Emission abatement using integrated catalysts in log wood stoves

Ingo Hartmann

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sponsored by DBU Deutsche Bundesstiftung Umwelt

Challenges – General remarks

- Increasing importance of **energetic use of biomass**
- Energetic use mostly coupled **combustion process** → **Flue gases**
- **Primary measures** not sufficient to meet **future emission limits**
- Use of different biomasses → requires different **secondary measures**

Challenges – Biomass Combustion

Wood log for heat production
instationary process
strong influence of the catalyst on the overall system
T > 770 K
High dust emission

➢ This leads to…

Requirements for emission control catalysts	
Integrated catalyst	Downstream Catalysts
Very low back pressure	Low back pressure
High temperature resistance (ca. > 1150 K) → **metal oxide**	Moderate temperature resistance (ca. < 950 K) → **noble metals**
high activity towards total oxidation of CO and C_XH_Y at high T	high activity towards total oxidation of C_XH_Y at T < 720 K

Background: Micro-scale biomass combustion

Small-scale combustion systems in Europe[1]

- Heating appliances in the capacity range 0-15 kW on the European market are basically fireplaces and stoves (26 Mio wood log stoves in EU 27)
  - → batch operation, upper flame combustion, user influence
  - → high emissions of CO, OGC and PM
- Pellet boilers and stoves: ≥ 10 kW
- Wood log gasification boiler (downdraught): ≥ 15 kW

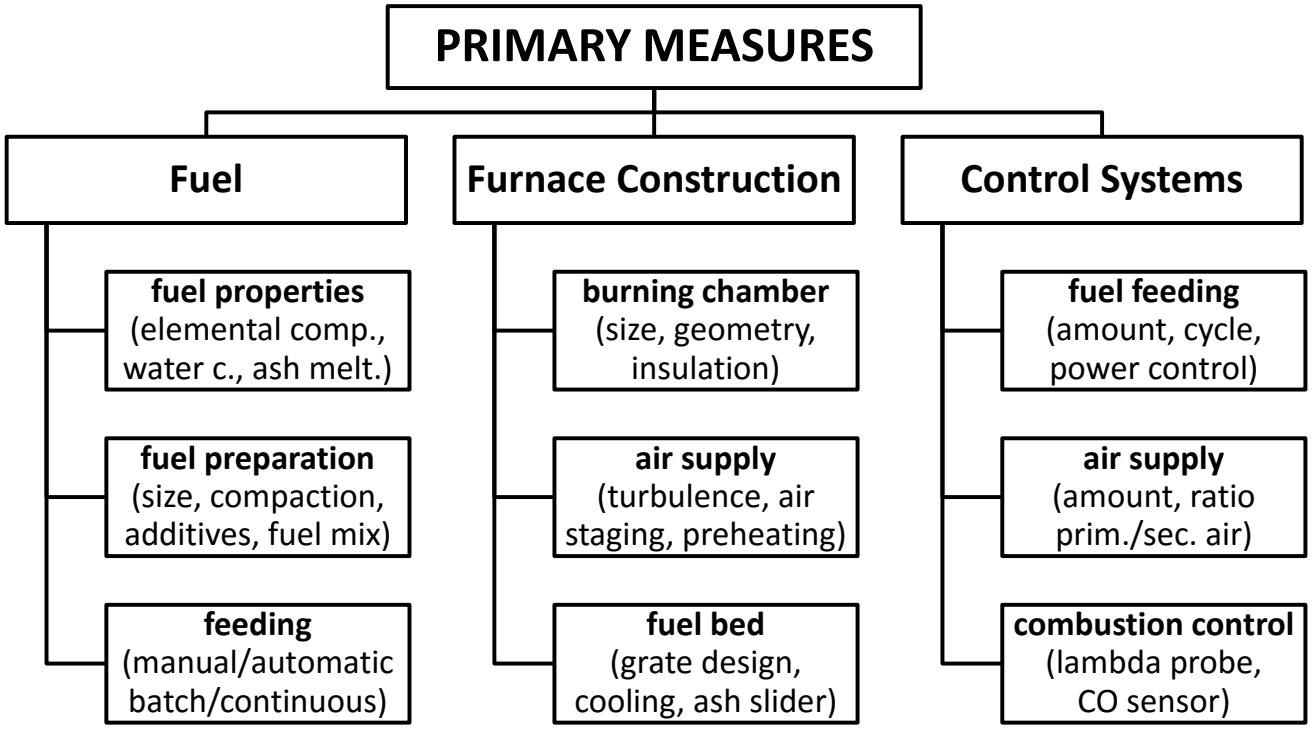
Better energy performance of buildings

- Decrease of heat demand (<< 10 kW, for low-energy houses < 5 kW)
- Currently available systems achieve small annual utilization ratios, frequently operation at partial load with low efficiency and high emissions

→ Development of continuous biomass combustion systems < 5 kW

[1]Mudgal S. et al., LOT 15 Solid fuel small combustion installations – Economic and market analysis, Bio Intelligent Service S.A.S, France, 2009

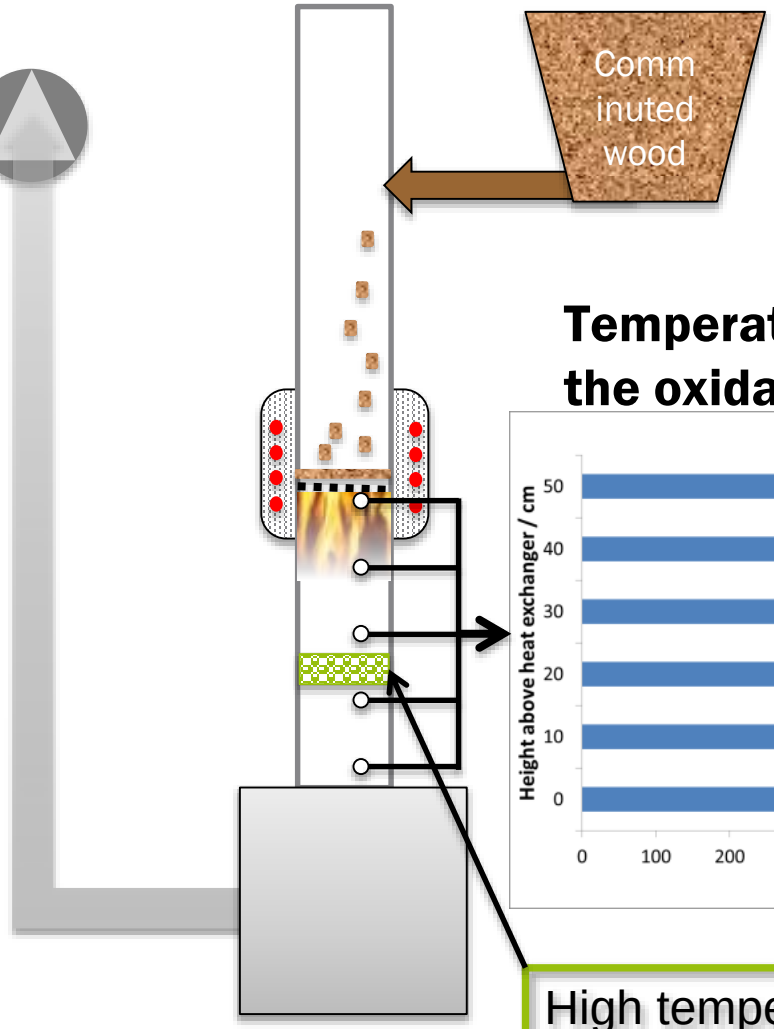
Development of a micro-scale installation



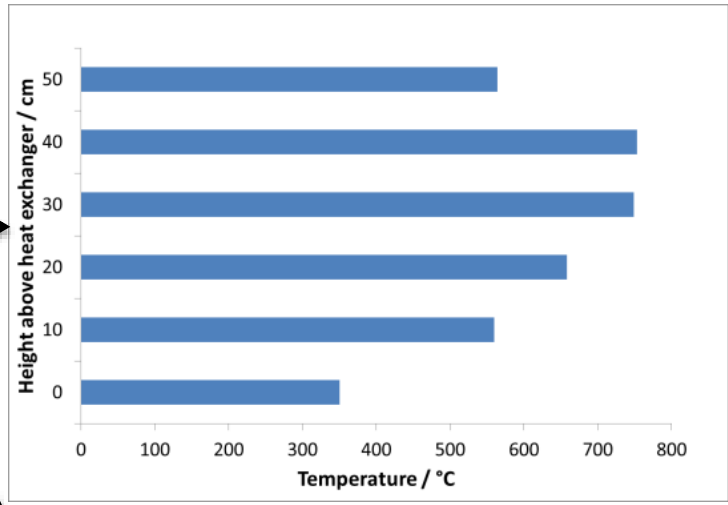
For the development of micro-combustion systems 3 research topics were identified:

- fuel preparation and feeding (automatic and continuous fuel supply)
- Furnace construction (down draft, grate design)
- control systems (air supply, combustion control)

Development of a micro-scale installation



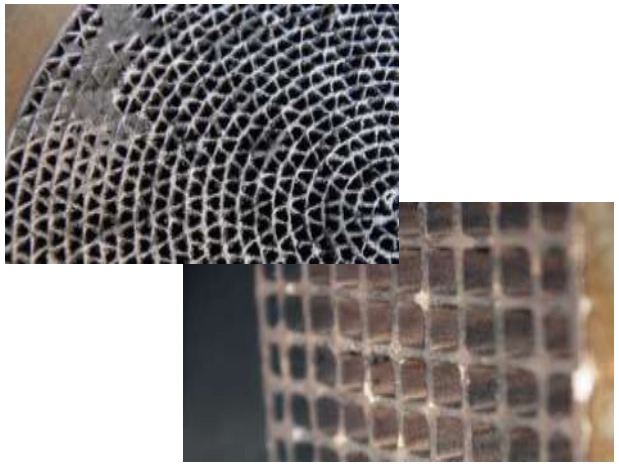
Temperature profile in the oxidation reactor



High temperature stable catalyst (Alumina foam)

Emission reduction by catalysis

- **Some catalysts are commercially available for biomass combustion systems**
  - Noble metals as active material on metal or ceramic support with γ-Al_2O_3 washcoat
- **Challenges for Application of Catalysts in smale scale biomass combustion**
  - Fluctuating temperatures and flue gas composition
  - Wide range of pollutants: CO, VOC, soot…
- **Deactivation of catalyst**
  - Catalyst poisons
  - Thermal
  - Blockage with particles



Main effects observed during use of commercial available catalysts

Emission reduction by catalysis

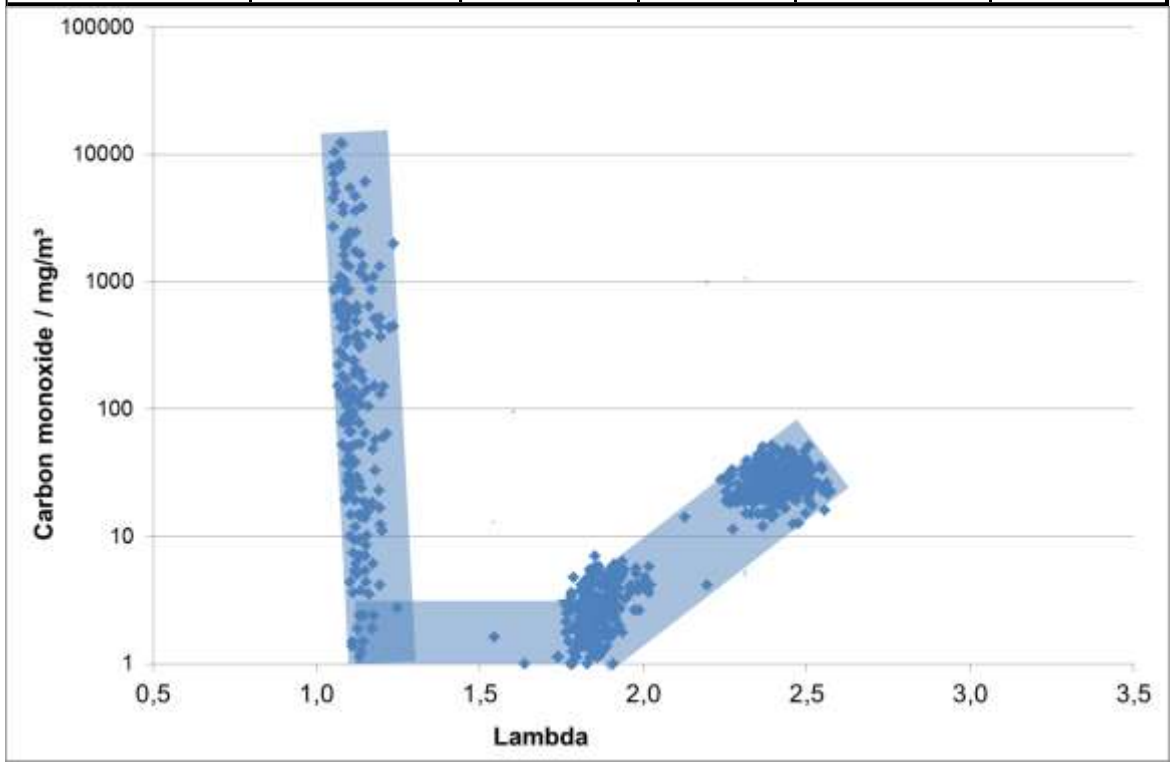
Application of ceramic foam in micro-scale installation

- **Mixed metal oxides on alumina foam**
  - Cell density: 10 ppi
  - Reduction of CO and VOC up to 70 % possible (tested in downdraught stove)
- **Integration into the combustion chamber**
- **No blockage after 25 h of operation**
- **Heat accumulation**
  - Temperature increase of 100-150 K in flame zone (Flue gas temperature zone: 700-800 °C)
- **Aim of Investigations: Characterization and analysis of materials and occuring processes during catalytic gas treatment in biomass combustion systems**

Emission data with Alumina foam

Mean Values (13 Vol.-% O_2)

Air Supply PA/SA	TSP	O_2	CO	Org.-C (FID)	$NO_{2Äqui}$
	mg/m³	Vol.-%	mg/m³		
0.7/1.0	4	8.3	0	0	193
0.7/0.6	2	2.7	125	1	165
0.7/1.4	5	12.2	28	1	223
0.7/1.0	3	9.6	2	0	185



- System Low emission combustion
  - PM < 5 mg/m³
  - CO < 5 mg/m³
  - Lambda: 1.1 – 2.2
- Reproducible operation with automnatic feeding of comminuted wood
- Developement towards practical system is going on
- System is used for catalyst screening
  - Activity
  - Ageing
  - Abatement Soot

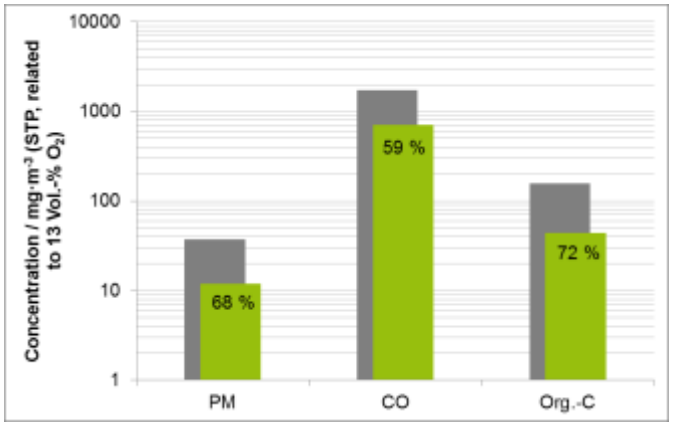
Emission reduction by catalysis

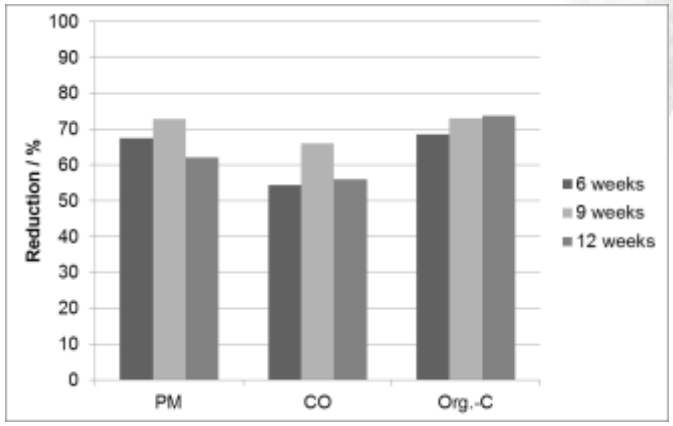
Possible emission reduction by integration of catalytic active foams

- **University Leipzig, DBFZ and Specht GmbH: Developement of catalyst for biomass combustion systems**
  - Mixed metal oxides on Alumina foam

→ **Patent application has been approved (2012)**

- **Effect and long-term stability for application in downdraught stove**

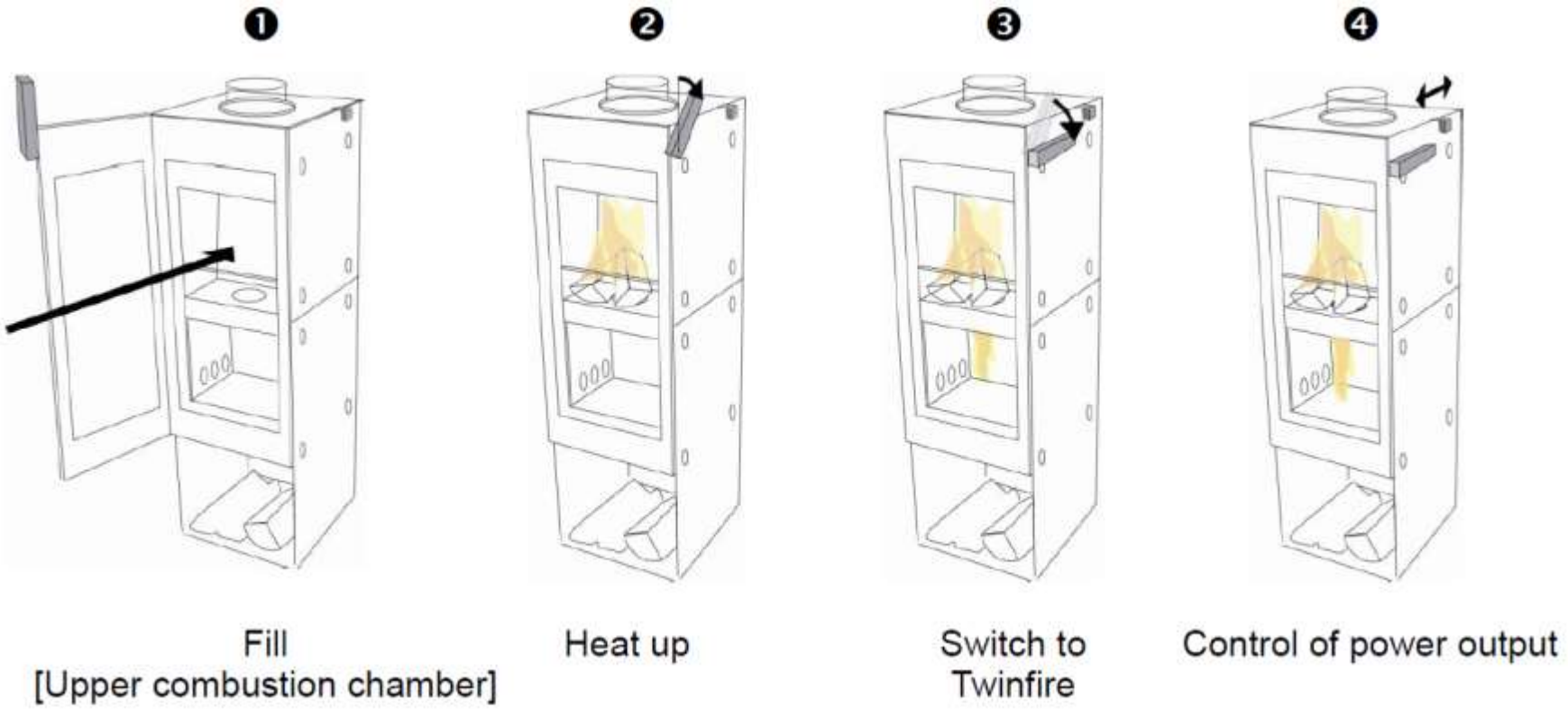




- **Comprehensive characterization for transfer to other installations**
  - Occuring catalytic reactions and catalyst properties (range of application)

Starting point for the development

xeoos „TwinFire“ wood log stove from German company Specht:



Patent: Stove for solid fuels (EP 1340943 A2)
Stahl- und Apparatebau Specht OHG (2002)

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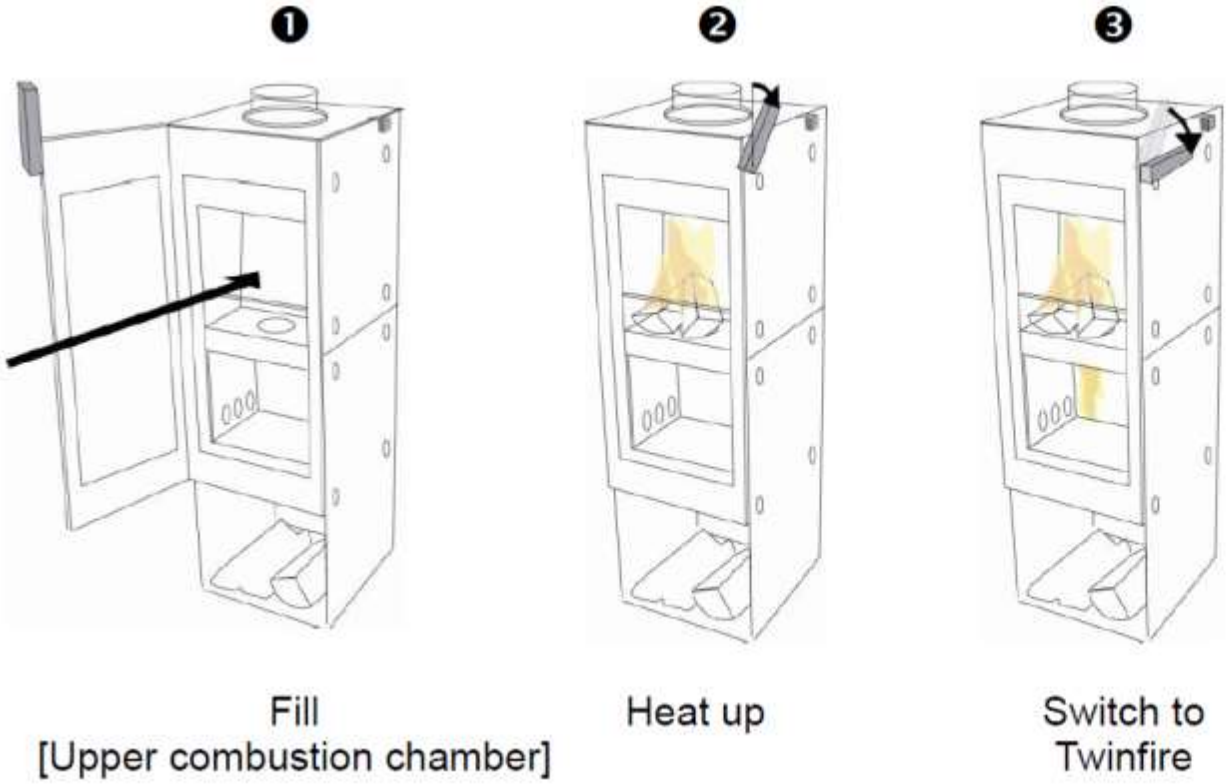

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Recent Developments - Catalyst

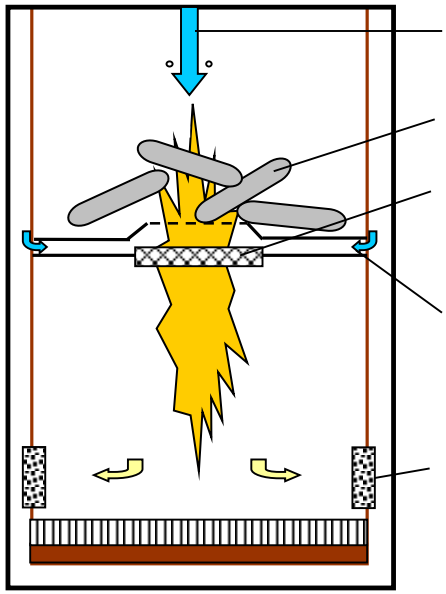
Patent: DE 102013020398 A1 (2013)
DBFZ, Specht Modulare Ofensysteme GmbH & Co. KG, Universität Leipzig

- spinel-type **mixed metal oxides promising to meet the requirements**
  → Catalyst screening
- Synthesis of mixed metal oxides on surface of monolithic structures via RSSA-Synthesis [1]

Experiment	Reference no cat.	New cat.	Aged 1	Aged 2	Aged 3	Aged 4
Time on stream	mg/m³ with 13 % O_2	0 h	185 h	338 h	458 h	654 h
CO / ppm	1718	725	833	222	837	677
org.-C.	156.4	65.1	33.0	8.6	64.1	71.0
dust	19.6	17.0	15.0	9.0	16.6	13.9

→ CO and C_xH_y conversion of > 50 %

α-Al_2O_3 sponge **MeO_x/ $MeAl_2O_4$/Al_2O_3**



References
[1] DE 102013020398 A1, 12.06.2014, Assignee: DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Germany; Specht Modulare Ofensysteme GmbH & Co. KG, Germany; Universität Leipzig, Germany; By: Specht, Bodo et al..

Down draft wood log stove NEKO

DBU: AZ: 28412/02

Project partner: Specht Modulare Ofensysteme GmbH and Co. KG, Universität Leipzig, DBFZ

- **Integration of catalyst: α-Al_2O_3 support with spinel-type catalyst**
  - Chamber integration of catalyst, stable under high temperature conditions
  - Without use of noble metals: RSSA synthesis of metal oxide catalysts
  - Without use of washcoat, catalyst coating by solid-state reaction route
- **Redesign of the furnace on the basis of xeoos X8**
  - Lengthening of lower chamber: Higher residence time and avoidance of flame contact
  - New development of double plate
  - Spliting of stove door and use of IR reflecting ceramic glass
- **Development of cost-effective control system**
  - Operation with natural draft!
  - Only one flapper valve (possible because use of down draft combustion)
  - Thermocouple for flame temperature („O_2-Sensor“)
  - Electronic control unit with display for refueling
  - Optional: Mass flow sensor for combustion air and lambda sensor

Down draft wood log stove NEKO

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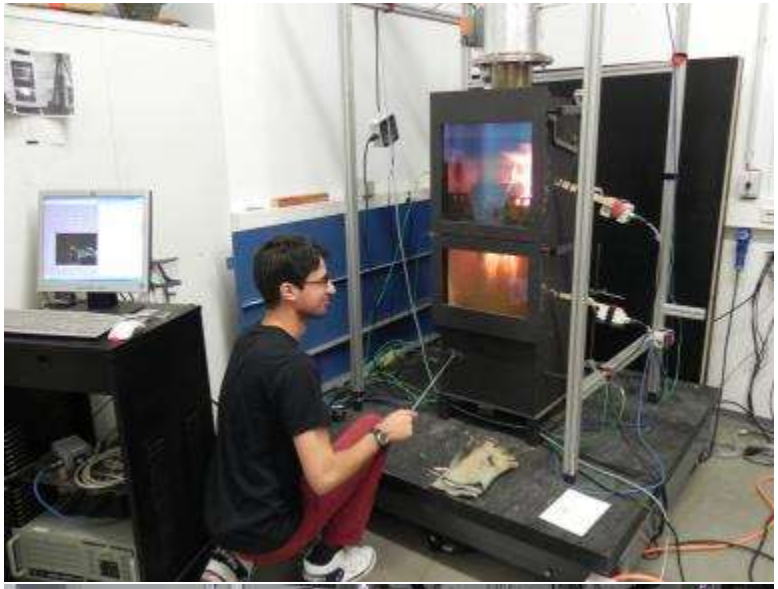


Emissions at 13 % O_2, standard conditions

- Particulate matter: < 10 mg/m³
- CO < 200 mg/m³
- VOC (Org.-C) < 20 mg/m³
- 2 Prototypes (of identical construction!)
  - Prototype 1 was presented in USA at „Wood Stove Design Challenge“ 2014: 2. Place!

    (4.-7. Nov. at BNL:http://www.forgreenheat.org/, „Team Wittus“)
  - Prototype 2 operated and demonstrated in field test at Coswig/Dresden by private user (Nov. 2014 - Mrz. 2015)
- Spin-off: Engineering office:

ETE EmTechEngineering GmbH

Homepage: www.ete-ing.de

Flyer for Donwload:

http://www.ete-ing.de/sites/default/files/ETE_Flyer_English.pdf

NEKO catalyst: First References

AZ: 28412/02

ETE EmTechEngineering GmbH

Homepage: www.ete-ing.de

References:

1. New Zealand: xeoos with NEKO catalyst

http://www.xeoos.co.nz/

„German Design"

"Brought to New Zealand to meet the need for Canterbury residents to install log burners, this German engineered range combines innovation with quality materials such as stainless steel, glass, wood and aluminum"

See also: Environment Canterbury's Air Quality Programme: Ultra-Low Emission Wood Burners

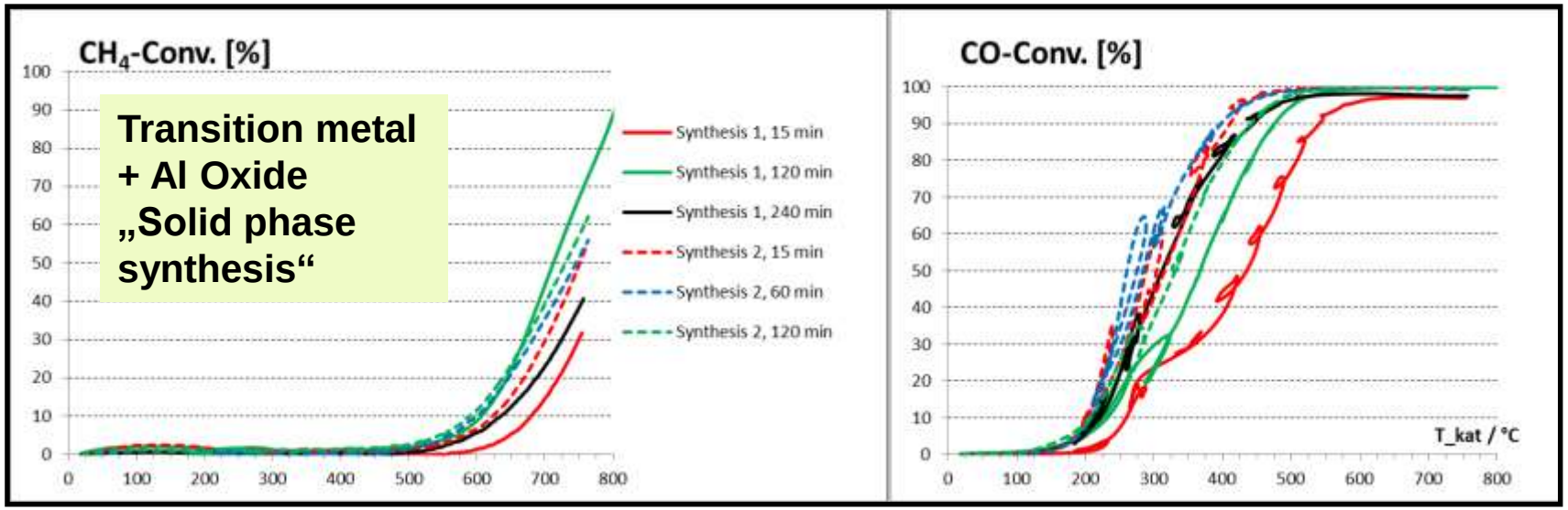
http://ecan.govt.nz/advice/your-air/Pages/uleb.aspx

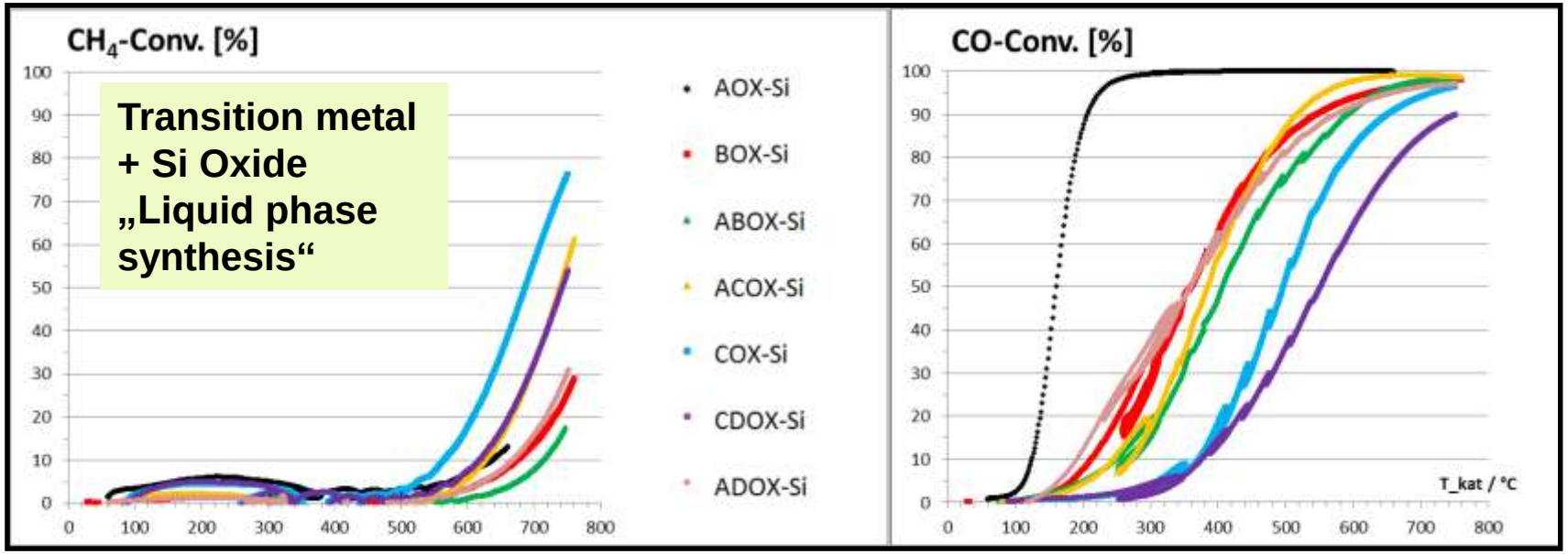
2. Sauna stove (Anonymous Manufacturer) with NEKO catalyst to comply with regulations according to the 2nd stage of the 1st BImSchV

3. Two privat users in Regensburg: xeoos X5 with NEKO catalyst (Demonstration campaign)

4. Other furnaces / manufacturers in progress

Future catalysts under development
Example: ALL-CERAMIC CATALYST





ETE www.ete-ing.de
EmTechEngineering GmbH

xeoos

UNIVERSITÄT LEIPZIG

Deutsches Biomasseforschungszentrum
gemeinnützige GmbH

DBFZ

Working Group Small scale furnace systems, Department Thermo-chemical Conversion

„Small scale furnaces and catalyic emission reduction“

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Development of a micro-scale installation

Continuing Developments

- Improvement of insulation and tight connections
- Ash removal

Modification of flue gas sampling