An Overview of Waste to Energy Technology

Thermochemical Waste Processing

Solutions, Developments and Trends.

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OVERVIEW

(1) Justification of WtE

(2) The Challenges of processing household refuse

(3) Solids processing technologies

(4) Combustion vs. Gasification

(5) Grate Combustion Technologies

(6) Fluidized Bed Combustion Technologies

(7) Grate vs. Fluidized Bed (Mass Burning vs. RdF Production, ash quality)

(8) Technological Features of WtE Steam Generators

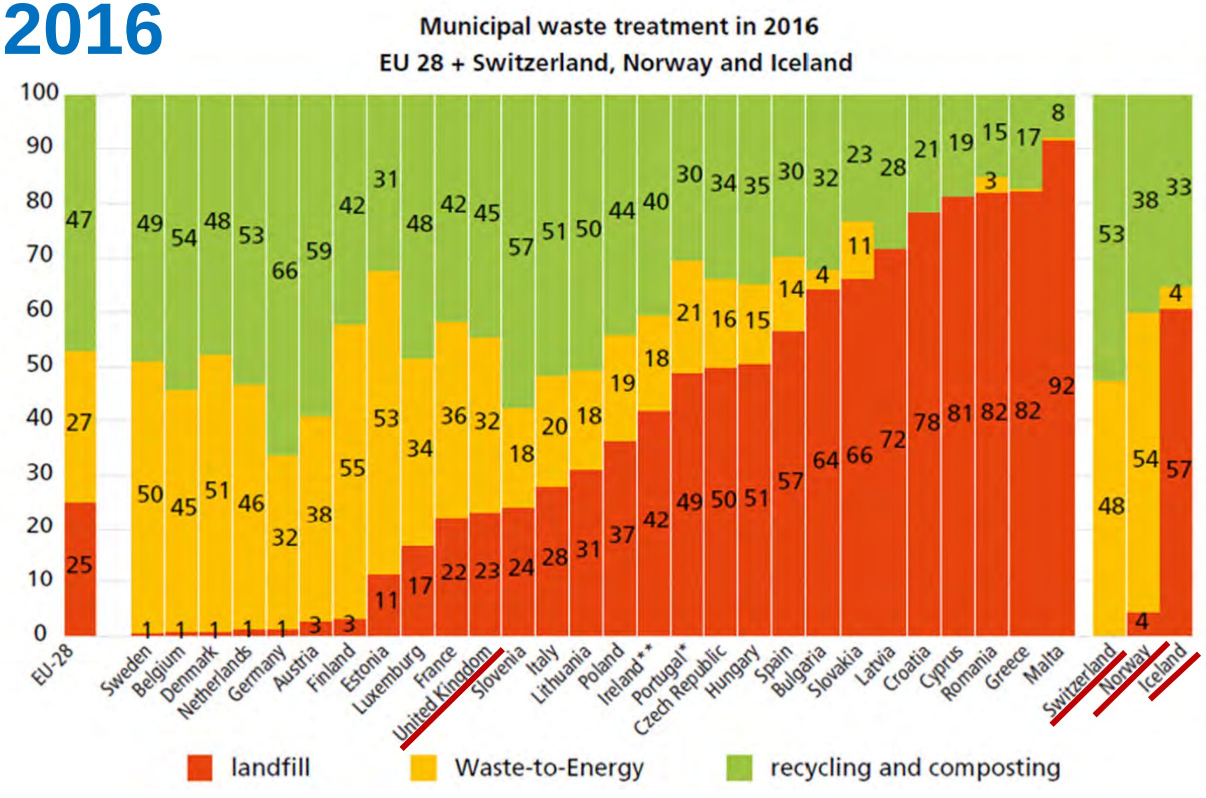
(9) Flue Gas Cleaning Technologies

(10) Considerations about Circular Economy

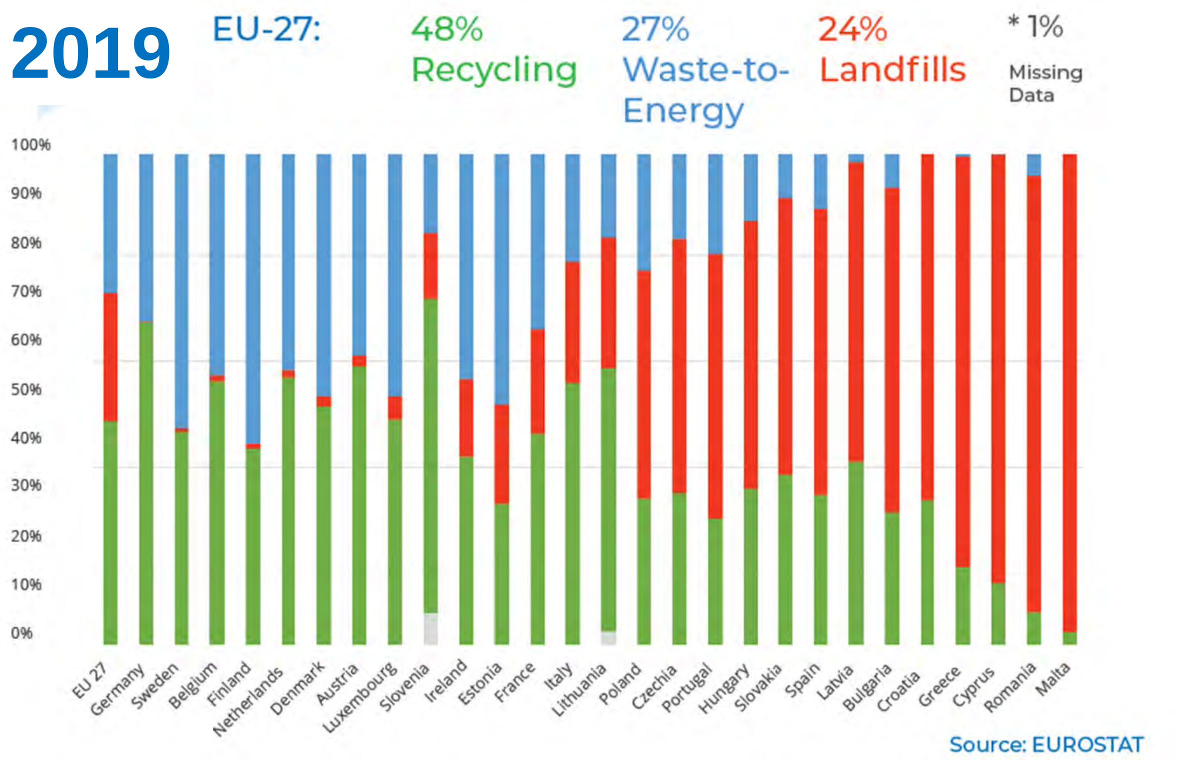
(11) Carbon Capture and other Future Trends

1 - Justification of the Waste to Energy Approach

2016



2019



Source: EUROSTAT

- ➢ It is difficult to exceed 60% of recycling
- ➢ WtE allows to fill the gap to 100% in a flexible and the best possible manner

1 - Justification of the Waste to Energy Approach

- Originally driven by **biologic / hygienic motives** (UK 1874; GER, DK: 1905)
- Environmental and climate protection (no land fills) => => **pollutant sink: groundwater protection, no methane emissions**)
- Maximizing the **recovery value of residual waste (energy, metals,..) => contribution to circular economy**
- **Volume reduction by approx. 90%**
- **Cleaning of exhaust gas and solid streams (ashes)**

Full oxidation on a grate *was the first approach because it is the simplest and most robust technology. It has established as the techno-economically best solution*

Some new technologies *emerged, but only fluidized bed combustion has made it up to full commercial validation*

2- The Challenges of processing household refuse

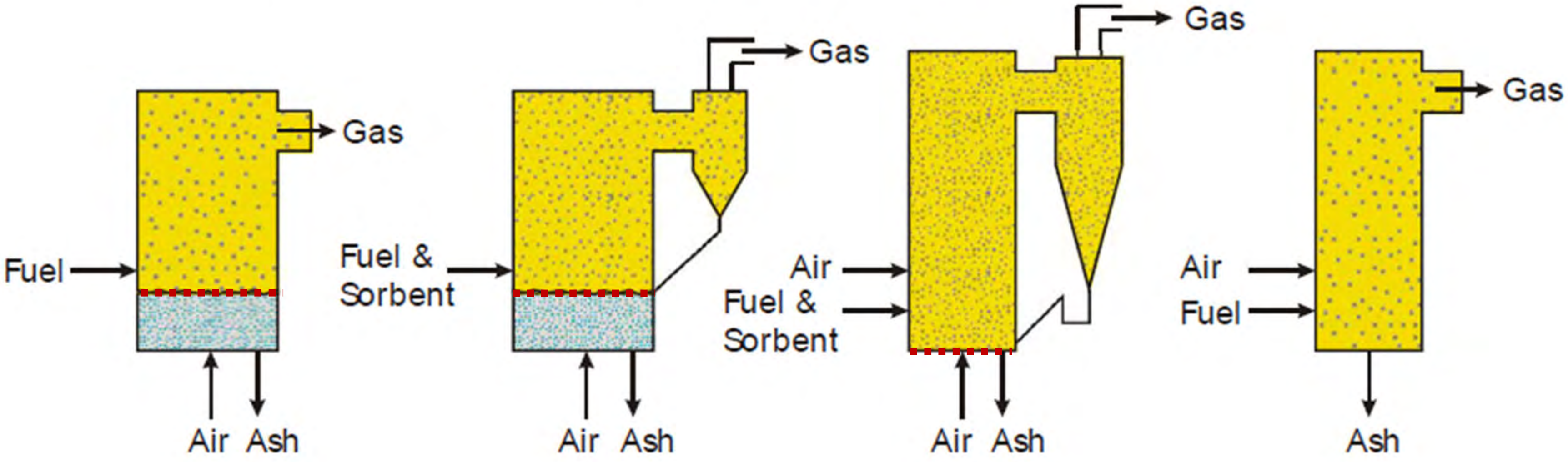
Municipial Waste is THE most challenging of all fuels

- **Physically and chemically inhomogeneous**, contains the complete periodic table
- **Varying over time => highly robust processes required**
- **High ash content;** ash with **eutectics melting at low temperature =>** **fouling**
- High content of chlorine and heavy metals => **high temperature corrosion** and **low temperature corrosion**

Some Consequences:

- ***Inhomogenity*** *=> either high air excess in mass burning or complex fuel pre-treatment for RDF*
- ***Corrosion*** *=> Metallic surfaces can only be employed at surface temperatures between 130 and 400°C. Even with this temperature restriction, complex protection measures are needed (ceramic tiles, nickel cladding…) In consequence, the chemical to electric conversion efficiency is between 20 % and 30%.*
- ***Fouling and Corrosion*** *=> very low flue gas velocities and extensive customized cleaning technologies*

3- Conversion Technologies for Solid Fuels



	Stoker /Grate	Fluidised Bed BFB	Fluidised Bed CFB	Entrained Flow
Velocity	2.3 - 3.0 m/s	1.2 - 3.0 m/s	4.6 - 7.0 m/s	4.6 - 10.0 m/s
Average Bed Particle Size	6,000 μm	1,000 μm	100 - 300 μm	50 μm
	Travelling Grate Pusher Grate	Bubbling Bed	Circulating Fluidised Bed	Pulverized Coal

These approaches apply ***both for combustion and gasification***

Source: Alstom

4 - Combustion vs. Gasification

Gasification agents can be either **steam**, **pure oxygen** or **air**.

A classification of basic thermochemical processes regarding heat supply and reactant is

- Processes with external heat supply (**pyrolysis**),
- Processes with oxygen (**autothermal gasification** and **combustion**)
- Processes with water/steam (**allothermal water-steam gasification**),

Objectives of Pyrolysis and Gasification technologies for waste :

a) producing **high quality syngas for downstream upgrading (“waste-to value”)**

b) producing a clean gaseous fuel which can be valorized in nearby processes (**e.g.** **co-gasification**), e.g. for imporoved chemical to power efficiency

c) producing **solid waste streams** **with perceived high quality, i.e.** **vitrification**. (**approach in Japan**: pyrolysis gas and generated coke are combusted at temperatures above the melting temperature of the slag. The generated slag is a vitrified product with favorable elution values.

Among these objectives, the **“waste-to value” objective** **is the most sustainable and important one, in particular in a circular economy with high renewable power generation by PV and wind**.

4 - Combustion vs. Gasification

Several dozens (~+/- 50) gasification technologies for waste have been developed and marketed over the last 50 years. They claim either *higher electrical efficiency* and/or a ***higher quality of conversion products***, for example vitrified slag or non-fossil liquid fuels

They shared comparably **complex systems engineering and process equipment**.

Unfortunately, **none of these systems has reached a status of a proven technology**.

Most systems **failed to prove reliability or techno-economic viability**.

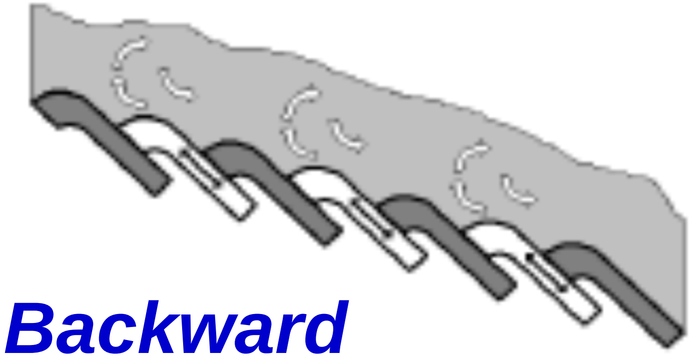
Some produced **spectacular failures** (e.g. Thermoselect in Germany, Air Products in the UK)

One **Japanese melting gasification system** has proven to be reliable. But in a circular economy, melting gasification processes have reduced interest, as vitrified ash is good for landfill but hinders advanced recycling methods.

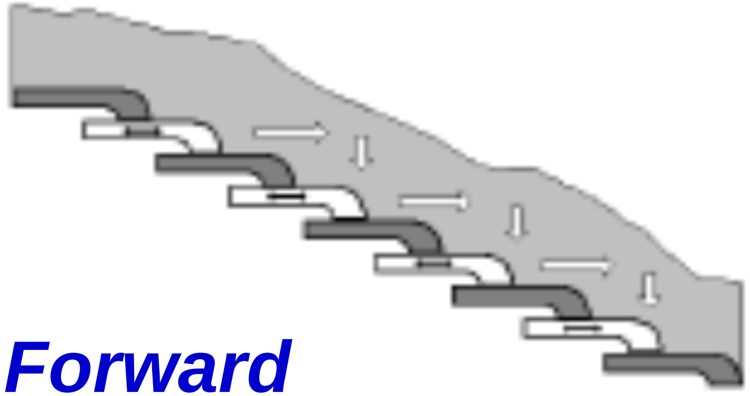
In view of "waste to value", steam gasification and oxygen gasification appear to have the highest potential.

Given that both concepts were so far not able to compete successfully against combustion in the biomass industry, it is questionable if they will be techno-economically successful in the waste industry.

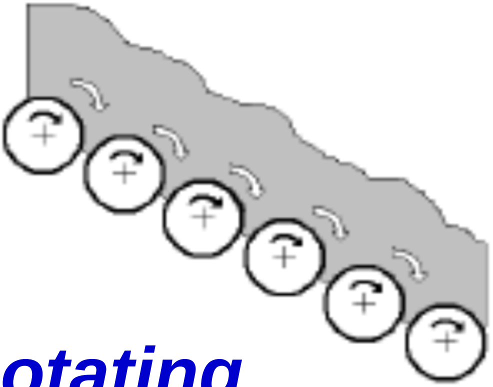
5 - Grate Combustion Technologies



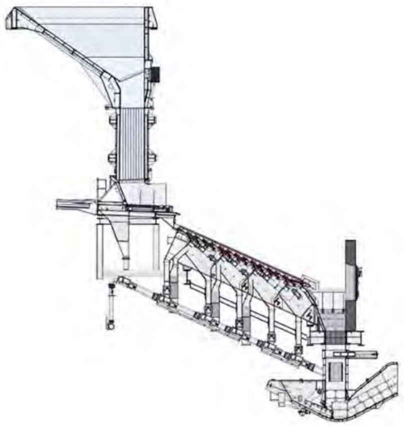
Backward Action

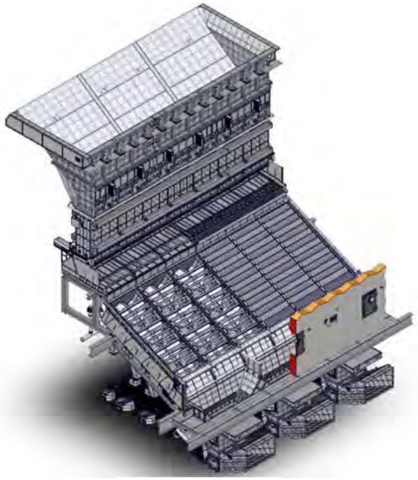


Forward Action



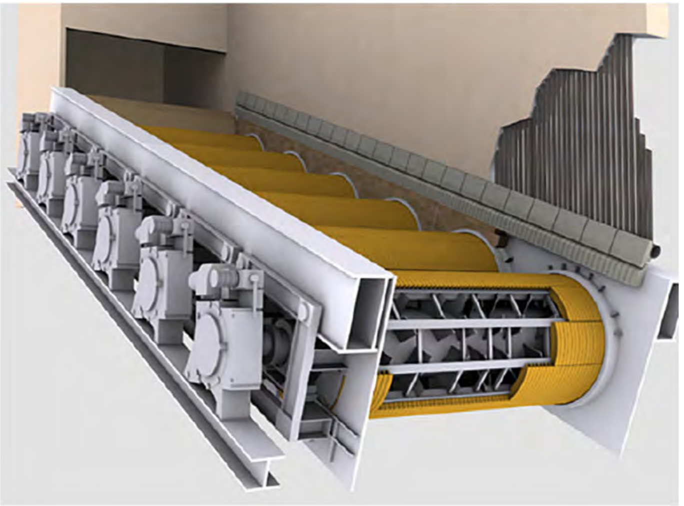
Rotating





Source: Hanenkamp, **Martin GmbH**, BKAEW 2021

Source: www.**hz-inova**.com ,2024



Source: EaA 2020, Turba, Vinci

5 - Grate Combustion Technologies

All three types of grate systems have proven robustness and reliability in ~ 2000 WtE plants worldwide

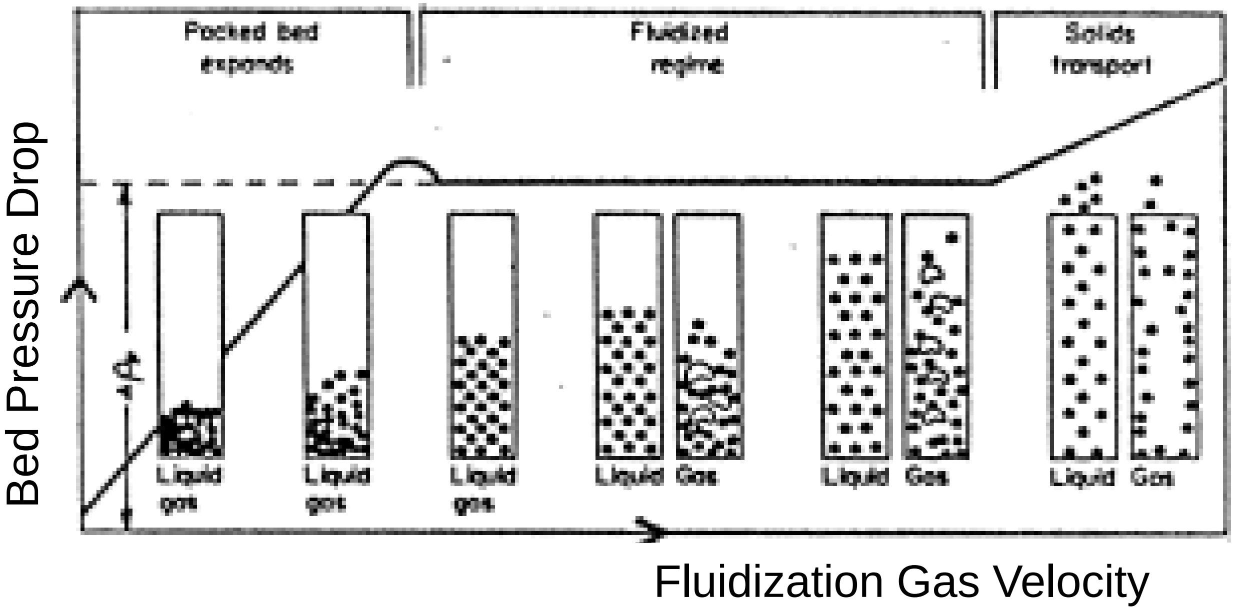
Backward and forward acting grates have the largest market share.

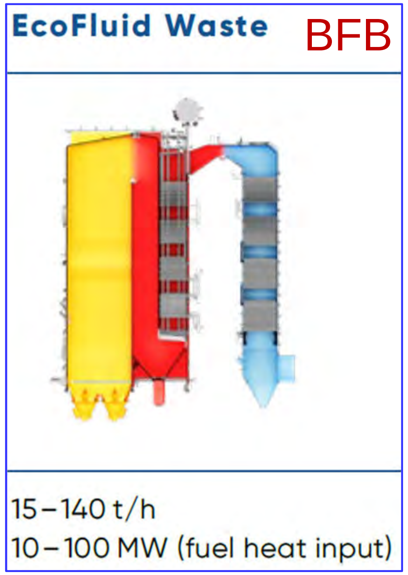
- **backward acting grates** (angle ~ 24°) allow thicker fuel/ash layers, can handle a wider range of LHV (up to 18 MJ/kg) without water cooling
- **forward acting grates** (angle ~ 15°) require water cooling for LHV> 12 MJ/kg
- **rotary grates** also require water cooling for LHV> 12 MJ/kg, have smaller market share, claim on average lower but variable grate bar temperatures

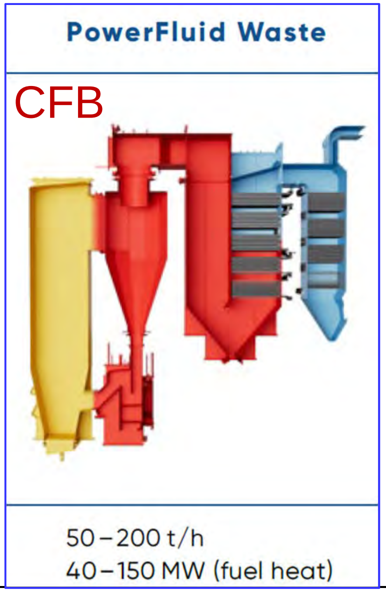
Grates typically operate with λ**~0.9-1.1**for primary air and λ**=1.3-1.65** in total

Most systems have wet ash extraction, but e.g. **Martin and HZI offer dry extraction.**

6 - Fluidized Bed Combustion Technologies







Staged Combustion:

BFB typically operates with **λ_P~0.3- 0.5** for primary air, CFB with **λ_P~0.5- 0.7**

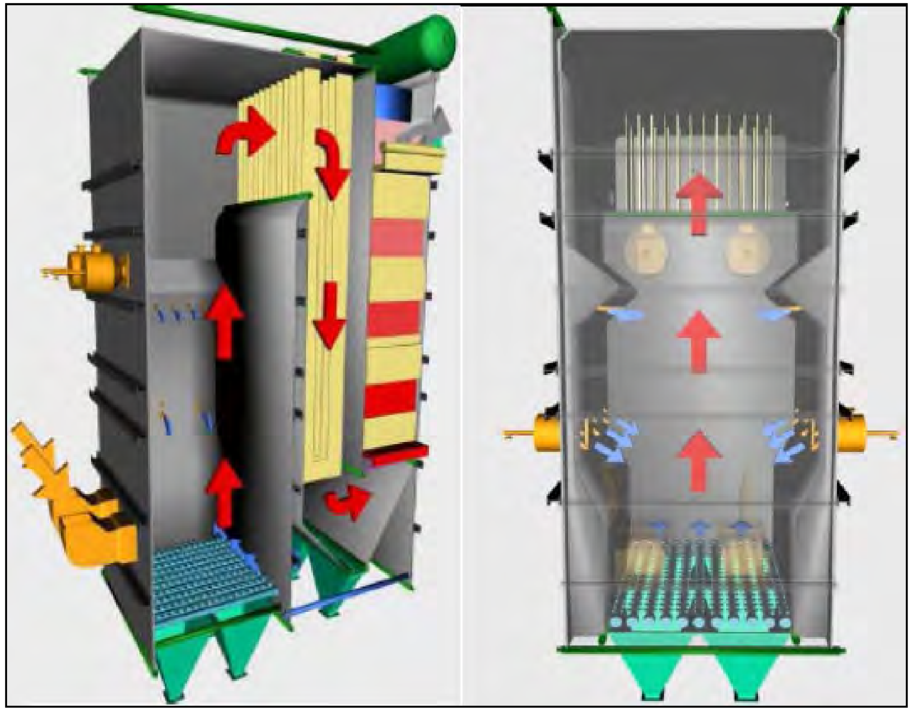
Both BFB and CFB have global **λ=~1.2** (primary air + secondary air)

Both BFB and CFB have dry ash extraction.

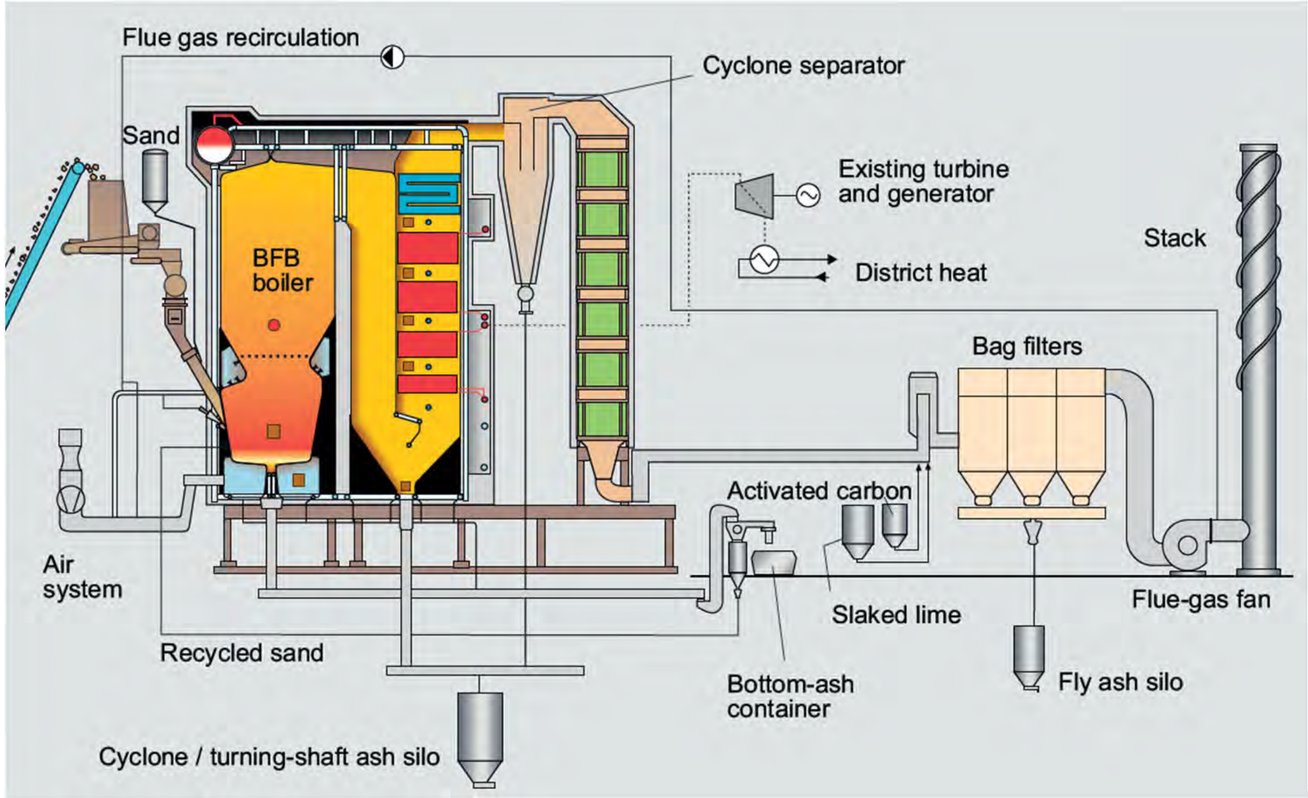
Temperatures and concentrations are very homogeneous.

Source: www.andritz.com, 2024

6 - Fluidized Bed Combustion Technologies



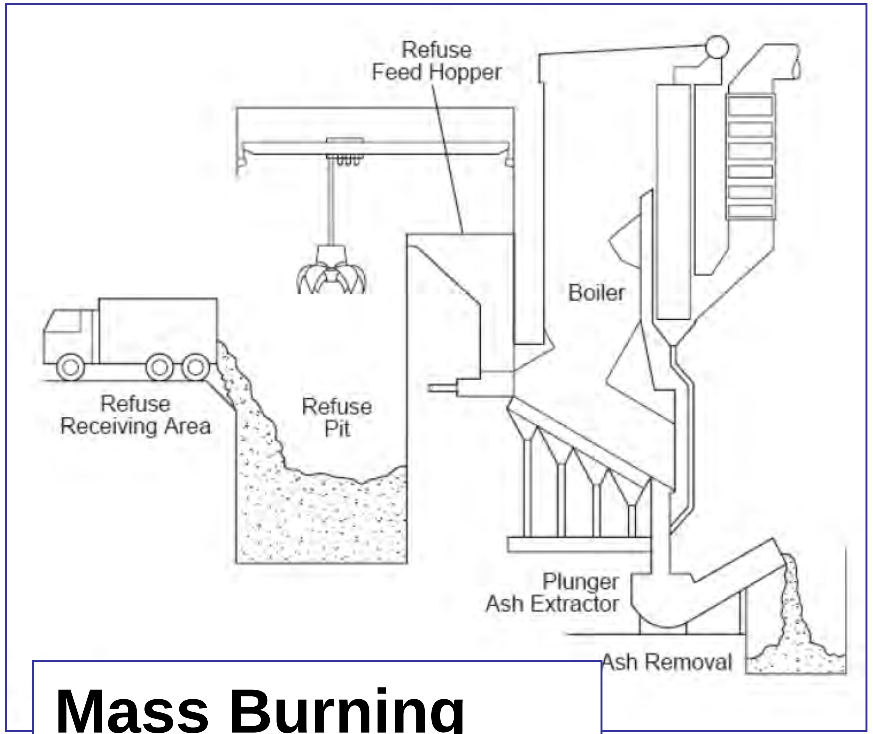
Andritz - BFB: „Ecofluid“



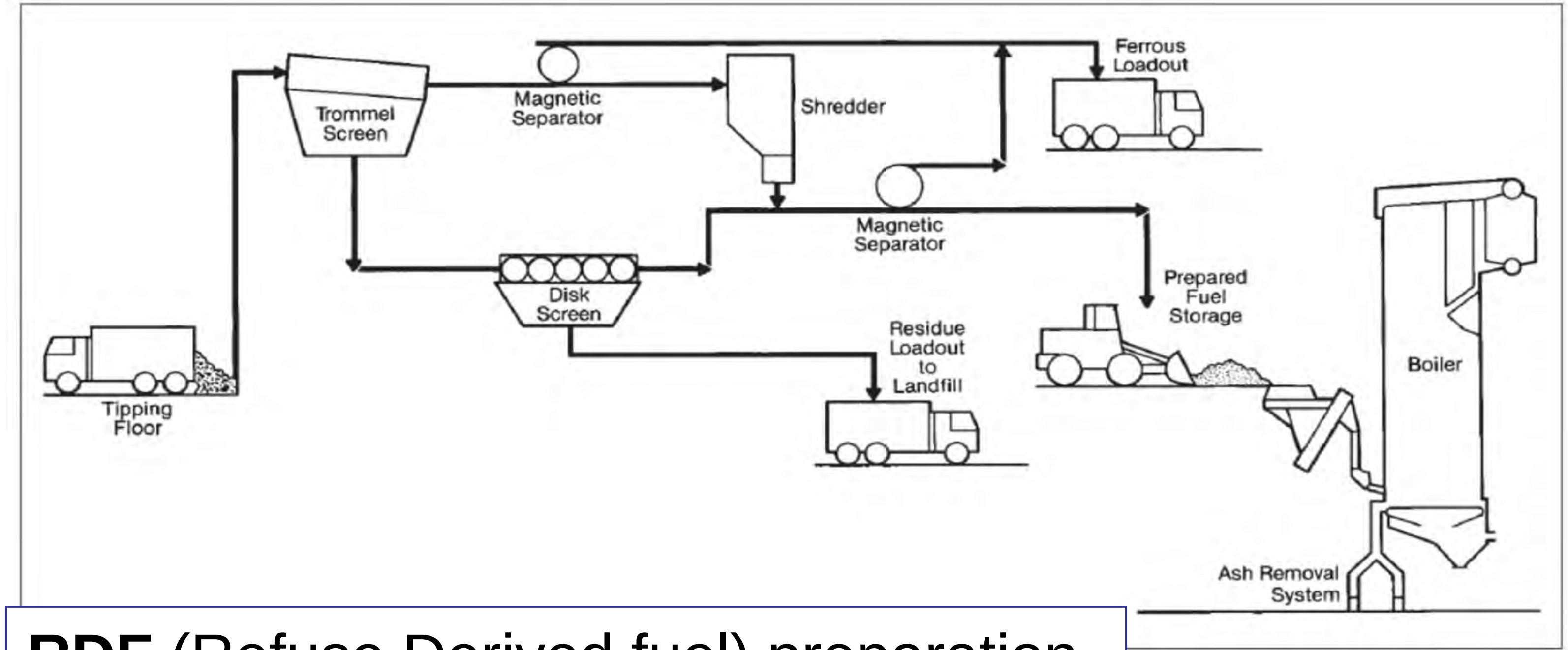
Valmet – BFB „Hybex“

- *Waste needs first to be processed to RDF*
- *Primary air zone is strongly substoichiometric, hence operating in gasification mode. Primary air stoichiometric number λ is used for bed temperature control*
- *Open fluidization grid for ash extraction*
- *Complex fuel preparation vs. simple process arrangement (only one primary air circuit)*

7 - Grate vs. Fluidized Bed **(Mass Burning vs. RdF Production)**



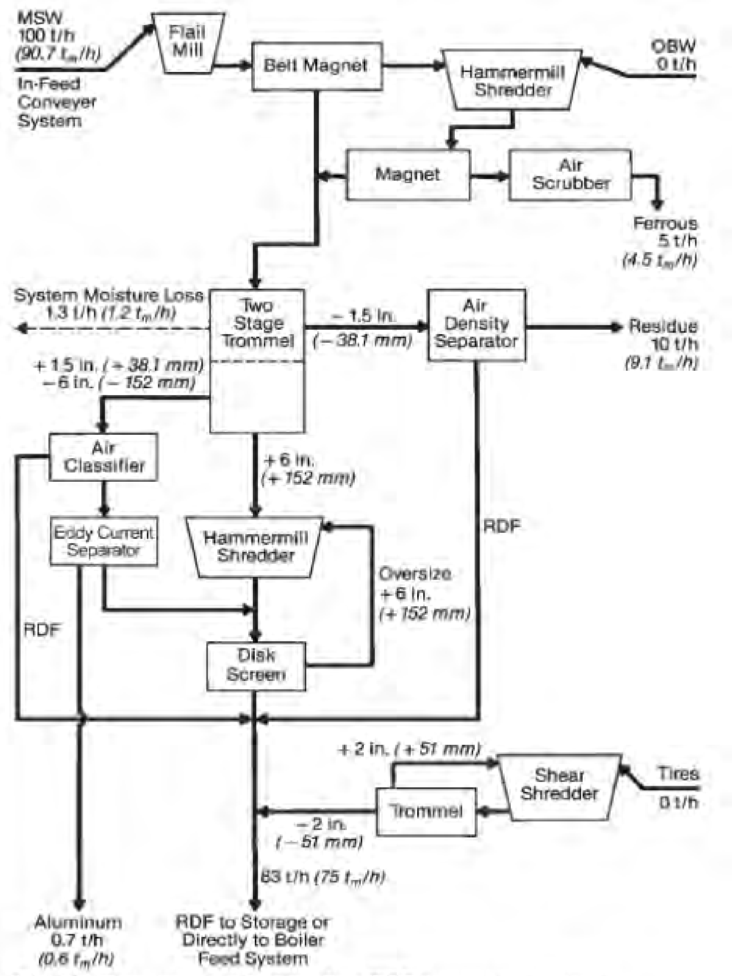
Mass Burning for grate systems



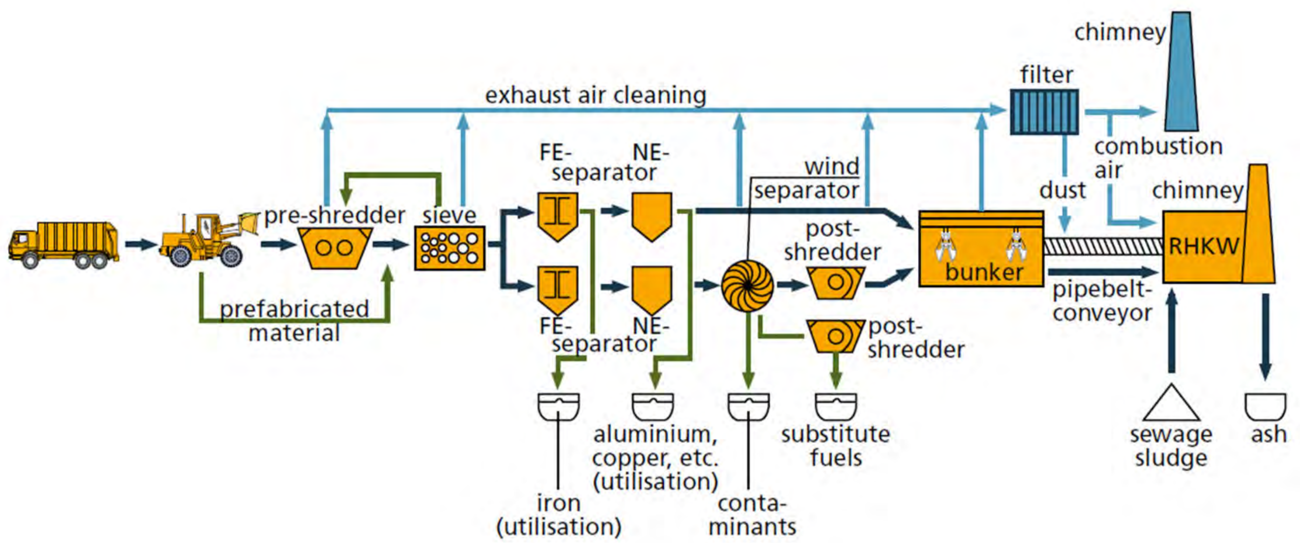
RDF (Refuse Derived fuel) preparation for BFB and CFB

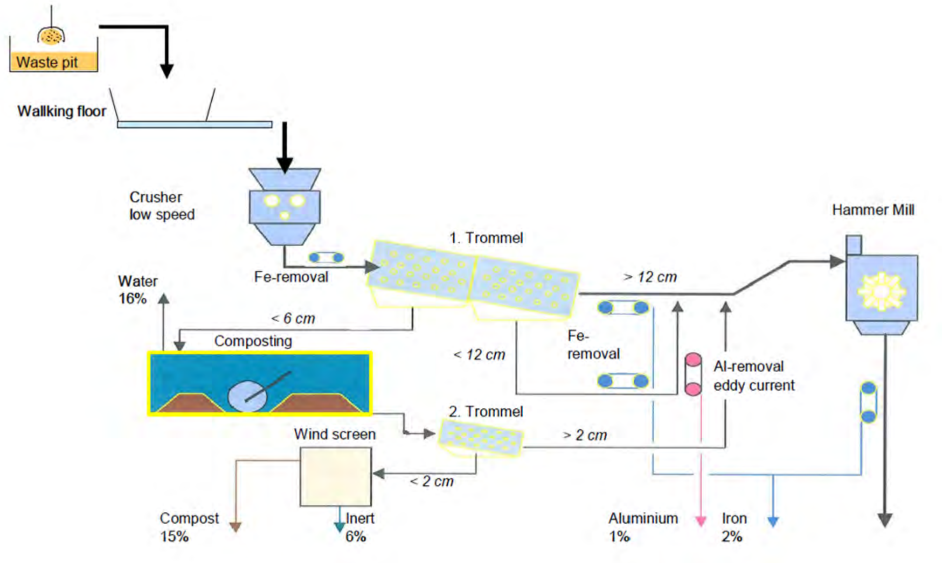
Source: B&W Steam 42, 2020

7 - RdF Production



Components of a complete RDF processing system.





RDF processing plants

- 2-3 Crushers/shredders
- 2-3 trommels/sieves
- Magnets
- Eddy current separators
- Classifiers
- Belts
- ….

Source1: B&W Steam 42, 2020

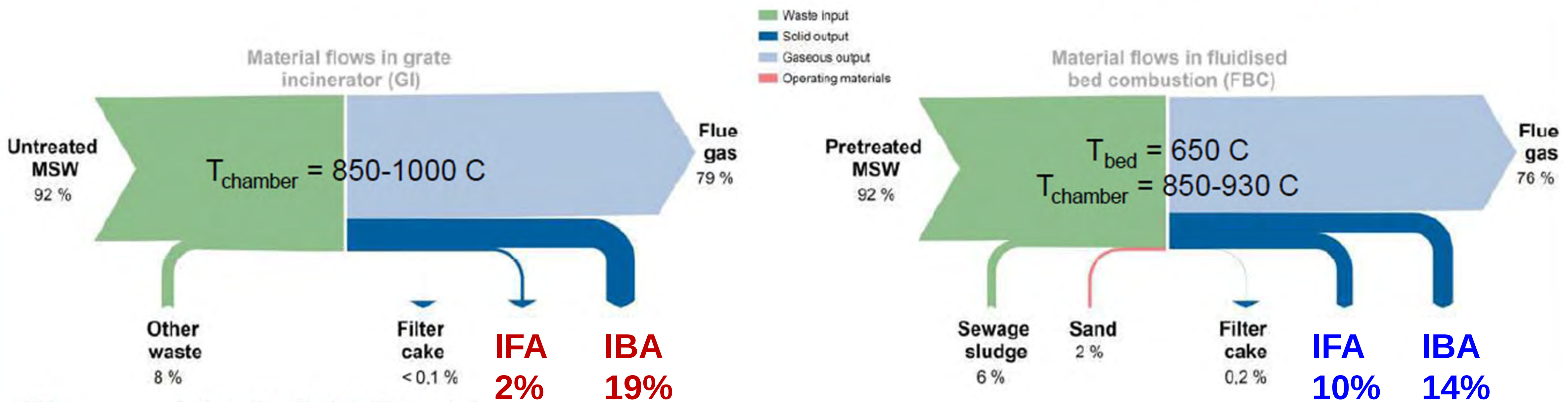
Source2: Ph. Kolbitsch, IRCC 2012

Source3: Holopainen, FBC Conf 2006, Vienna, RDF plant Lomellina

7 – Grate vs. Fluidized Bed -- Ash Types and quality

Grate Combustion

Fluidized Bed Combustion



IFA	Incineration Fly Ash (Flugasche)
IBA	Incineration Bottom Ash (Bett- und Rostasche)

BLASENBAUER, D., HUBER, F., MÜHL, J., FELLNER, J., & LEDERER, J. (2023). COMPARING THE QUANTITY AND QUALITY OF GLASS, METALS, AND MINERALS PRESENT IN WAST INCINERATION BOTTOM ASHES FROM A FLUIDIZED BED AND A GRATE INCINERATOR. WASTE MANAGEMENT, 161, 142-155.

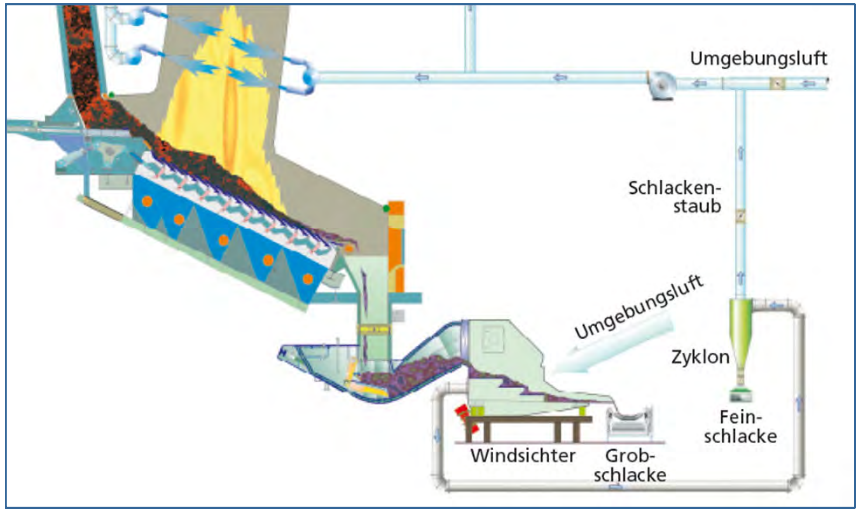
LECKNER, B., & LIND, F. (2020). COMBUSTION OF MUNICIPAL SOLID WASTE IN FLUIDIZED BED OR ON GRATE–A COMPARISON. WASTE MANAGEMENT, 109, 94-108.

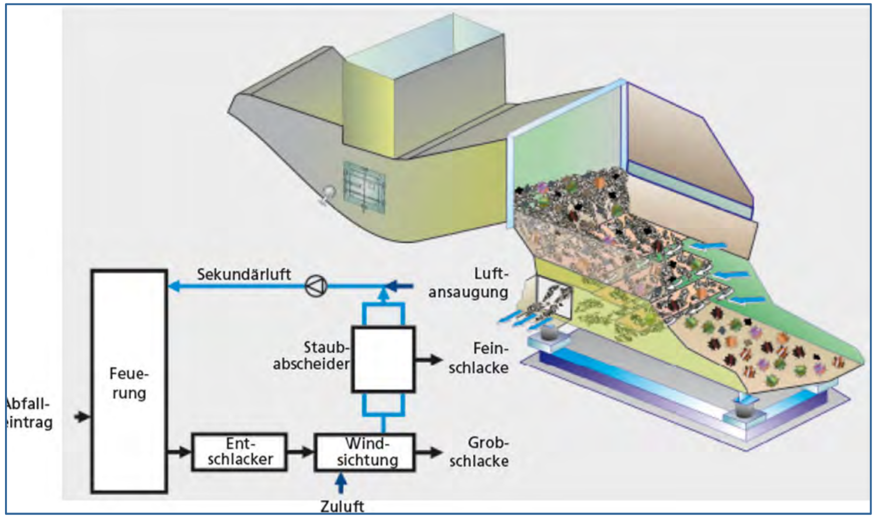
KELLNER, M., SCHINDLER, I., & JANY, A. (2022). STATUS REPORT WASTE INCINERATION. REPORTING YEAR 2022. REPORT NO. 0831. ENVIRONMENT AGENCY AUSTRIA, VIENNA

BFB Bottom Ash

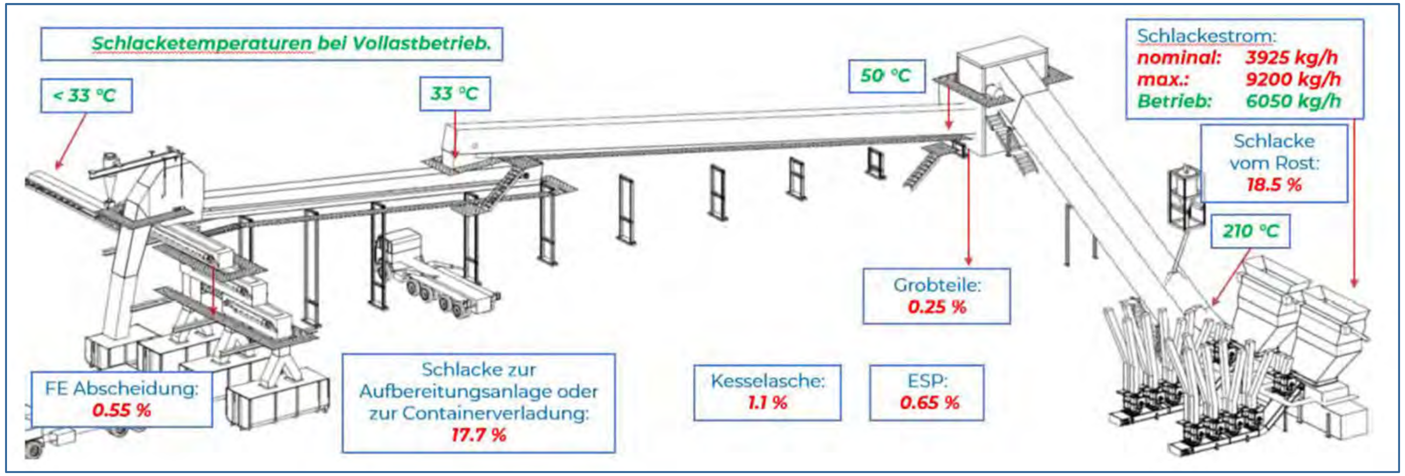
Grate Ash (wet extraction)

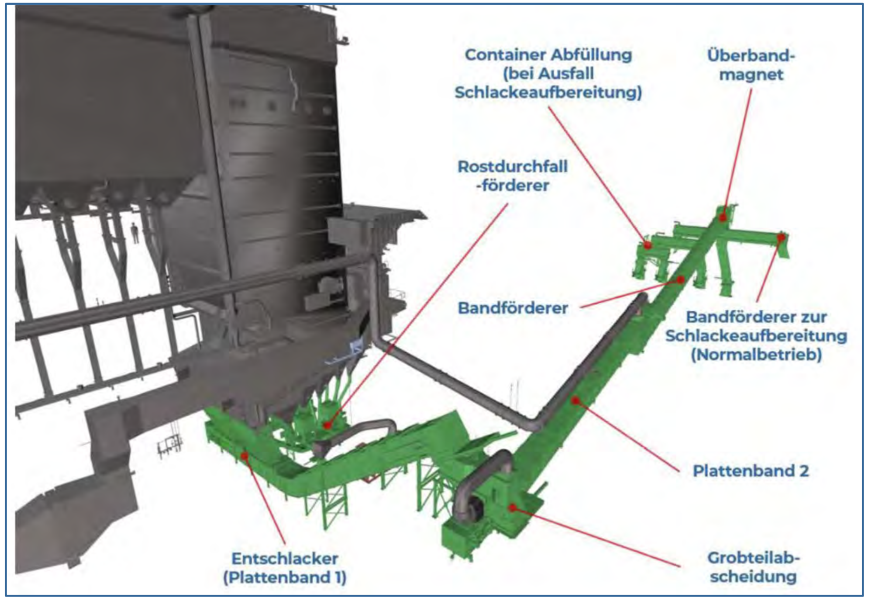
7 – Grate vs. Fluidized Bed – Dry Ash Systems for Grate





Source: Martin et al., BKAEW (EaA) 2009





Source: HZI, Sohnemann, BKAEW 2021

7 – Grate vs. Fluidized Bed – Summary

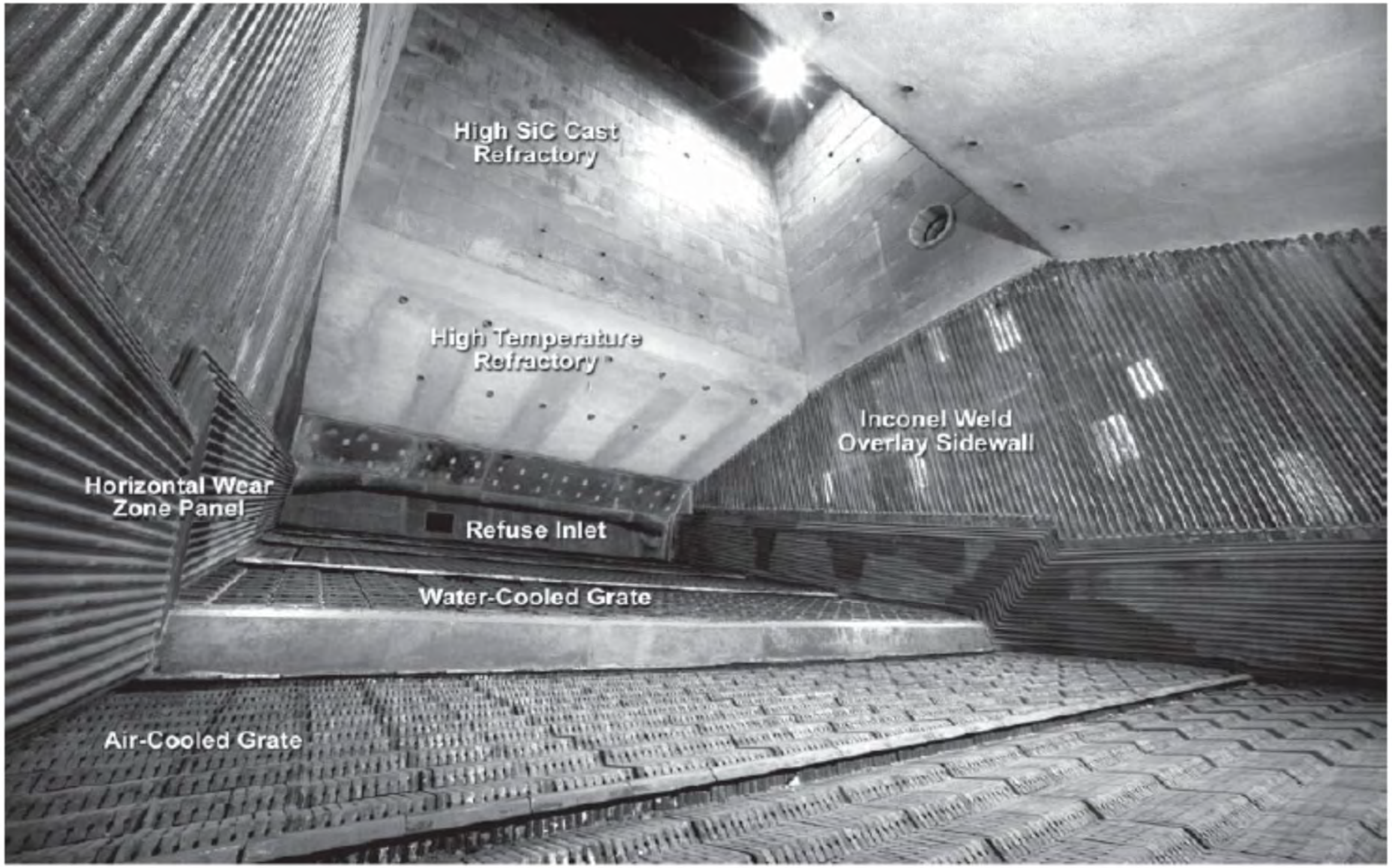
GRATE:

- more than 90% of all installed WtE units worldwide
- many suppliers
- **no fuel preparation (mass burning)**
- higher excess air (λ > 1.4), higher flue gas mass flow
- typically 5 primary air zones (complex combustion control)
- **Low percentage of fly ash**
- more bottom ash, complexity in case of dry ash extraction

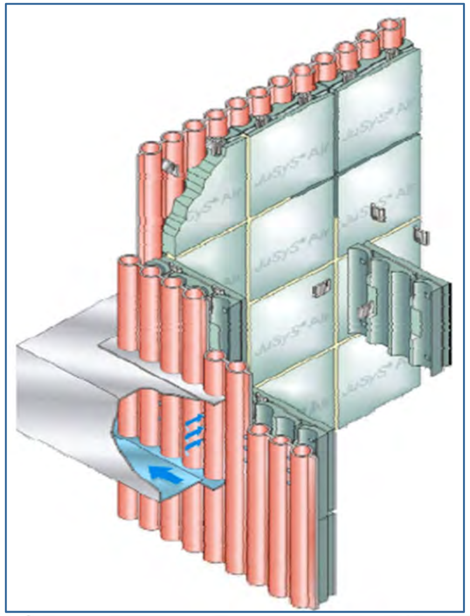
Fluidized Bed:

- requires upstream RdF production
- **higher fuel flexibility**
- Lower primary combustion emissions,
- **Easier to exploit bottom ash quality**
- **low excess air** (λ ~ 1.2), 20% lower flue gas higher flue gas mass flow (advantage for flue gas cleaning and post combustion capture)
- one primary air zone (simple combustion control)

8 - Technological Features of WtE Steam Generators

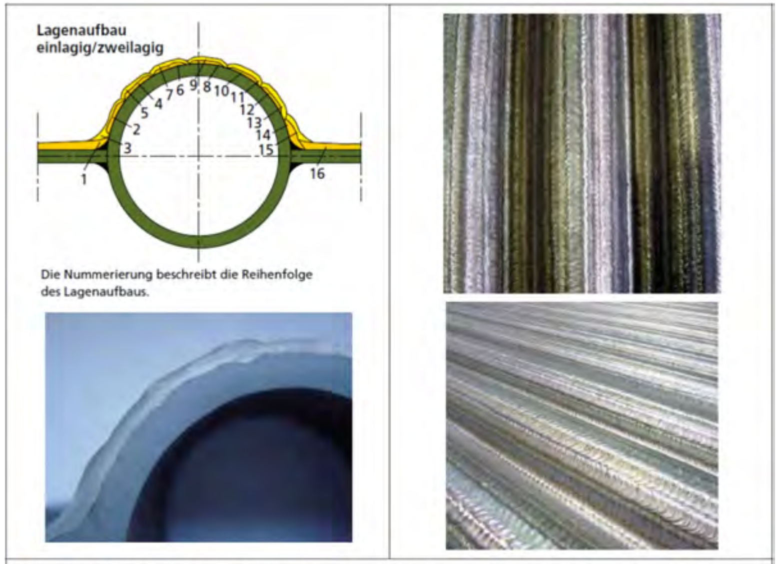


Corrosion protection and design of a 26 t/h mass-fired unit.



Air swept SiC tiles

Inconel cladding (overlay weld)

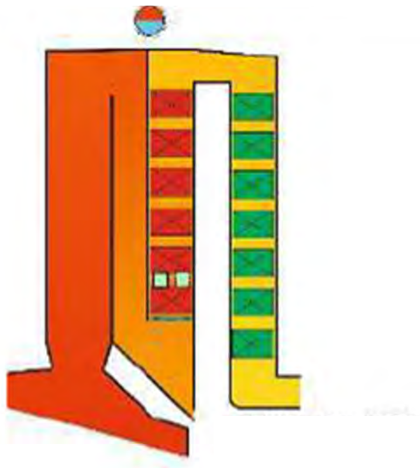


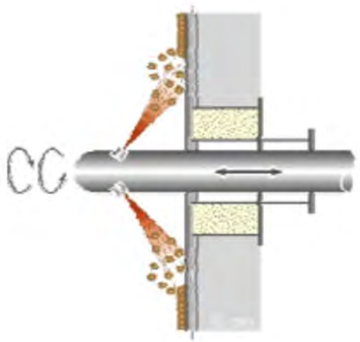
Examples of cladding practice for membrane walls in the waste to energy industry [Uhlig2017]

Sources: B&W Steam 42, 2020; Jürgen&Gräter (J&G) company (top right), Uhlig company (bottom right)

8 - Technological Features of WtE Steam Generators

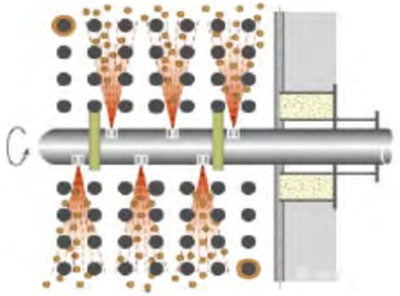
WtE: HEX surface cleaning by hammering and explosion rather than steam sootblowing

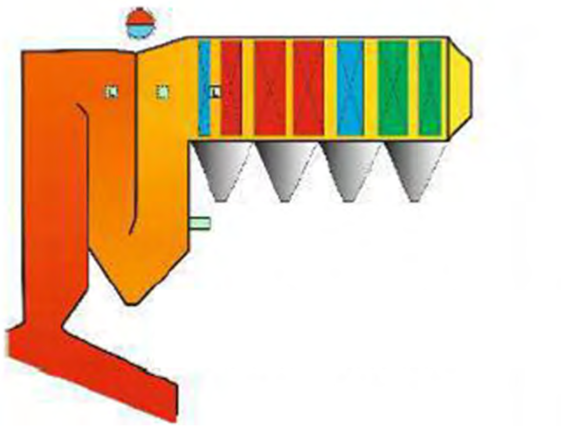




Classical steam generator design

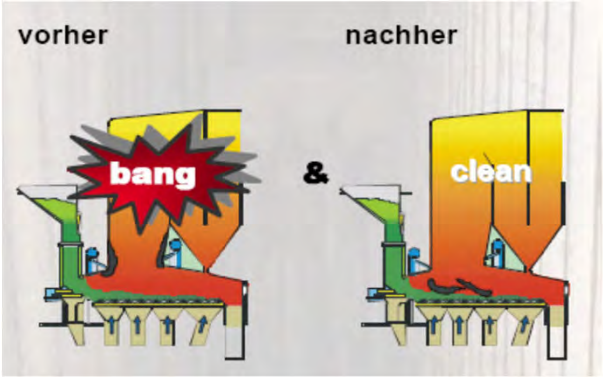
(*horizontal tubes*, sootblowing)





steam generator design alternate for WtE

(*vertical tubes*, cleaning by hammering on lower headers)



Sources: SPGr, Clyde Bergemann, Norgren

9 - Flue Gas Cleaning Technologies

Flue Gas Cleaning utilizes a **toolbox of**

~10 processing technologies

- Electrostatic precipitator,
- Baghouse Filter,
- SNCR (noncatalytic deNOx),
- SCR (noncatalytic deNOx),
- Semi-dry absorber
- Dry absorber
- Wet absorber
- Mixers, humidifiers, etc
- Flue gas condenser
- Combustion air humidifier

utilizing **chemical agents**

- CaO / Ca(OH)2 for absorption of HCl, SO2
- NaHCO3 sodium bicarbonate (SBC) for absorption of HCl, SO2, dioxines/furanes
- Ammonia NH3 Electrostatic precipitator,
- Active carbon for dioxines/furanes
- NaOH for wet absorption
- H2O for acid wet absorption (Zinc process)

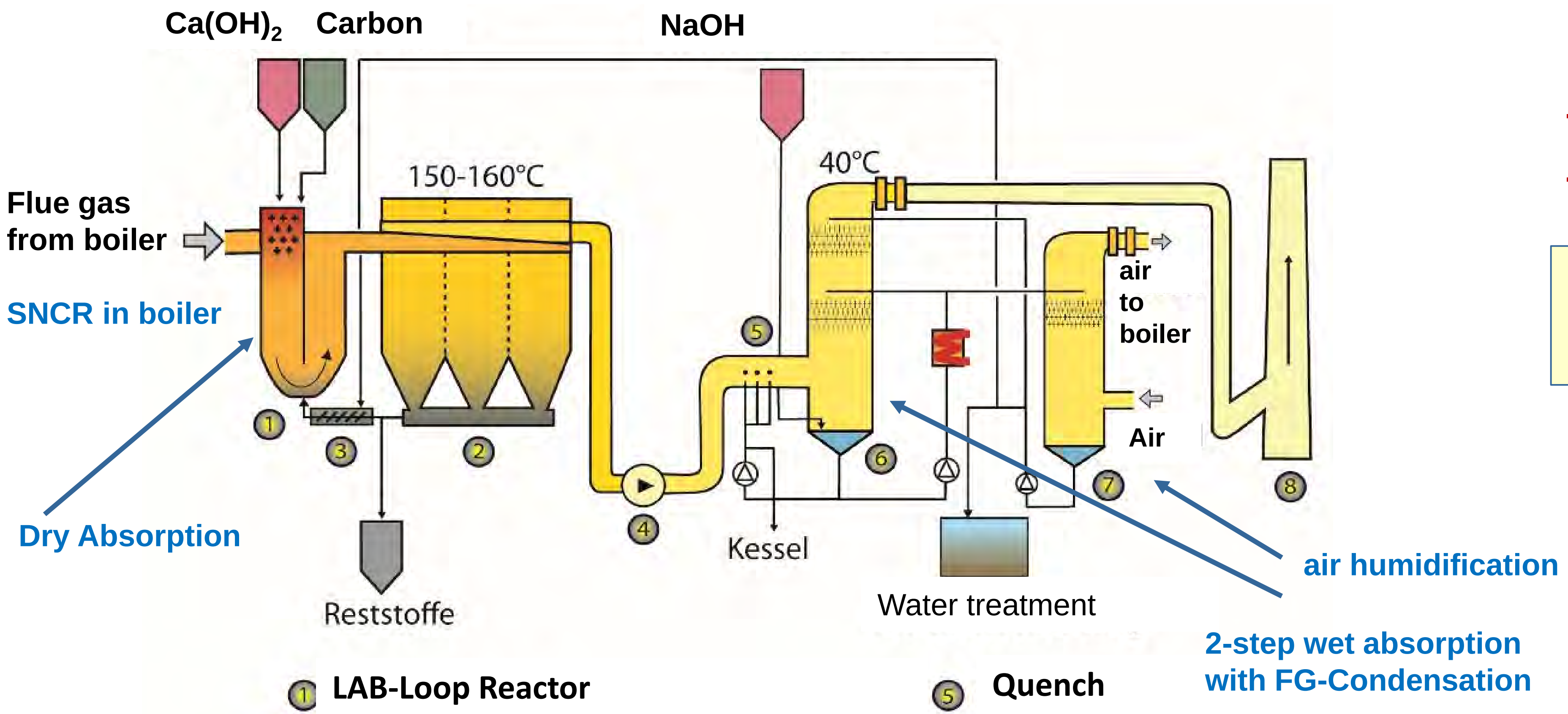
More than 100 configuration options compliant with European regulation. Specific design results from

- **National Regulation (on ashes, on energy efficiency, on liquid effluents)**
- **Project Specification for fuel range**

9 - Flue Gas Cleaning Technologies

Flue Gas Cleaning typical for Northern Europe („Waste-to-Energy CHP Plant Kaunas“ Lituania)

- 200.000 t Waste /year
- 24 MW-el power + 70 MW-th Heat (of which 22 MW-th from flue gas condensation)



① LAB-Loop Reactor
② Baghouse
③ Double wave mixer with humidification
④ ID-fan
⑤ Quench
⑥ Condenser+
⑦ Combustion Air Humidifier
⑧ Chimney

Key specific Requirement:

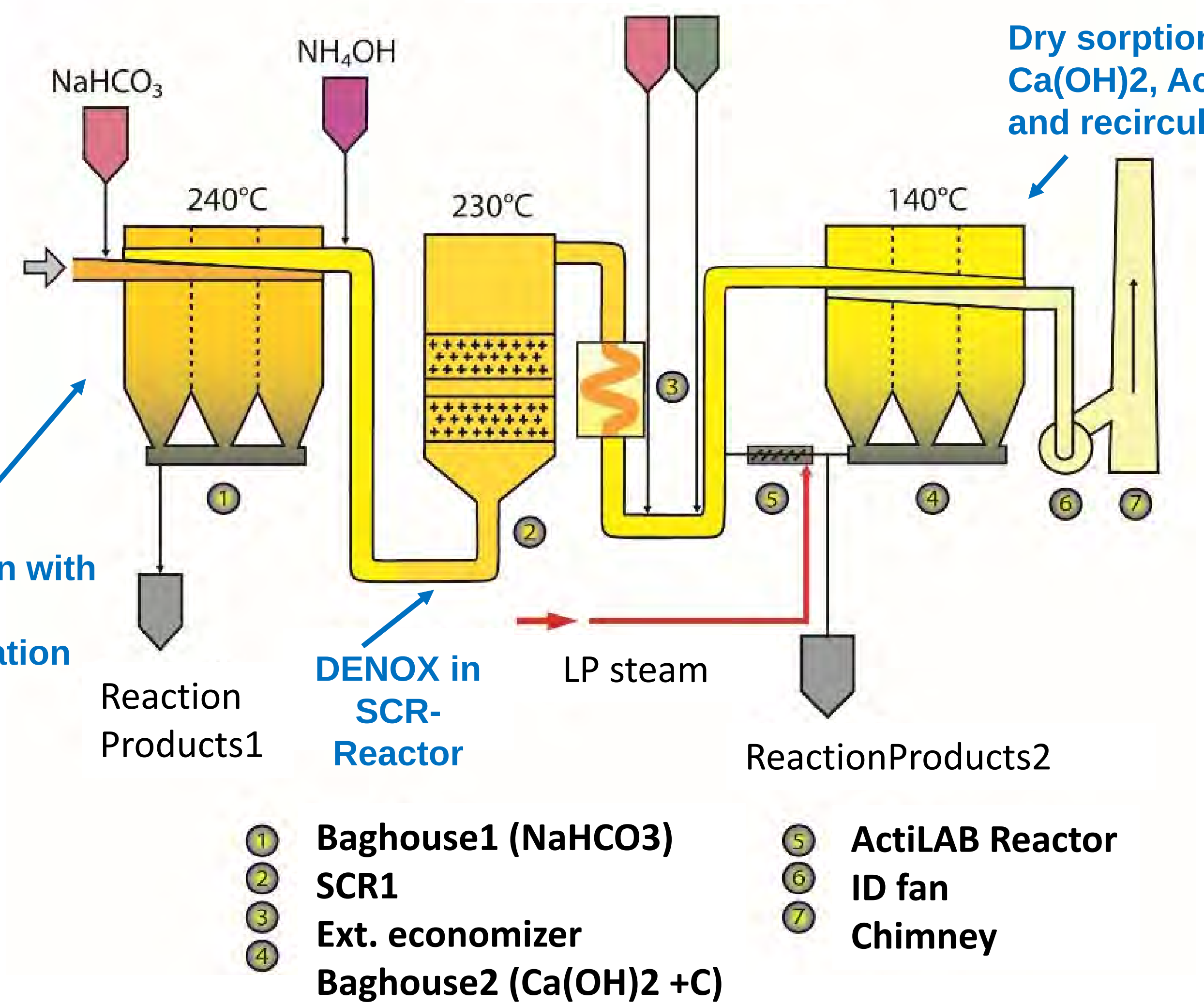
Maximum energy efficiency for CHP

Source:
Spöhrer et al.,
LAB GmbH,
BKAEW21

9 - Flue Gas Cleaning Technologies

Flue Gas Cleaning typical for Germany

$Ca(OH)_2$ Carbon



Flue gas from boiler

Dry sorption with $NaHCO_3$, no recirculation

DENOX in SCR-Reactor

Dry sorption with Ca(OH)2, Active Carbon and recirculation

Key specific Requirement:

No wet effluents

Source:
Spöhrer et al.,
LAB GmbH,
BKAEW21

9 - Flue Gas Cleaning Technologies

Flue Gas Cleaning typical for Switzerland („KVA KEBAG ENOVA Zuchwil)

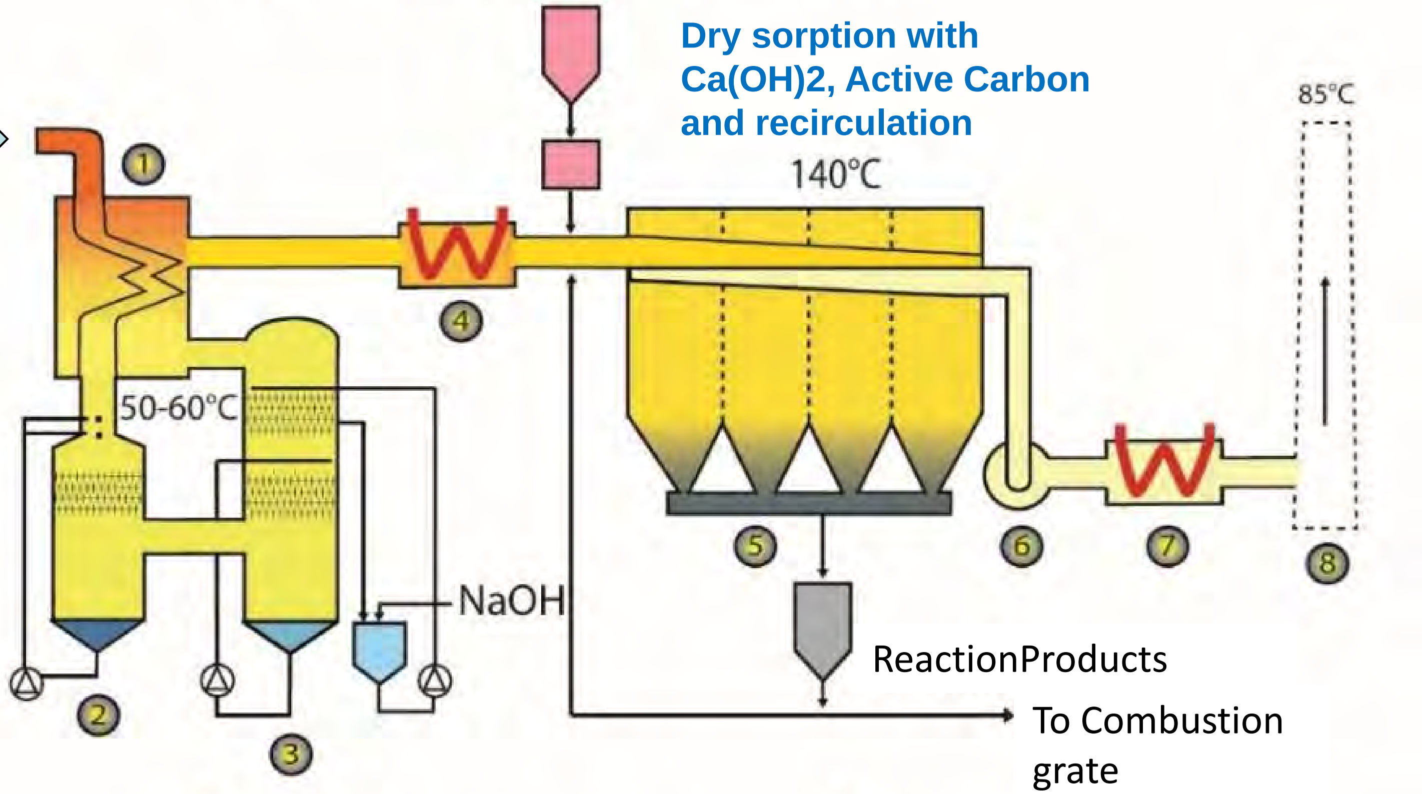
mixture $Ca(OH)_2$ + Active Carbon

Flue gas from boiler ⟹

SNCR in boiler

2-step
wet absorption
(1)acid
(2)neutral

Dry sorption with Ca(OH)2, Active Carbon and recirculation



- ① **Gas-Gas HEX**
- ② **HCl wet absorber**
- ③ **SO2 wet absorber**
- ④ **LP steam /flue gas HEX**
- ⑤ **Baghouse**
- ⑥ **ID fan**
- ⑦ **Heat Recovery**
- ⑧ **Chimney**

Key specific Requirement:

acidic first step of wet absorption produces acid for fly ash recycling

Source: Spöhrer et al.,
LAB GmbH
BKAEW21

10 - Considerations about Circular Economy

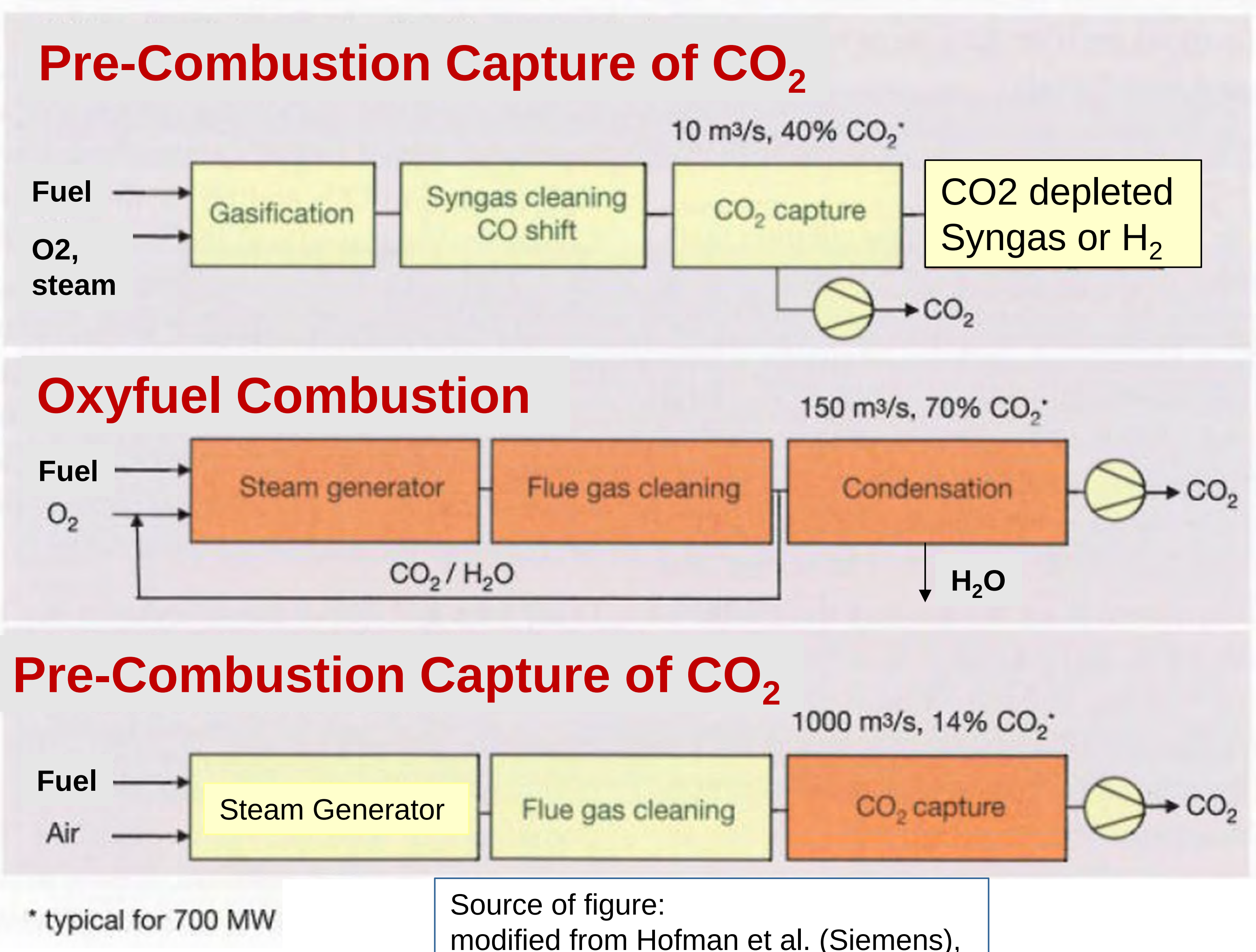
- WtE / Thermochemical Conversion is a **flexible complement to recycling**
  - **Metals can be fully recycled** after the thermochemical step (full or partial oxidation), provided that the ash is not vitrified (antagonism: recycling vs. inert andfill)
  - Also **non-ferritic metals** (Al, Zn, heavy metals) can be extracted (dry extraction, Swiss approach,..)
  - Research for **exploiting the anorganic residue** (e.g. in cement) is ongoing
  - If and to which extent the organic constituents carbon C and Hydrogen H2 are recycled is a **techno-economic question**. Recycling is possible in all three technologies of carbon capture
  - Negative CO2-emissions are possible

11 - Carbon Capture and other Future Trends

- Gasifier atmospheric or pressurized
- **Low volume flows** (no N2, pressure)
- **Flexible CO2 capture**
- **Syngas for Fischer Tropsch etc.**

- **Simplicity** (considering a black box air separation unit (ASU))
- medium CO2 quality
- **Modified flue gas composition in the steam generator** (corrosion, fouling?)

- End of the pipe,
- **High volumetric flow**
- **Low CO2 concentration**
- Potential degradation of solvent
- **High CO2 quality**



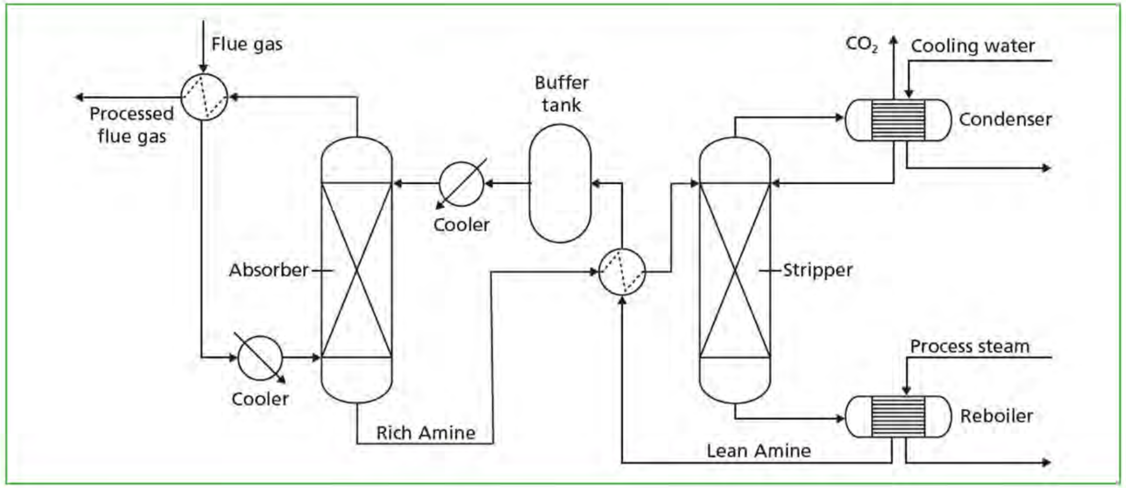
Source of figure:
modified from Hofman et al. (Siemens), VGB power tech 7/2008

11 - Carbon Capture and other Future Trends

Current (April 2024) Status

(1) Rising Interest in WtE Carbon Capture

- mainly Post Combustion Capture considered so far
- Operating post combustion capture plants in the Netherlands
- Construction/pilot plants in Norway and Denmark
- Feasibility planning in Switzerland and Austria



Source: Moll, SICK AG, IRCC 2022

(2) Rising Interest in Flue Gas Condensation (Energy efficiency)

- Synergy with Post Combustion Capture

(3) Rising Interest in Bottom Ash and Fly Ash Recycling

- Interest for dry bottom ash extraction
- Research towards advanced iron- and non-iron extraction, utilization of anorganic rest in special concrete..
- Research towards Fly –Ash Recycling (SwissZync,…)