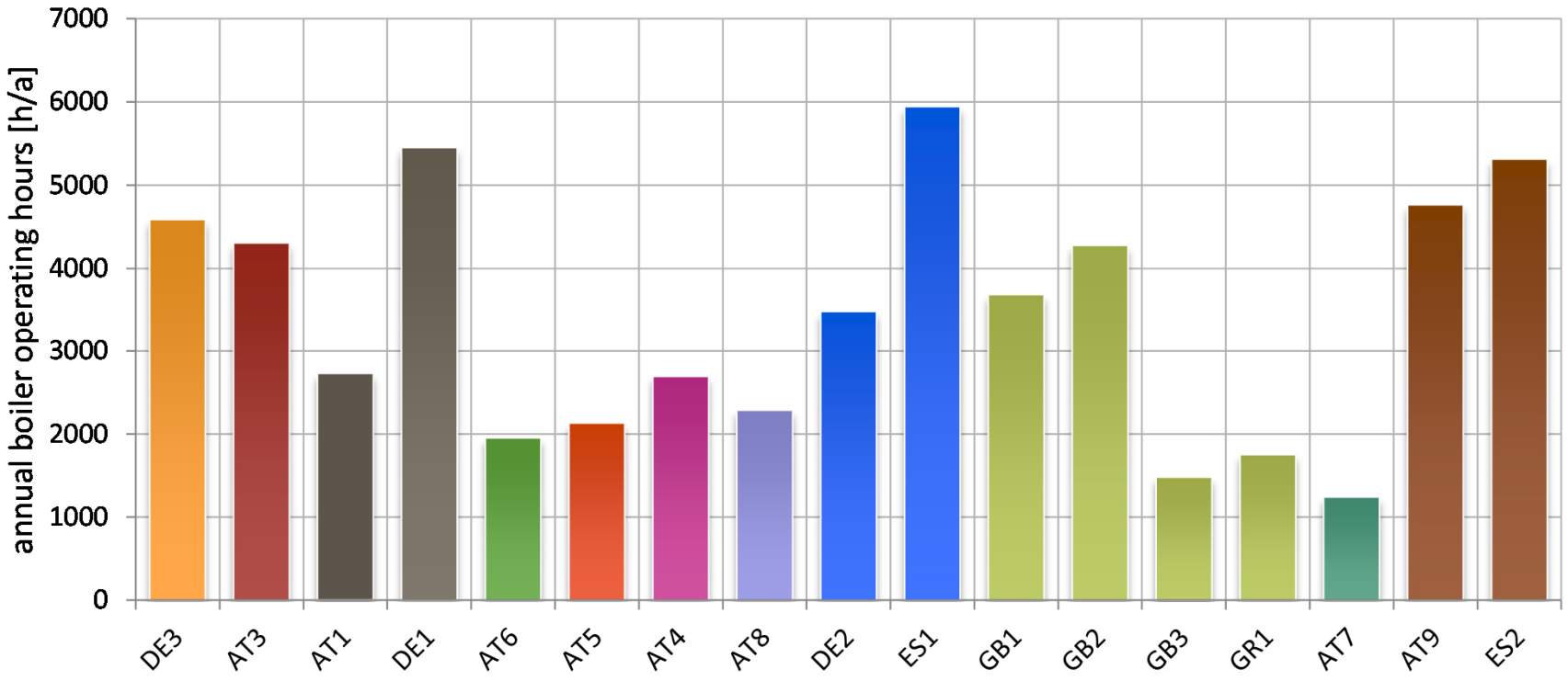
# Methodology Study 2: Dilution Sampling for TSP and BaP



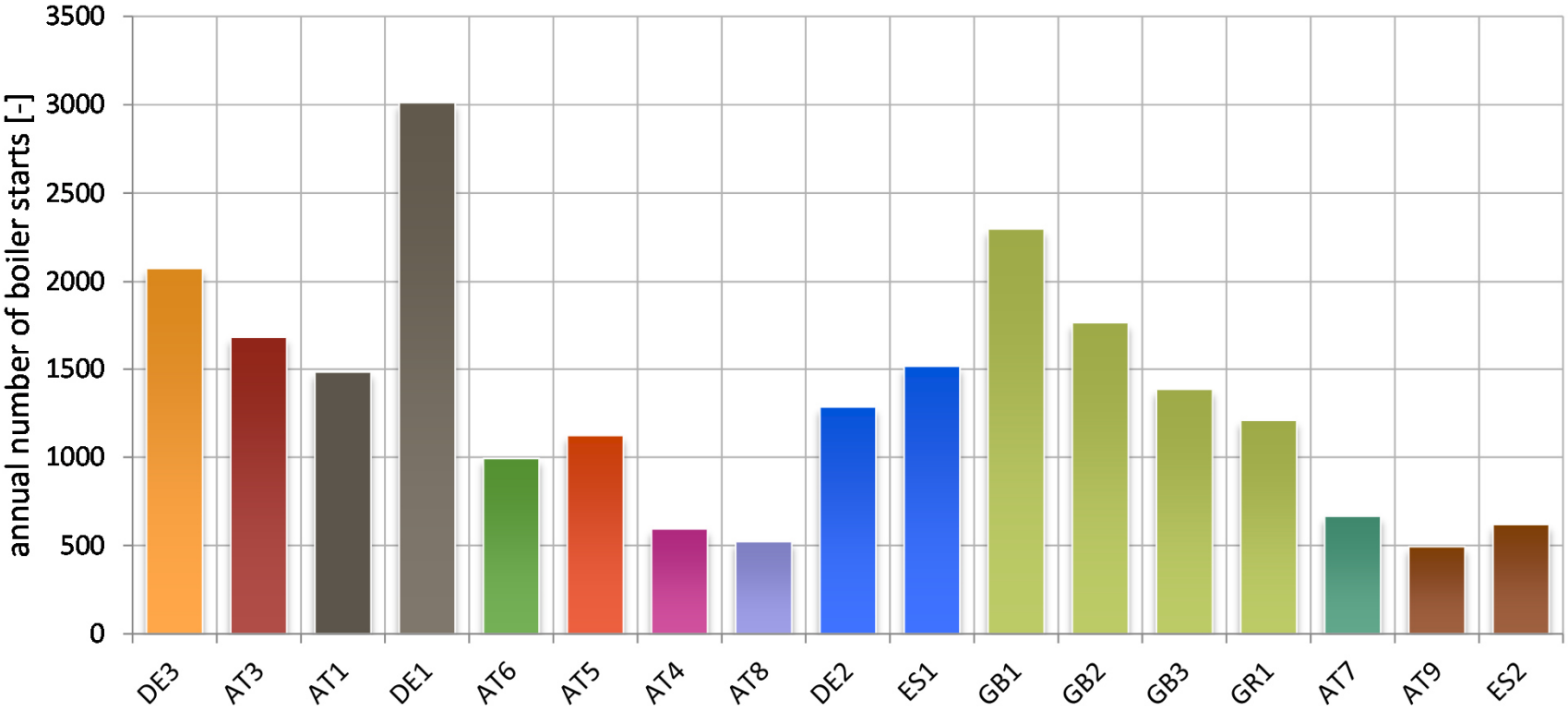

- Sampling:
  - Start/Stop/Nominal-/Part-Load
  - Dilution method (ISO 11338-1)
  - Dilution ratio: 1:10
  - Filter T <40°C
  - Isokinetic sampling at steady state operation
- Storage/Transport: sealed filter or solution; T < 0°C
- Analysis:
  - Adapted to DIN EN 15549:2008 and VDI 3874
  - Diluted in cyclohexane and dichlormethane
  - Analysis with  GC-MS (Quadrupole – mass spectrometer)



# Boiler operation hours



# Boiler starts



# Methodology: definition of sampling phases

| | From: | Until: |
|---|---|---|
| **Start:** | Start of the ignition system | CO- **&** Temp- criteria are fulfilled<br>→ **(100ppm + ∅ $CO_{full\ load}$) &**<br>**(90% from ∅ $T_{full\ load}$)** |
| **Stop** | Decreasing fuel load → indicated by increasing CO-conc | Air fan (air supply) stops. |
| **Full load** | At least 1 hr at steady conditions | |
| **Partial load** | At least 1 hr at steady conditions, 30 % of nominal load | |