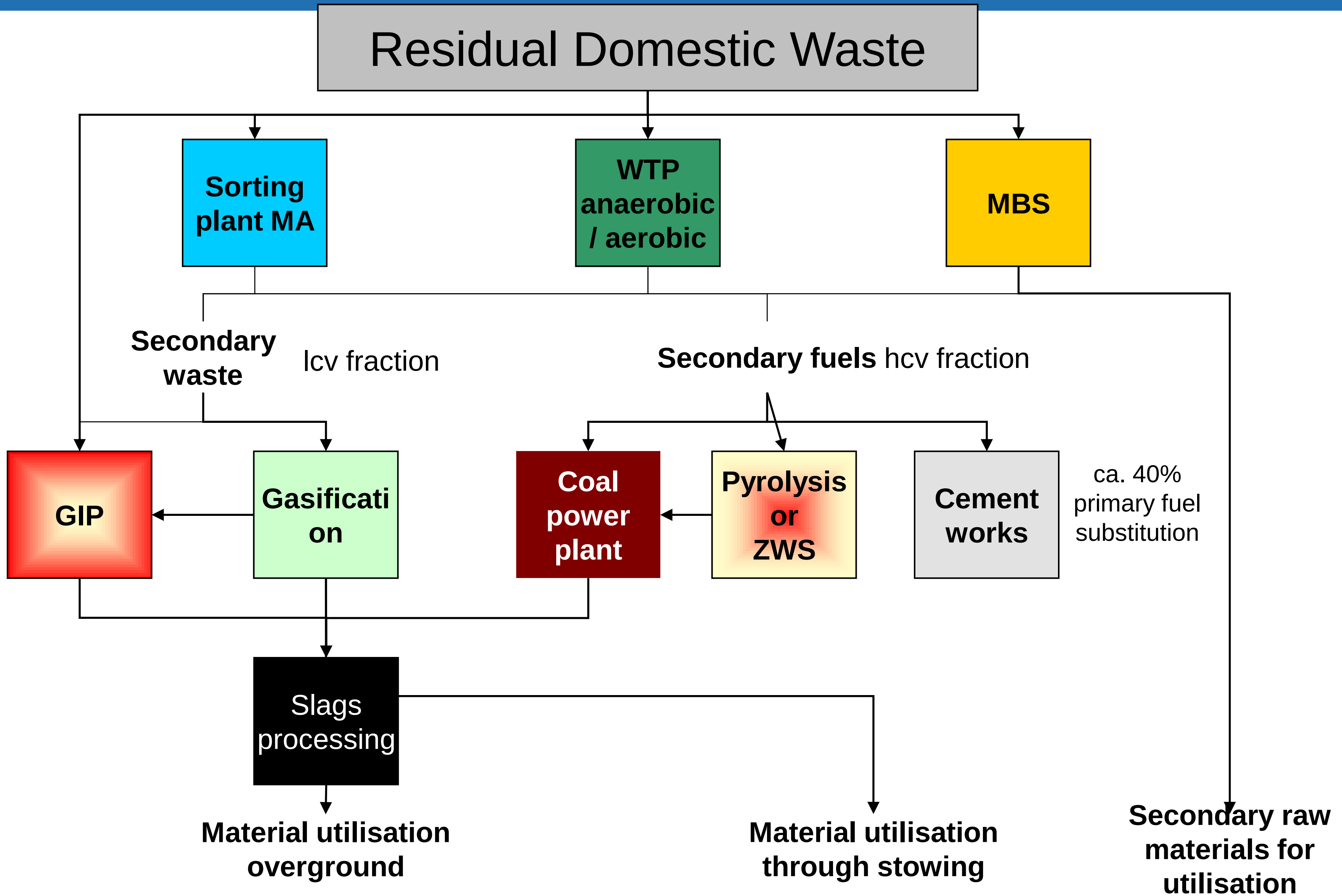
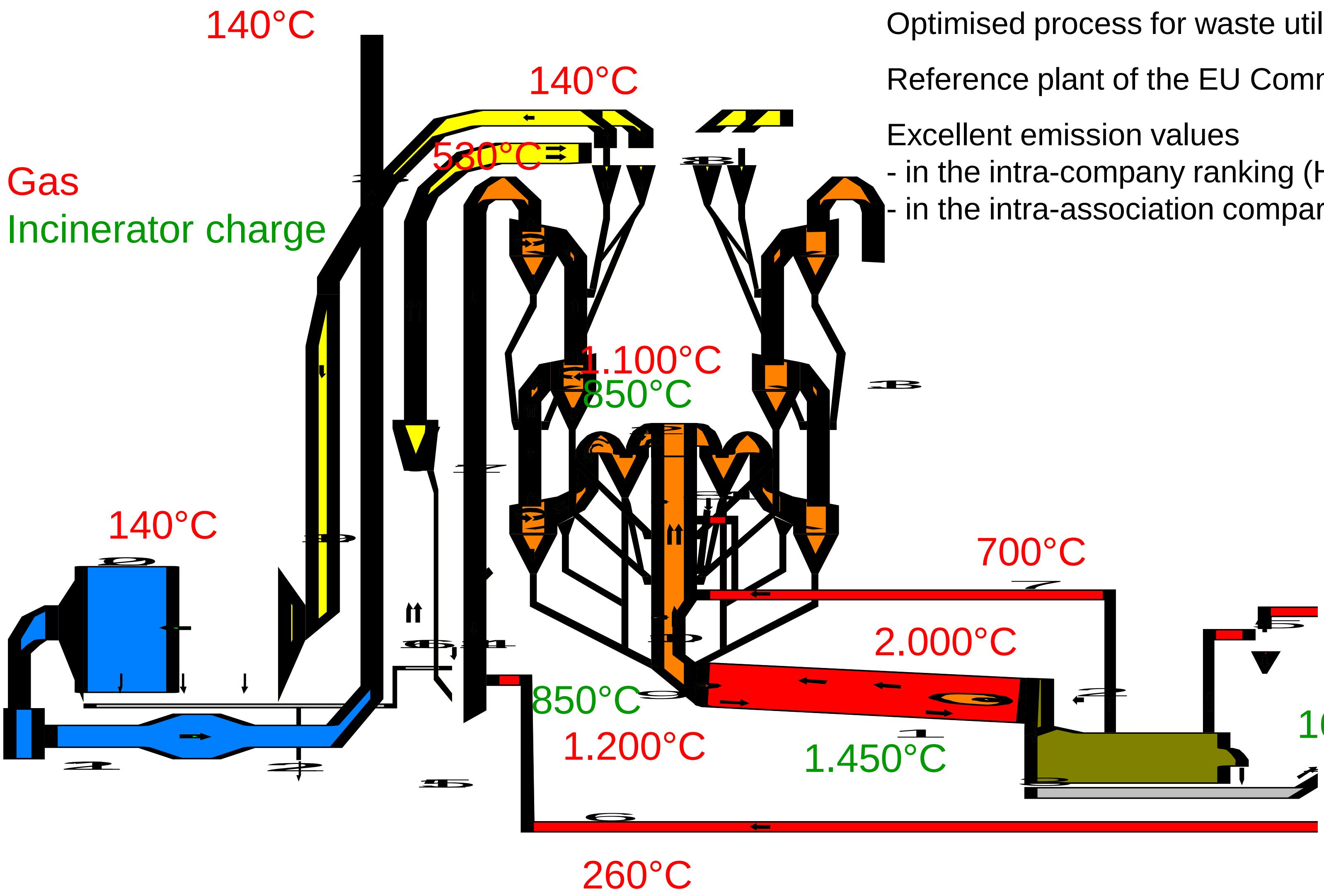
9. Thermal waste treatment I
Thermal waste treatment II

Disposal Concept „Target 2020“ for Residual Waste



Processes and their Suitability for Waste Co-Combustion



Optimised process for waste utilisation

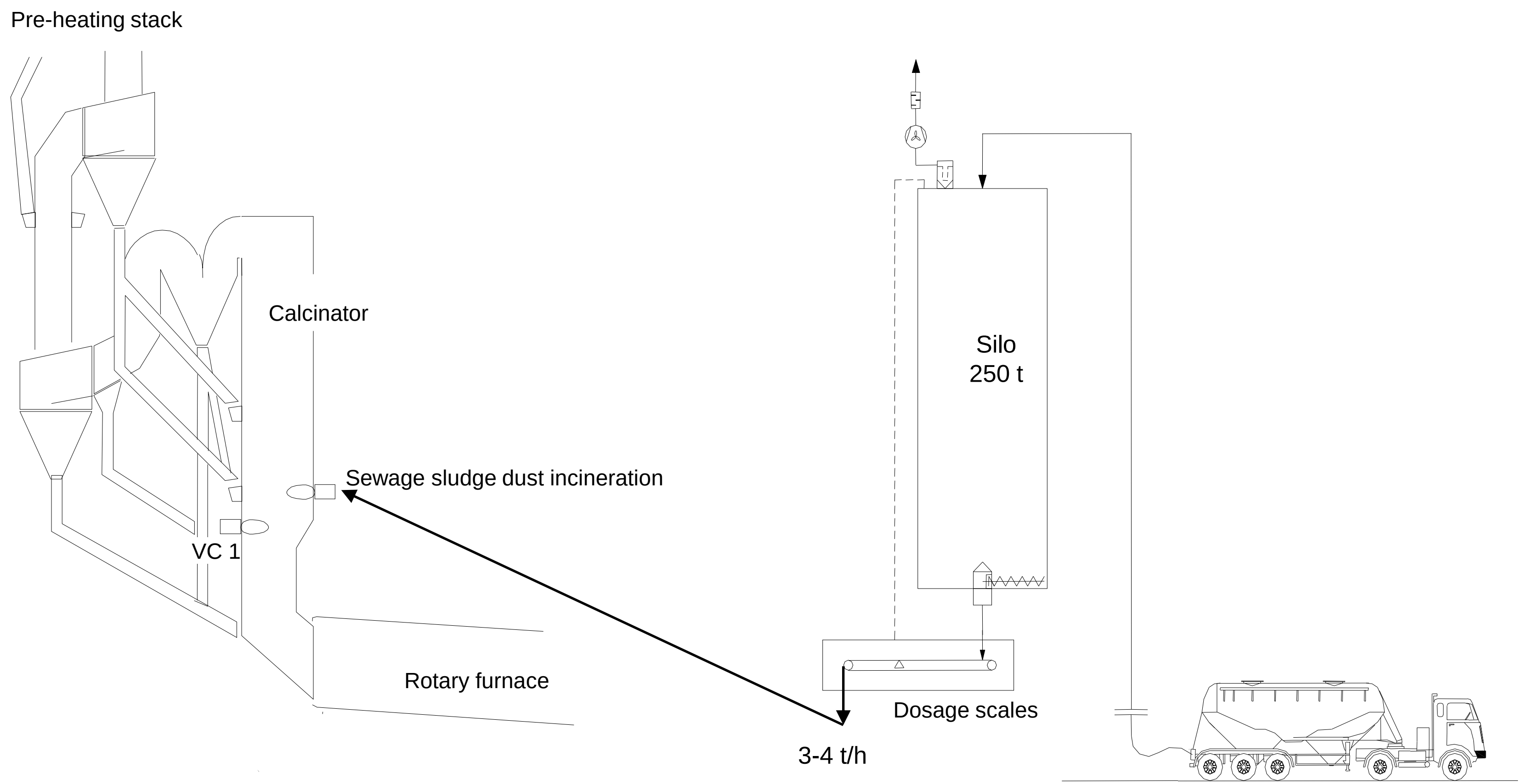
Reference plant of the EU Commission (BAT)

Excellent emission values
- in the intra-company ranking (Holcim)
- in the intra-association comparison (VDZ)

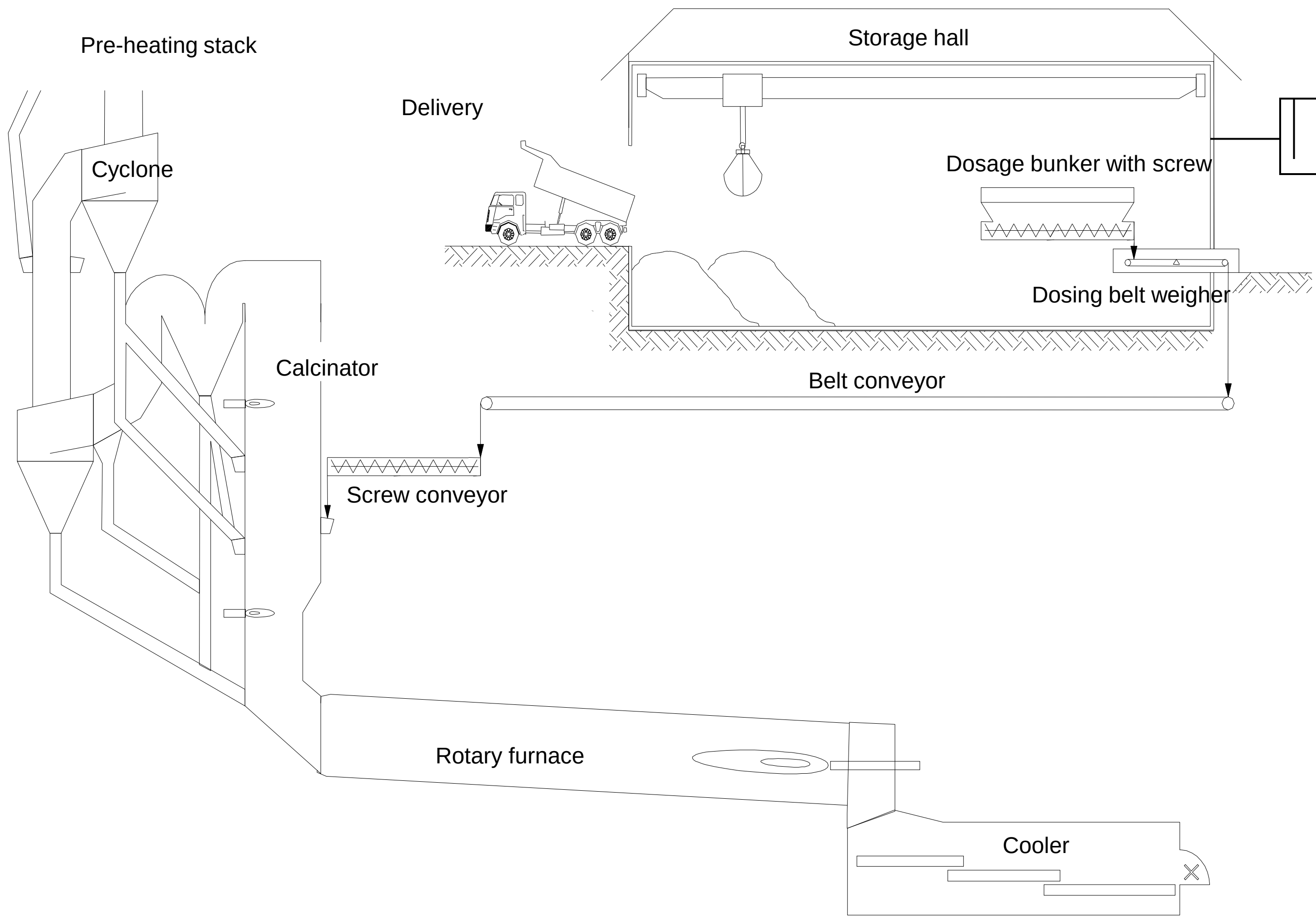
Process-Technological Features for the Emploment of Waste in the Cement Production Process

- Gas temperatures in the rotary pipe (primary firing) of ca. 2000°C
- Contact time of the gas in the rotary furnace of approx. 3 to 8 seconds
- Oxidising gas atmosphere in the rotary furnace
- Temperature of the incinerator charge of approx. 1,450° C in the rotary furnace and 850° C in the secondary firing
- Contact time of the gases of more than 2 seconds at temperatures of 850°C
- Destruction of organic pollutants through the high temperatures at sufficiently long contact times
- Sorption of gaseous components such as HCI, HF or $S0_2$ to alkaline reaction partners
- High retention capacity for particle-bound heavy metals
- Chemical-mineralogical incorporation of heavy metals into the cement clinkers

Storage and Dosage of Fully Dried (>90% DS) Sewage Sludge



Storage and Dosage of Partly Dried (75%-85% DS) Sewage Sludge



Energy Utilisation at Different Calorific Values H_u

Energy ratios	HEIZWERT H_U (kJ/Mg Abfall) 8.600	10.200
Loss through		
- Incombustibles	3%	3%
- Radiation	1,5%	1,5%
- Ash heat (palpable heat)	4%	4%
Exhaust gas loss (incl. reheating to 80°C)	7,2 %	6,8 %
Subsistence (85 kWh/t waste)	14%	11,8%
Wastewater evaporation (ca. 1m³/t)	6,0%	5,1%
Externally utilisable energy (%)	64%	68%
Externally utilisable energy (kJ / Mg)	5.500	6.940
Externally deliverable energy with exclusive conversion into electric energy: kJ/Mg * 0,25 / 3,6 (kWh/kJ)	380 kWh/Mg	480 kWh/Mg

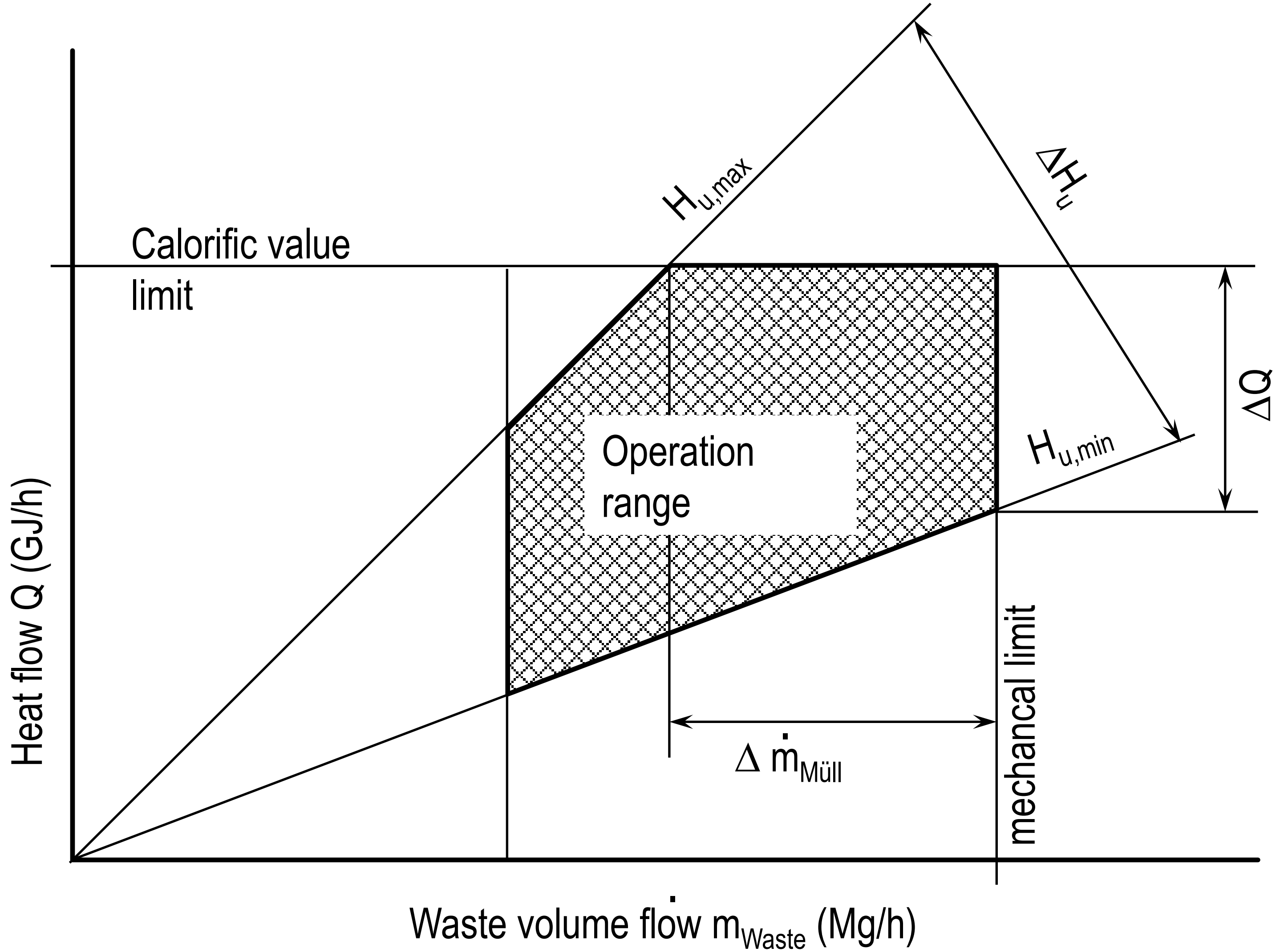
Energy ratio utilisable for steam generation: 100 - 3 - 1,5 - 4 - 7,2 - 6,0 = 100 - 21,7 = 78,3 %

With 2,654 GJ/t_{Steam} = Enthalpy difference per ton of steam with 41 baraund 410°C at H_U= 8600 kJ/kg, the steam amount which can be generated is:

$$\frac{8600 * 0{,}783}{2{,}654}$$ = 2,53 t steam/t waste, or at H_U= 10.200 kJ/kg corresp. to 3.15 t steam/t waste

- Energy profits from electric energy cover only 10%-20% of the incineration costs; with steam, however, high amounts of coverage can be achieved
- In eco-balances, there will be emission bonuses

Incineration Diagram of a Waste Furnace



Dimensioning – Failure Probability

Furnace, boiler, flue gas treatment, and heat utilisation are commonly dimensioned for an availability of 7,000 to 8,000 h/a (decent maintenance provided) (**Availability d** = 7000/8760 = ca. 80%. **Failure probability** of a single line = 1 - 7000/8760 = 20%).

$$\frac{\text{Annual waste amount (t/a)}}{\text{7,000 to 8,000 h/a}} = \text{effective incineration capacity (t/h) of the entire plant}$$

Possibly allowances for seasonal variations.

Distribution to n units, with the failure probability in relation to the number n of units amounting to the following:

Failure of 1 unit	$n * d^{n-1} * (1-d)$	
Failure of all units	$(1-d)^n$	e. g. 20% with 1 unit/plant, 4% with 2 units/plant, and 0.8 % with 3 units/plant

Number n of units	1	2	3	4
Failure probability d of 1 unit	20,00%	20,00%	20,00%	20,00%
Availability d	80,00%	80,00%	80,00%	80,00%
Failure 1 of n units	20,00%	32,00%	38,40%	41,00%
Failure all n units	20,00%	4,00%	0,80%	0,16%
Failure of no unit	80,00%	64,00%	51,20%	41,00%

Bunker

$$\text{Nec. Bunker volume} = 3 - 4\,\text{d} \cdot 24\,\text{h/d} \cdot \text{incineration capacity of all units which must run simultaneously (t/h)} \cdot \text{ca. (2.0 to 2.5) m}$$

Bunker dimensions according to:

- Pouring angle of the waste 60-80°
- Length from width of the boilers units and from number/width nec. discharge points E:

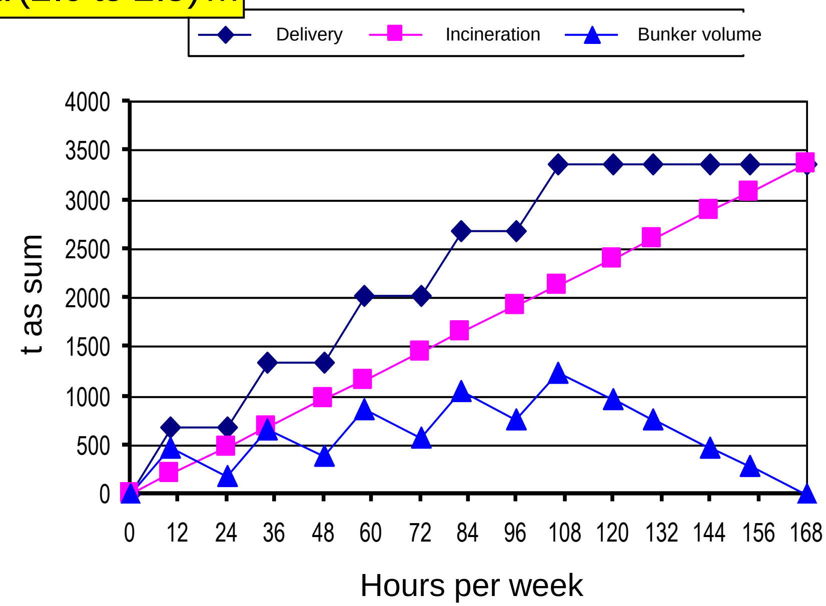
$$E = \frac{\text{annual-input (t/a)} \cdot t_E \cdot \text{peak factor}}{250\,\text{Ad/a} \cdot \text{payload/vehicle} \cdot 8\,\text{h/d}} =$$

t_E [h] unloading time 7 vehicle, e.g. 6 min

peak factor ratio of max / min deliveries per hour, e.g. 3

Example:

Payload/Vehicle reception 60 % of delivery amount with 20t-press containers
via transfer stations and rest with an average of e.g. 4 t/lorry:



- Depth highest pouring point at discharge top edge bunker floor;
- Height height over highest pouring point to top edge inner bunker long wall
  Minimum height from altitude of the furnace and height of feeding chute and Dropshaft (pouring angle see above)
- Width from dimension ing of opened grapnels + stacking width or from bunker volume/ (length * average height); recommende width > 15 m

$$V_{Bunker}[m^3] = [T + (H - T)/2] \cdot W \cdot L$$

$$E = \frac{400{,}000\,\text{t/a} \cdot 6/60 \cdot 3}{250\,\text{Ad/a} \cdot (0.6 \cdot 20 + 0.4 \cdot 4) \cdot 8\,\text{h/d}} = 4.41\,\text{tipping sites}$$

Selected 5 + 1 tipping sites for manuel discharge

Bunker

$$\text{nec. bunker volume } V_{B,nec} = 3\text{ - }4\,d \cdot 24\,h/d \cdot \text{incineration capacity of all units which must run simultaneously } (t/h) \cdot \text{ca. } (2.5 \text{ to } 3.5)\, m^3/t$$

Bunker dimensions according to

- Waste pouring angle 60°– 80°
- Length from width of the boiler units and number/width of the necessary discharge points E

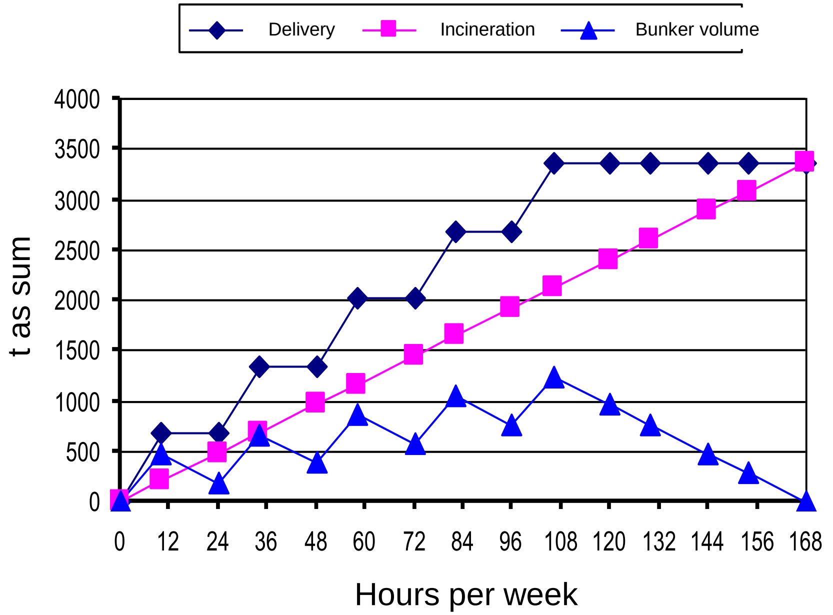
$$E = \frac{\text{annual input } (t/a) \cdot t_E \cdot \text{peak factor}}{250\,Ad/a \cdot \text{payload ut/vehicle} \cdot 8\,h/d}$$

t_E(h) discharge time/vehicle, e.g. 6 min;
peak factor ratio between max/min deliveries /h; e.g. 3

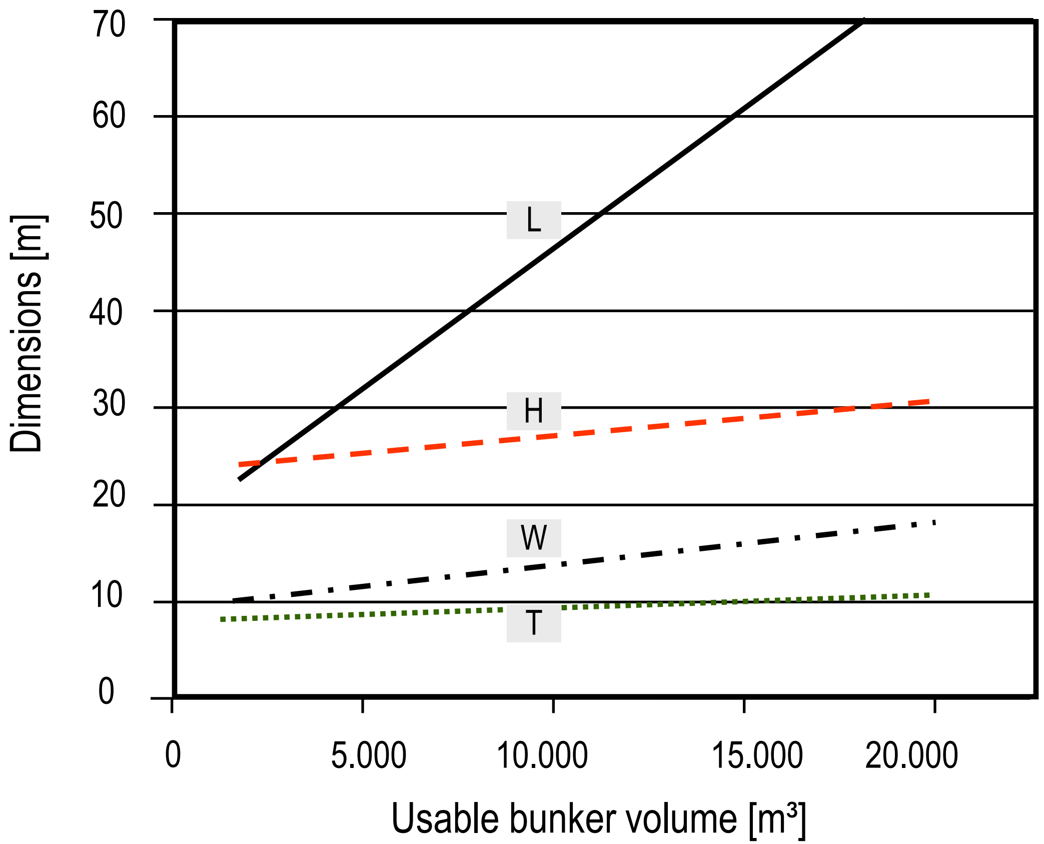
Example payload/vehicle at reception:
60% delivery amount with 20t press containers +
40% delivery amount with an average of e.g. 4 t/vehicle

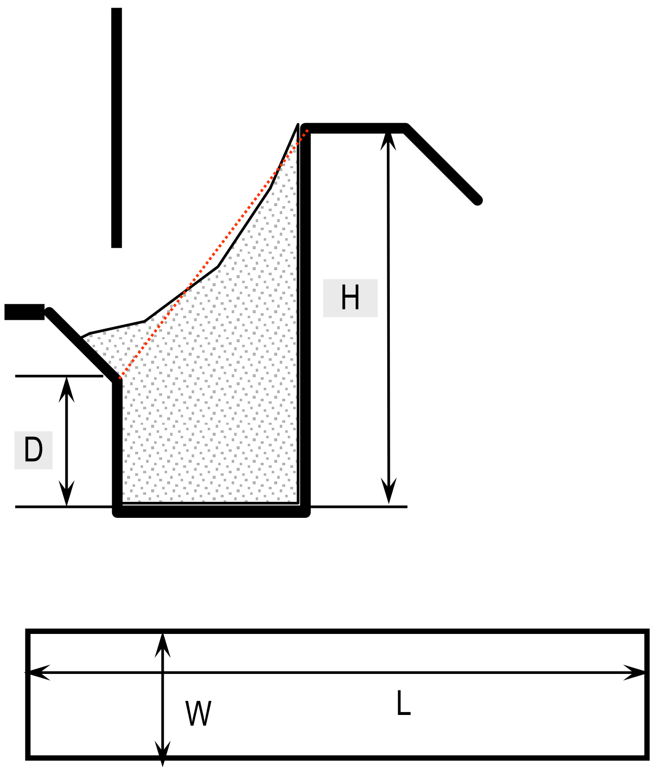
$$E = \frac{400.000\,t/a \cdot 6/60 \cdot 3}{250\,Ad/a \cdot (0{,}6 \cdot 20 + 0{,}4 \cdot 4) \cdot 8\,h/d} = 4{,}41 \text{ tipping sites}$$

chosen 5 + 1 tipping sites for manual discharge

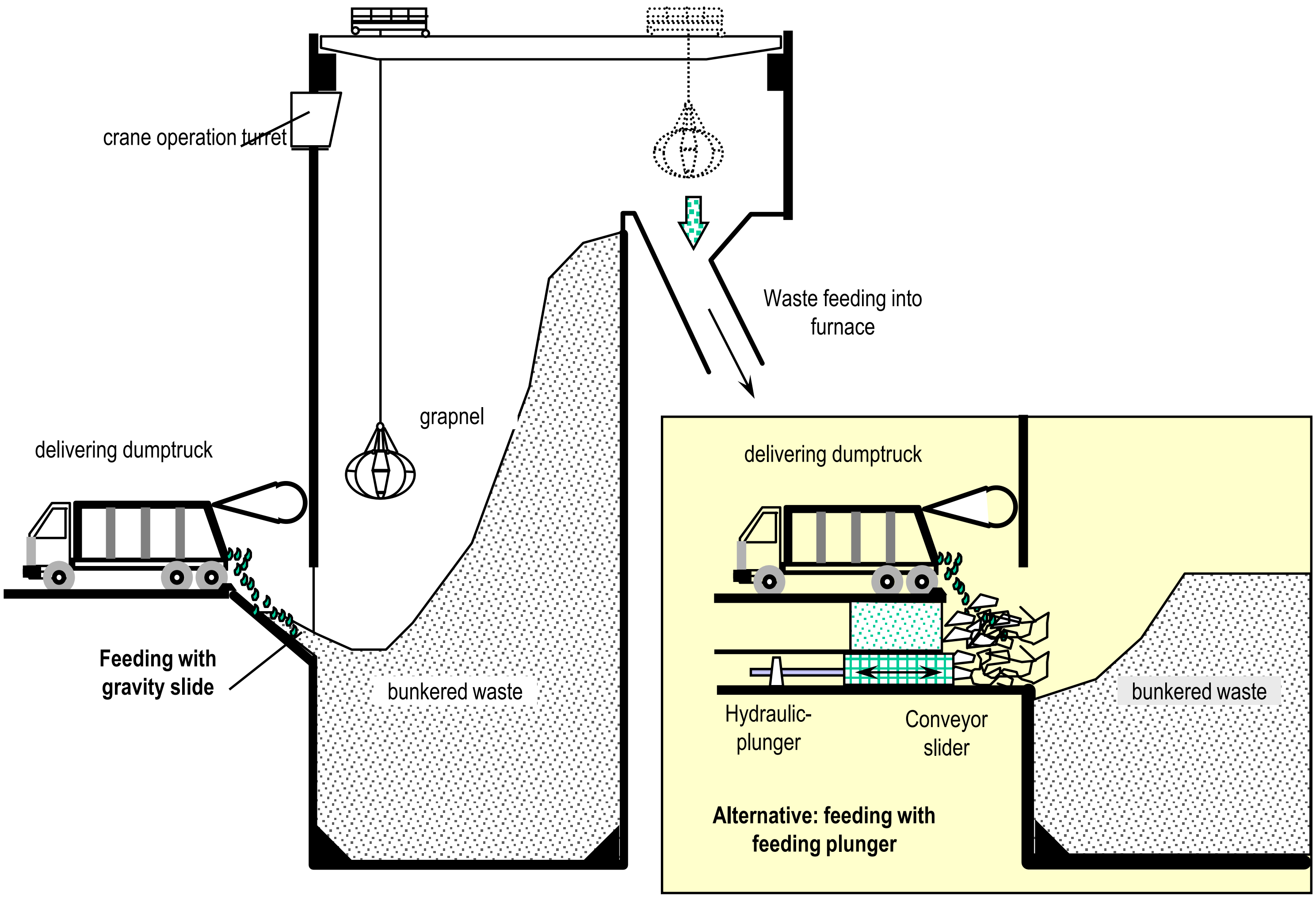


Typical GIP Underground Bunker Dimensions according to Zimmermann, 1994; MHB 7145

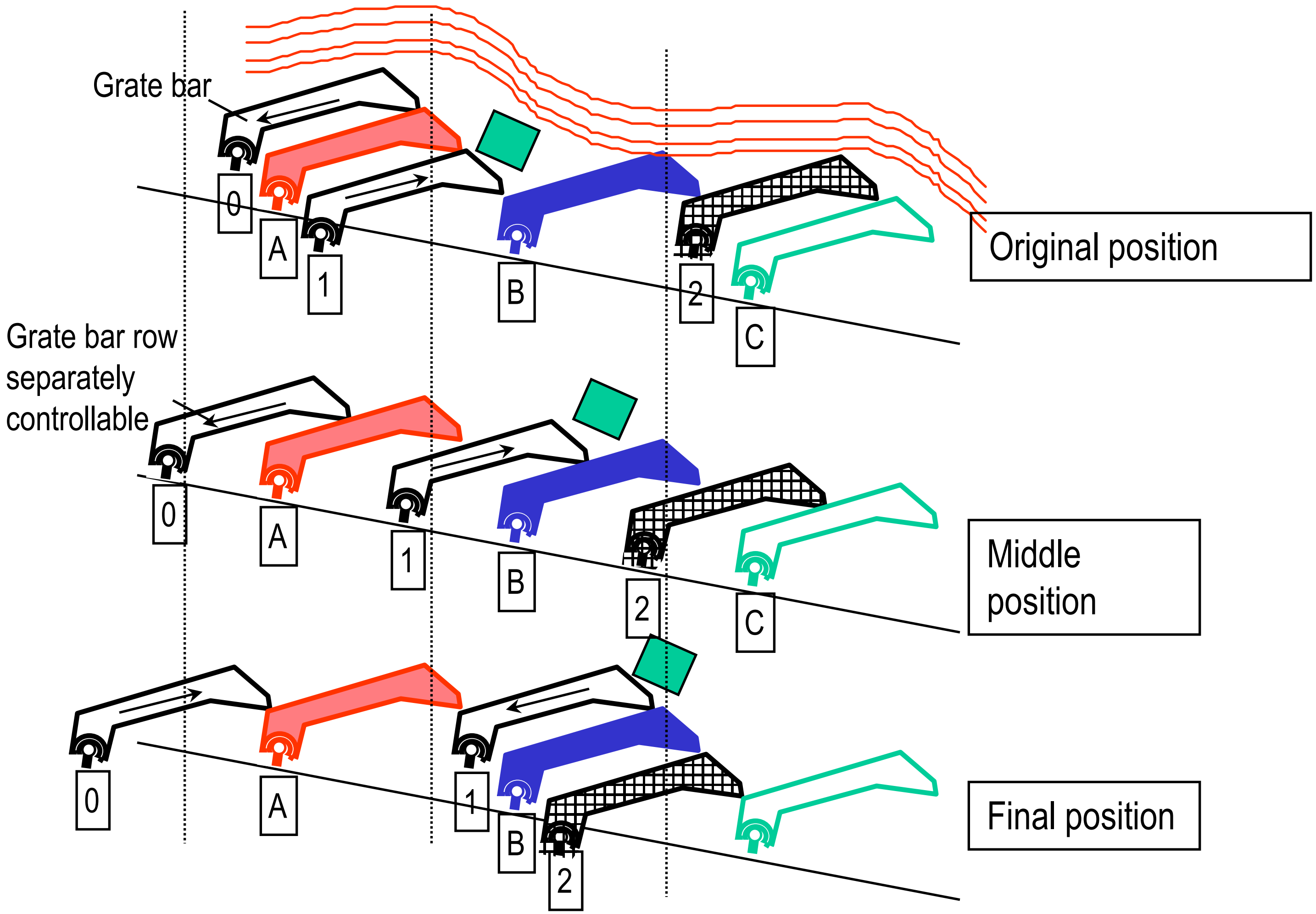




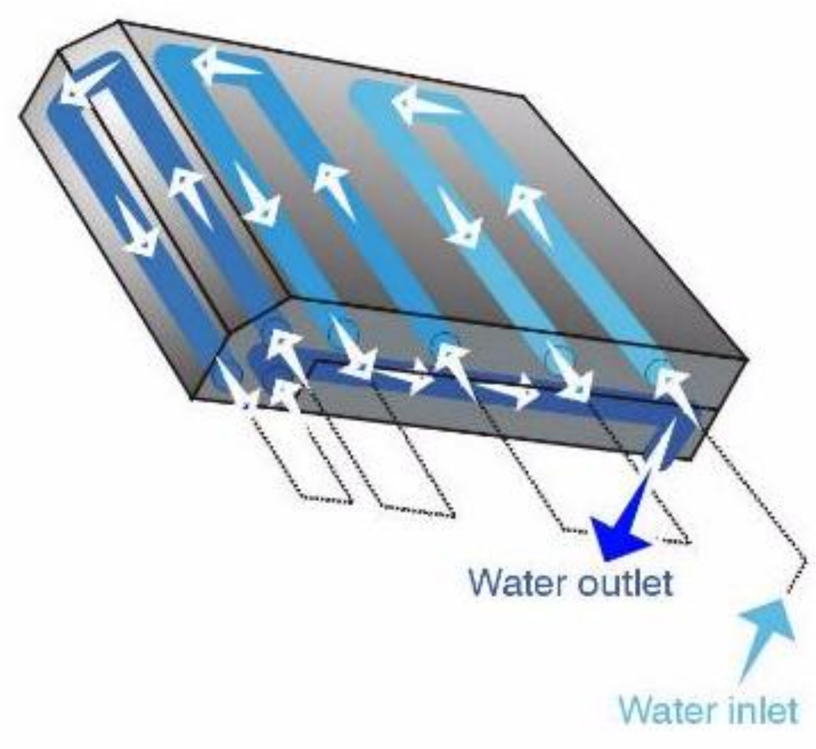
Underground Bunker – without centre wall, feeding with sloping slide or feeding plunger

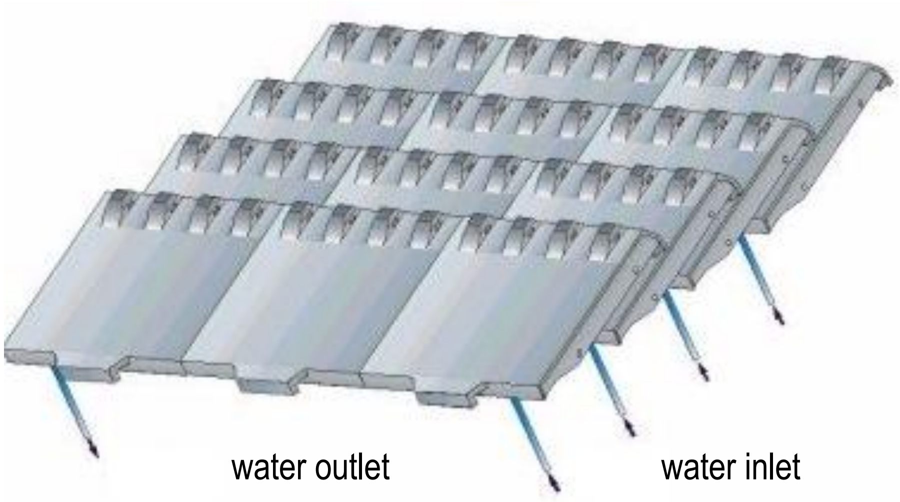


Grate Systems: DBA Reverse Thrust Grate System according to Christmann in Reimann, 1991, S. 152, Grate incineration



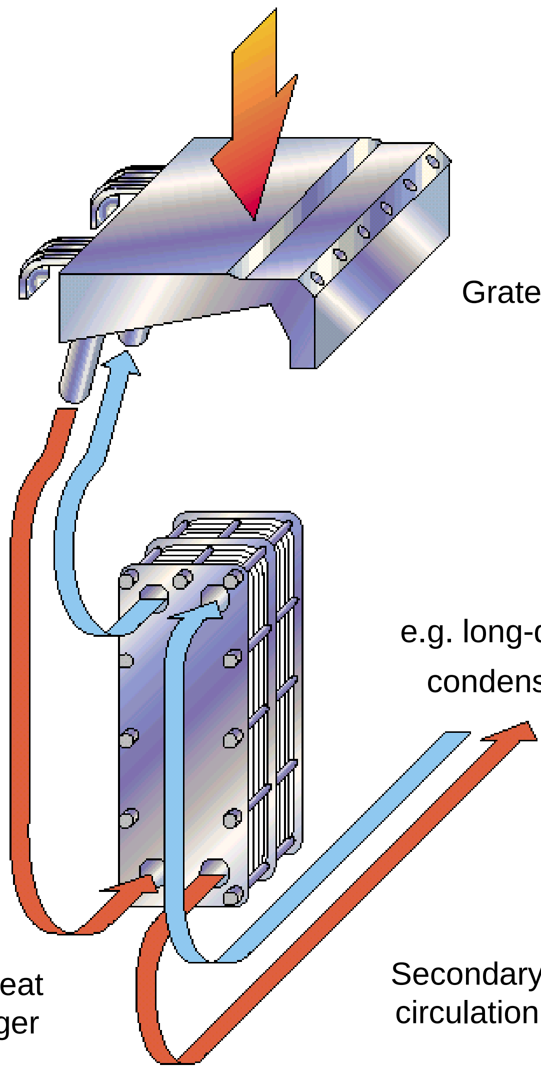
Water-cooled Grate for High H_u Source: www.martingmbh.de



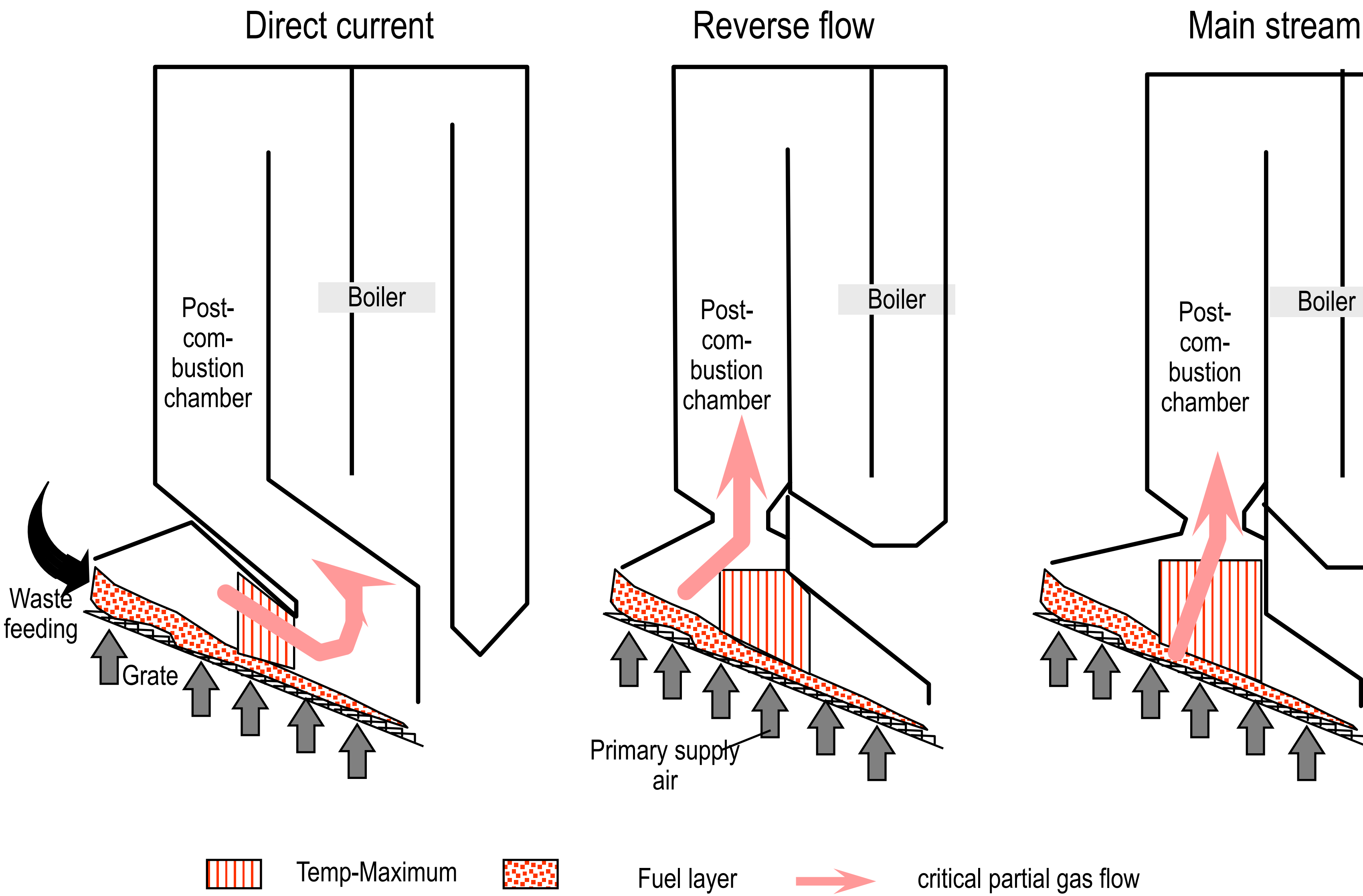


Cross section through a water-cooled grate step
with integrated cooling ducts and a through-flow pressure of 2-5 bar for the cooling medium

Water-Cooled Grate „Aquaroll" Source: Prospectus of the Roll company, 2001



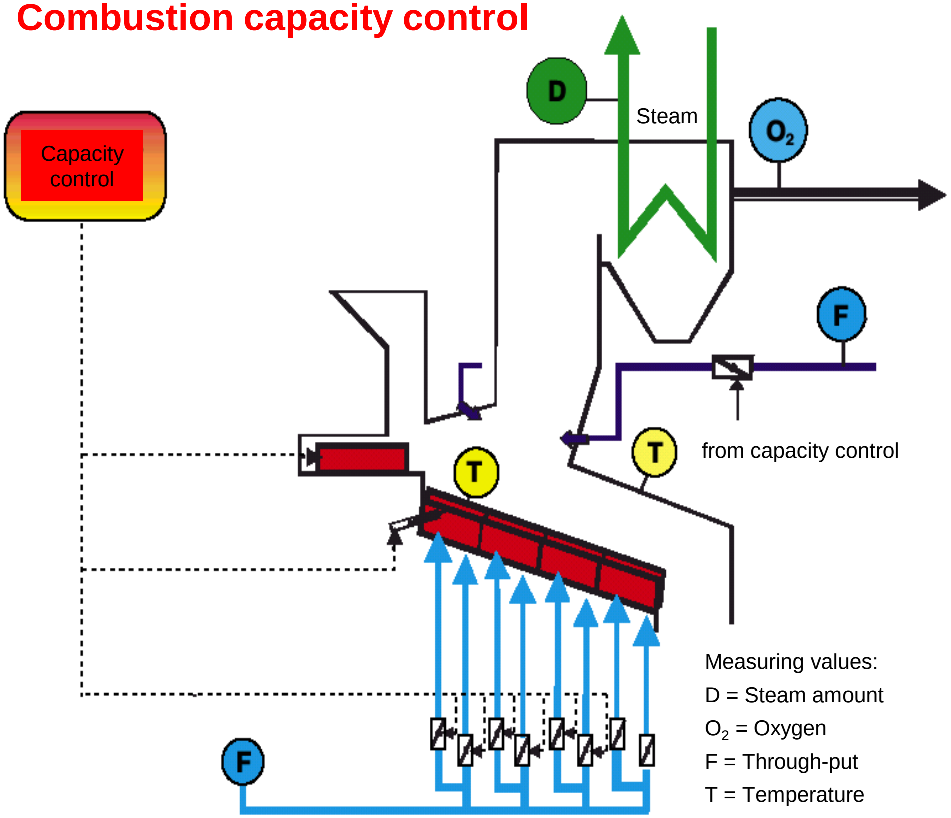
Combustion Chamber Concepts on GIPs



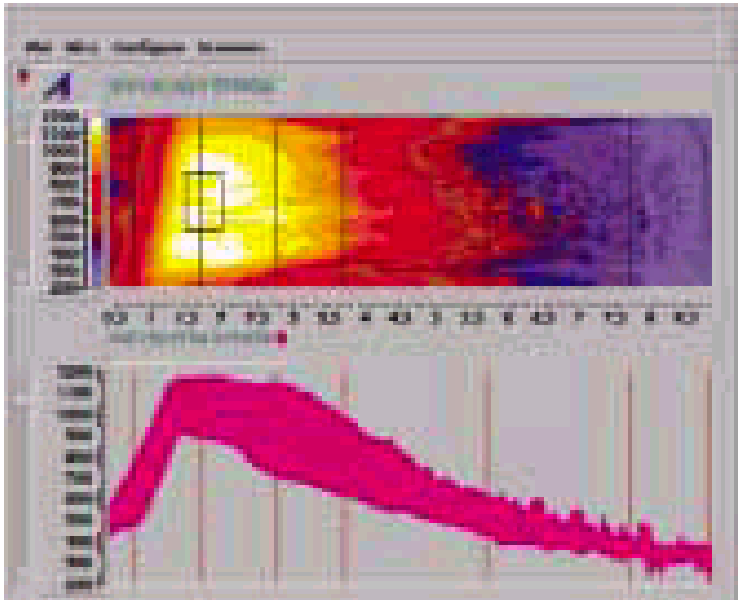
Combustion Chamber and Air Supply / Control

- **Combustion chamber walls**
  - ceramic wall
  - membrane pipe wall
  - water-cooled ceramic wall
- **Air supply** as
  - primary air (undergrate air through grate), if necessary with preheating of the air (LuVo)
  - secondary air (prior to entry into post-combustion chamber)
- **Combustion capacity regulation**
  - measuring of fire position and length with infra-red cameras
  - measuring of CO, O_2, T, steam amount, etc.
  - control of
    - waste feeding;
    - auxiliary combustion;
    - grate velocity;
    - stoking;
    - air amounts and distribution

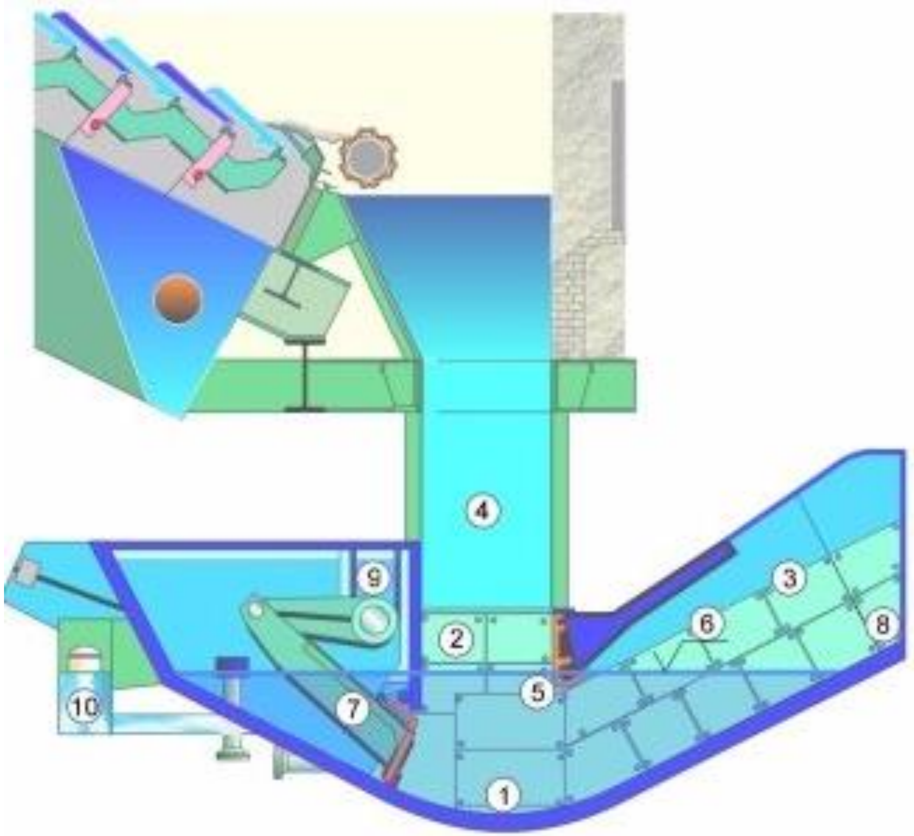
Combustion capacity control



Temperature distribution measured with infra-red camera



Wet Slags Purger Source: Martin gmbh.de

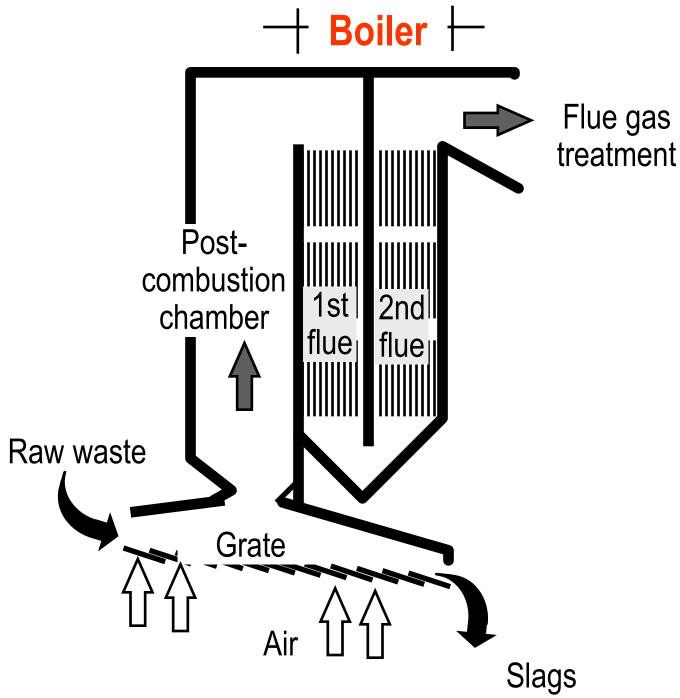


1	Arched pan	6	Water level
2	Dropshaft	7	Discharbe piston
3	Discharge chute	8	Tipping edge
4	Intermediate pipe	9	Drive shaft
5	Air exclusion wall	10	Floater box with valve

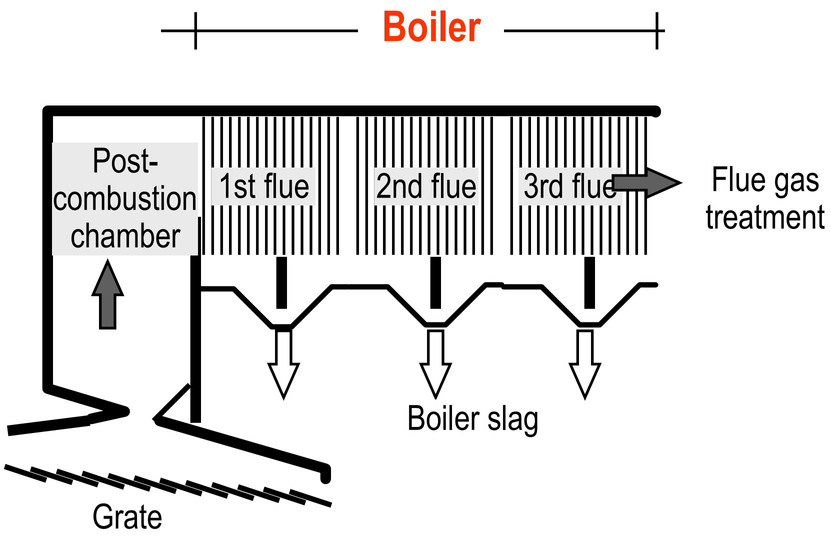
Boilers

- Energy utilisation
- Reduction of the exhaust gas temperature for ensuing flue gas treatment

stacked boiler



Triple-flue boiler



"Dimensions"

Prefix	Abbreviation	Power	Equivalent to	Name
Exa	E	10^{18}		Quintillion*
Peta	P	10^{15}		Quadrillion*
Tera	T	10^{12}	1.000.000.000.000	Trillion
Giga	G	10^{9}	1.000.000.000	Billion
Mega	N	10^{6}	1.000.000	Million
Kilo	k	10^{3}	1000	Thousand
Hecto	h	10^{2}	100	Hundred
Deka	da	10^{1}	10	Ten
Deci	d	10^{-1}	0,1	Tenth part
Centi	c	10^{-2}	0,01	Hundredth part
Milli	m	10^{-3}	0,001	Thousandth part
Micro	µ	10^{-6}	0,000 001	Millionth part
Nano	n	10^{-9}	0,000 000 001	Part in a billion *
Piko	p	10^{-12}	0,000 000 000 001	Part in a trillion *
Femto	f	10^{-15}		Part in a quadrillion*
Atto	a	10^{-18}		Part in a Quintillion*

In anglophone countries, the term „milliard“ is not common. Instead, „billion“ is used for 10^{9} and „trillion“ for 10^{12}.

Flue Gas Treatment - 17. BImSchV (valid for waste utilisation > 25% of the thermal output; exception cement furnaces >60 (40) %)

	Raw gas at HMVA* acc. to FAHLENKAMP et al.., 1988	17. BImschV at 11% O_2 Limit values			Achieved values 1)
		Daily average	1/2 h average	Average sampling time (1/2 to 2 h)	Daily average
	mg/m_N^3	mg/m_N^3	mg/m_N^3		mg/m_N^3
HCl	600-1500	10	60		<1
HF	5-15	1	4		<0.5
SO_X	200-500	50	200		<5
NO_X	200-350	200	400		80
Dust	2000-8000	10	30		<0.5
CO	30-100	50	100*		<10
C_{org}	5-20	10	20		<1
Hg;		0,03	0,05		<0.001
Cd + Tl;				0,05	
As, Pb, Cr, Co, Cu, Mn, Ni, V, Sb, Sn;				0.5 total	
As, Benzo(a)pyren,. Co, Cd, Cr				0.05 total	
PCDD/PCDF	0.5-20 $ngTE/m_N^3$			0.1 $ngTE/m_N^3$ 2) (6 to 16 h)	0.0036 $ngTE/m_N^3$

1) According to SCHÖNER, 1993; WBBau "Sonderabfälle", Kap. 5; CLEVE, U. (1994), Umwelt Oktober, 1994, V 25 ff.
2) TE = toxicity equivalents dioxins und furanes

* HMVA = garbage incineration plants for domestic waste

Development of the Limit Values in Germany (Source ITAD)

Limit values [mg/m³]	TI Air 1974	TI Air 1986	17. BImSchV (as of 8/2003)	Operation values of the GIP Würzburg 2003
Dust total	100	30	10	0.71
C_{total}	-	20	10	0.09
HCL	100	50	10	6.37
HF	5	2	1	0.3
SO_2	-	100	50	4
Nox	-	500	200	84.91
CO	1.000	100	50	13.62
Hg			0.05	0.001
	Hg, Cd, As, Ni, Pb, Cu, Cr, V: 20	Hg, Cd, Tl: 0.2	Cd, Tl: 0,05	Cd, Tl: < 0.001
		As, Co, Ni, Se, Te: 1		
Heavy metals		Sb, Pb, Cr, F, Cu, Mn, Pt, Pd, Rh, V, Sn, CN: 5	Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn: 0.5	Sb - Sn: <0.013
			As, Benzo(a)pyren, Cd, Co, Cr: 0.05	
PCDD/PCDF [ng TE/m³]			0.1	0.005

AS is about **twice** as dangerous as Cd, **five times** more dangerous than Cr, and 500 times more dangerous than benzol.

For the creation of a unified evaluation yardstick for the hazardousness of carcinogenic heavy metals and organic compounds, the riskiness of single substances is converted into arsenic values.

e. g.: 2 kg Cd = 1kg As equivalent
500 kg Cr = 1kg As equivalent

Comparison of the Exhaust Gas Limit Values of TI Air, 13. and 17. BImSchV. Source: Ifa Bavaria

Pollutant	Unit	TI Air General requirements	13. BImSchV Large incineration plants > 300 Megawatt	17. BImSchV Garbage incineration plants
Dust	[mg/m³]	20	20	10
C_{total}	[mg/m³]	50	-	10
CO	[mg/m³]	-	200	50
HCL	[mg/m³]	30	not relevant	10
HF	[mg/m³]	3	not relevant	1
SO_2	[mg/m³]	350	200	50
NOx	[mg/m³]	350	200	200
Dioxins	[ng TE/m³]	0.1	-	0.1
Dioxins in plants of the metal industry	[ng TE/m³]	0.4	-	-

Methods Used for Flue Gas Treatment

Dust: Cyclone, **E-Filter, fabric filter** (highest separation degrees), exhaust gas scrubbing

HCl, HF: **Quasi-dry and dry methods**, e.g. with $Ca(OH)_2$ suspension or powder,

$$HCl + Ca(OH)_2 \text{ --> } CaCl_2 + H_2O$$

need considerably super-stoichiometric $Ca(OH)_2$ addition with increased waste amounts in order to achieve high separation degrees. The predominant final product is $CaCl_2$ or – in case of neutralisation with NaOH – also NaCl (possibility of chlorine/alkali electrolysis).

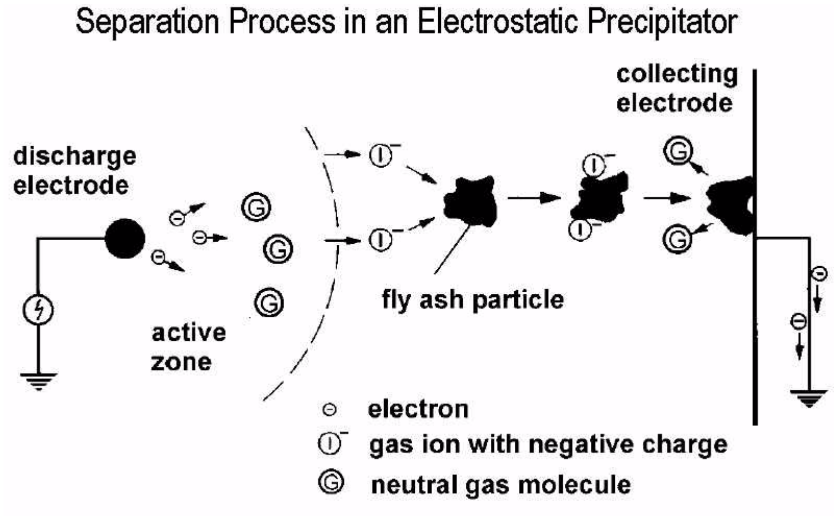
Scrubbing methods: Absorption in water, recirculation at pH-value pH 0.5-1, extraction of circulation water for scrubbing water treatment or, rather, evaporation, crystallisation (wastewater-free, wet flue gas treatment);

For utilisation: release of HCl dilute acid.

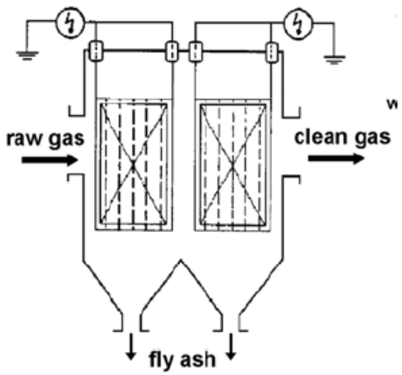
SO_2: Absorption in neutral to slightly alkaline solution (through addition of lime milk) with production of gypsum Gips ($CaSO_4$), e.g.

$$SO_2 + Ca(OH)_2 \text{ --> } CaSO_3 + H_2O$$

Electro-Filters for Dust Separation

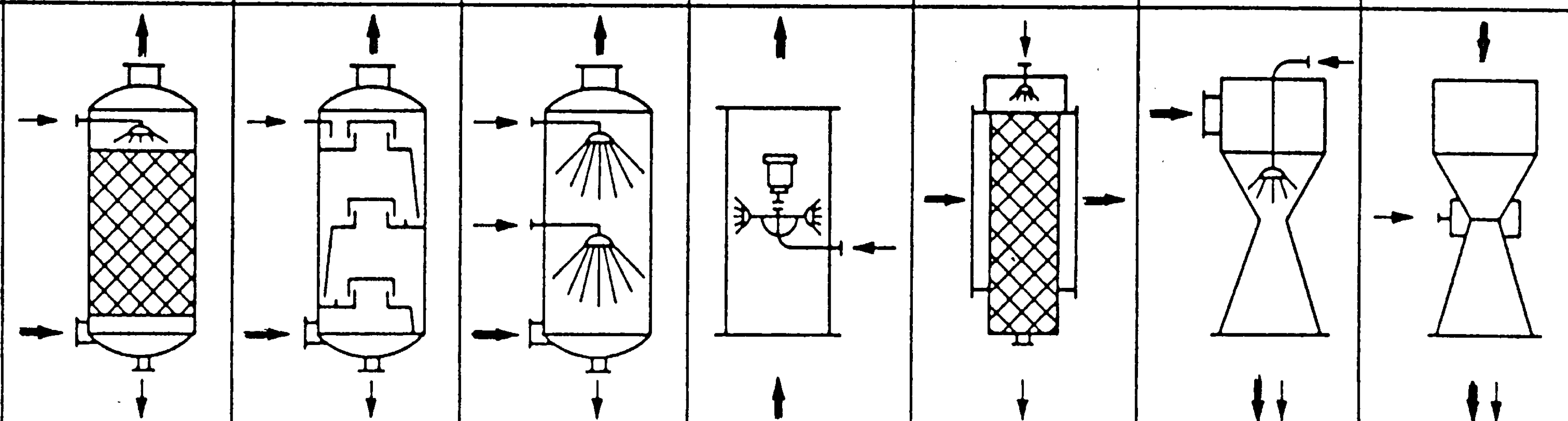


For a separation to take place, the dust particles have to be charged electrically. Charging of the particles takes place by negatively charged gas molecules which are formed in the active zone near the spray electrode. After this, the charged particles are transported in the electric field towards the so-called precipitation electrode. There, a dust layer deposits, which has to be removed regularly by shaking the precipitation electrode.



For particles of less than 0.1 µm in size, separation is based on another process. Brownian movement leads to the particles depositing on the precipitation electrode. A detailed description of the very complex processes in an electrostatic precipitator for dust separation can be found in literature (see e.g. [Kern]).

Scrubbers for Flue Gas Treatment

Flow principle	Reverse flow				Crossflow	Co-flow	
Function	The gas flows in reverse flow through a support medium column through which liquid trickles	The gas moves in bubbles through the liquid	The liquid is finely atomised in a gas compartment		The gas flows in crossflow through a support medium layer through which liquid trickles	The gas is sucked through the liquid and mixed with it	The liquid is dispersed in the Venturi chamfer
Description	Support medium scrubber	Gas bubble scrupper, plate column scrubber	Spray tower, jet scrubber	Rotation scrubber	Support medium crossflow scrubber	Jet scrubber	Venturi scrubber
Scheme Scrubbing liquid (→) Gas (➞)							

Methods Used for Flue Gas Treatment

NOx:

DENOX methods through injection of NH_3: $NO_x \rightarrow N_2$ and H_2O: e.g. with

SELECTIVE NON CATALYITC REACTION (**SNCR**)

$6NO + 4NH_3 \rightarrow 5N_2 + 6H_2O$ or

$4NO + 4NH_3 + O2 \rightarrow 4N_2 + 6H_2O$;

or SELECTIVE CATALYTIC REACTION (**SCR**).

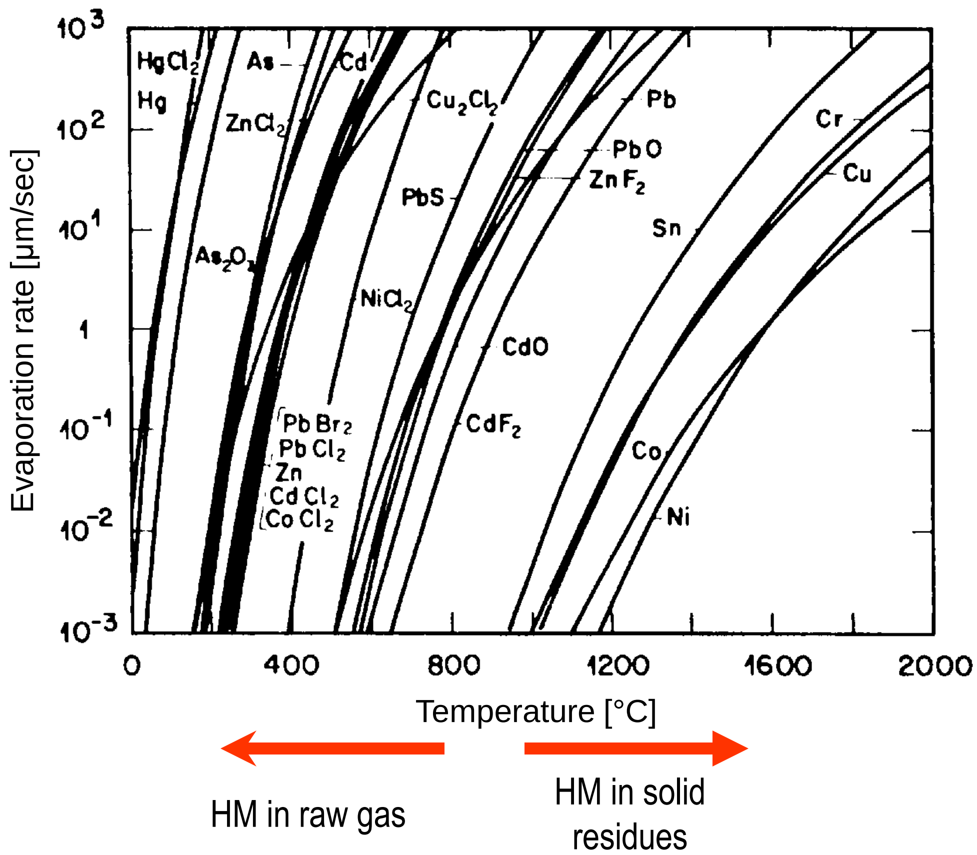
$2NO_2 + 2C \rightarrow 2CO_2 + 2N_2$

Heavy metals:

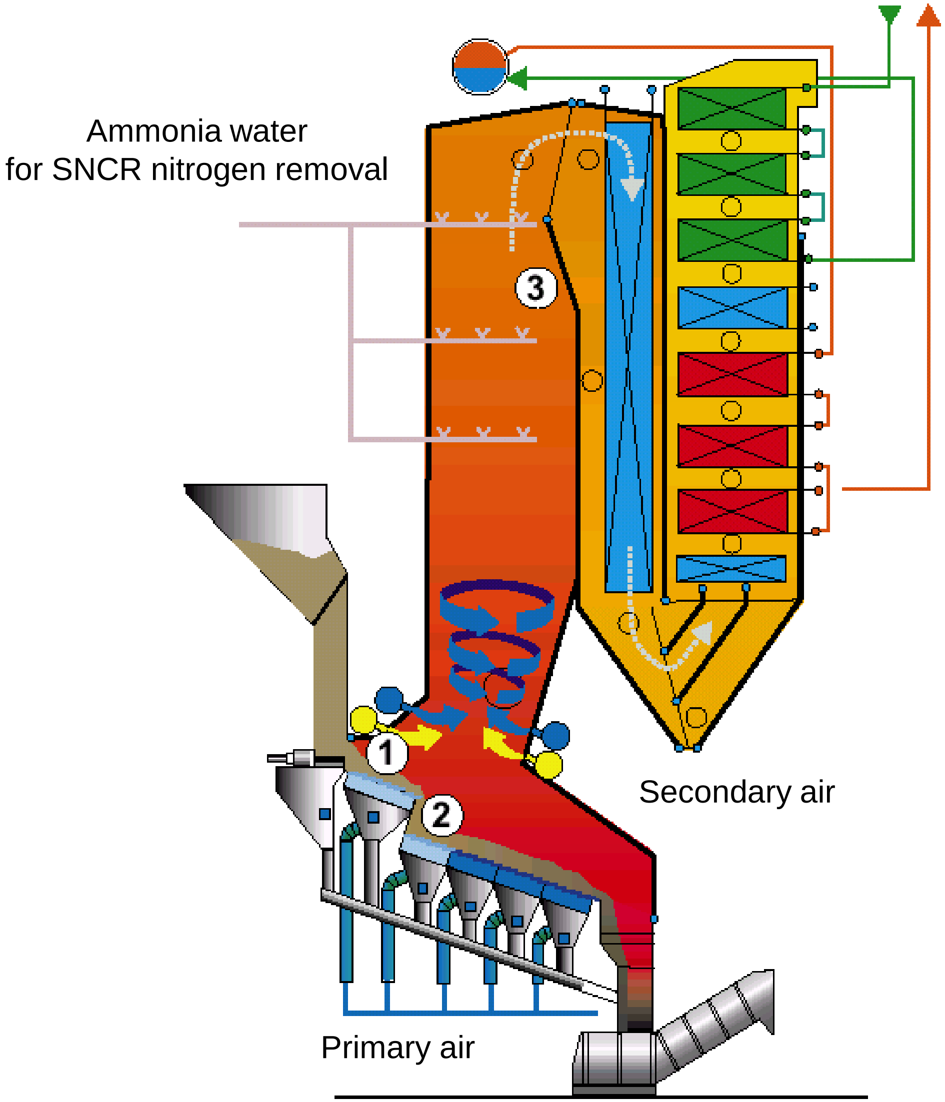
Depending on the evaporation rates, evaporation temperatures, and affinity to fine-grain dust and efficiency of the flue gas treatment, the metals gather in the four possible emission paths: slags, E-Filter dust, flue gas, and clean gas. Mercury can be eliminated only with scrubbing methods (if necessary, secondary treatment in activated carbon filters; also effective for remainders of Cd, As, Pb); scrubbing water treatment through precipitation or ion exchange.

Wastewater:

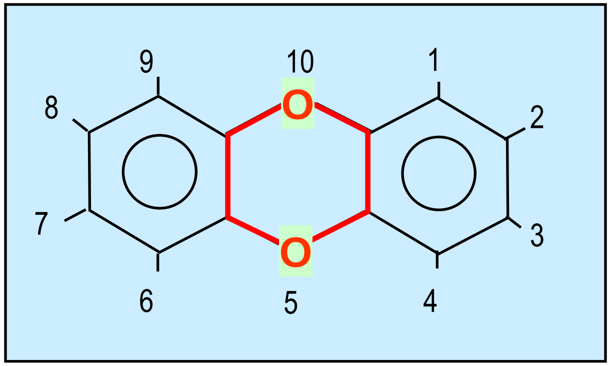
Discharge conditions according to Appendix 33 of the Wastewater Act; otherwise evaporation in the incineration process possible, with discharge of the steam via the flue.



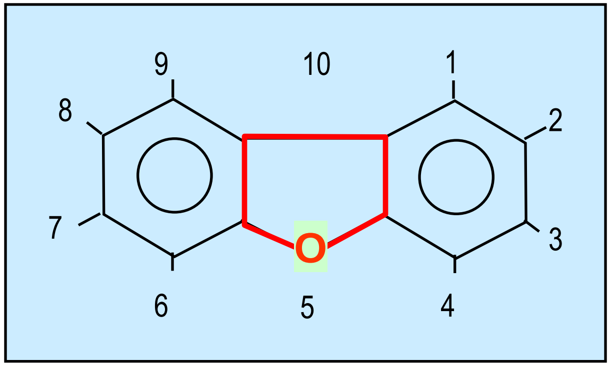
Grate + Boiler with SCNR Nitrogen Removal Source: Prospectus of the von Roll company, 2001



Polychlorinated Dibenzodioxins (PCDD) | Polychlorinated Dibenzofuran (PCDF)



Mono-CDD	2
Di-CDD	10
Tri-CDD	14
Tetra-CDD	22
Penta	14
Hexa	10
Hepta	2
Octa	1
Σ PCDD	75



Mono-CDF	4
Di-CDF	16
Tri-CDF	28
Tetra-CDF	38
Penta	28
Hexa	16
Hepta	4
Octa	1
Σ PCDF	135

Dioxin Reduction

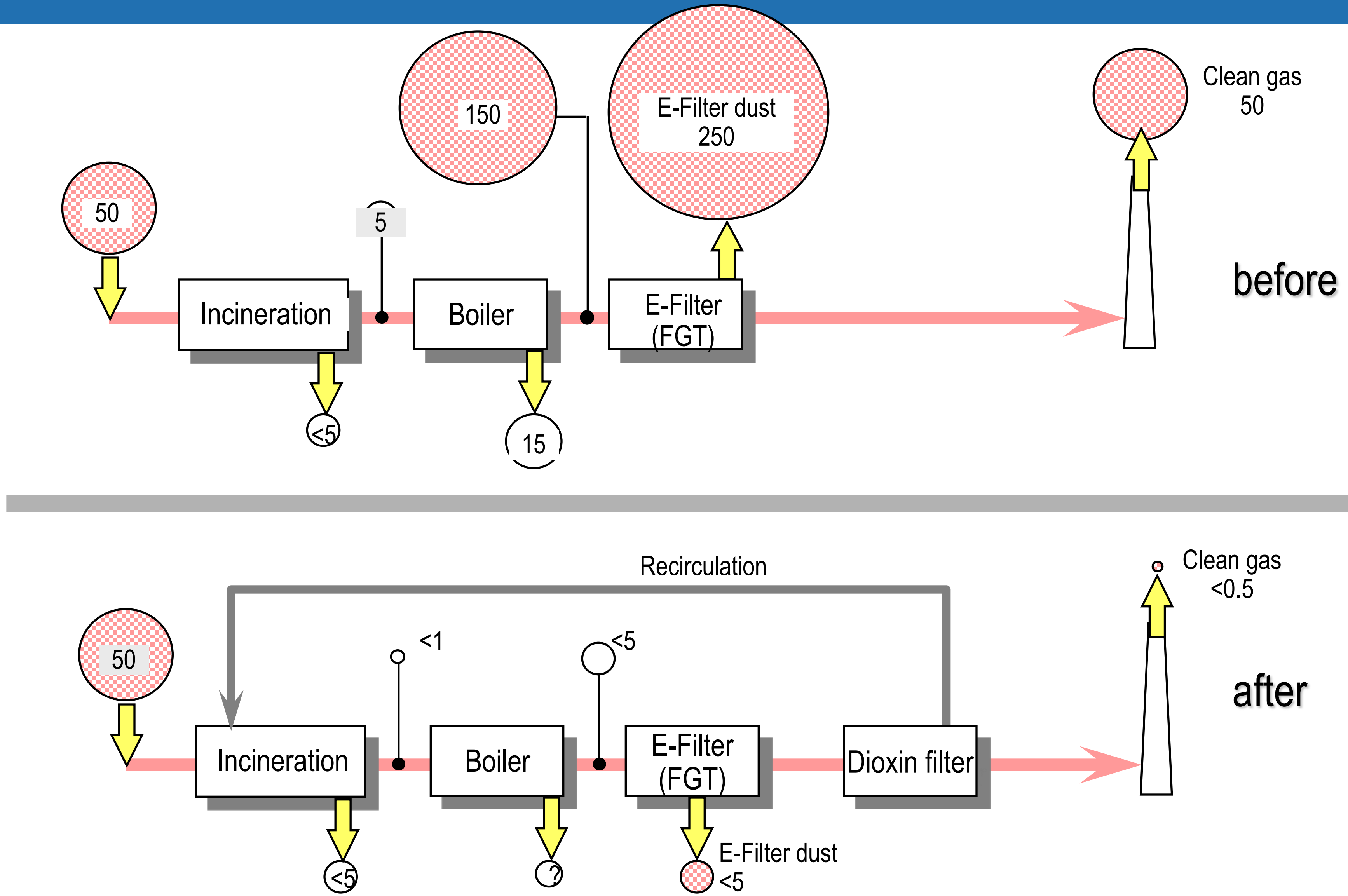
- Preventive measures
  - Exclusion of waste with high Cl loads (e.g. PVC)?

- Primary measures
  - Preliminary drying of the waste
  - Optimisation of the firing

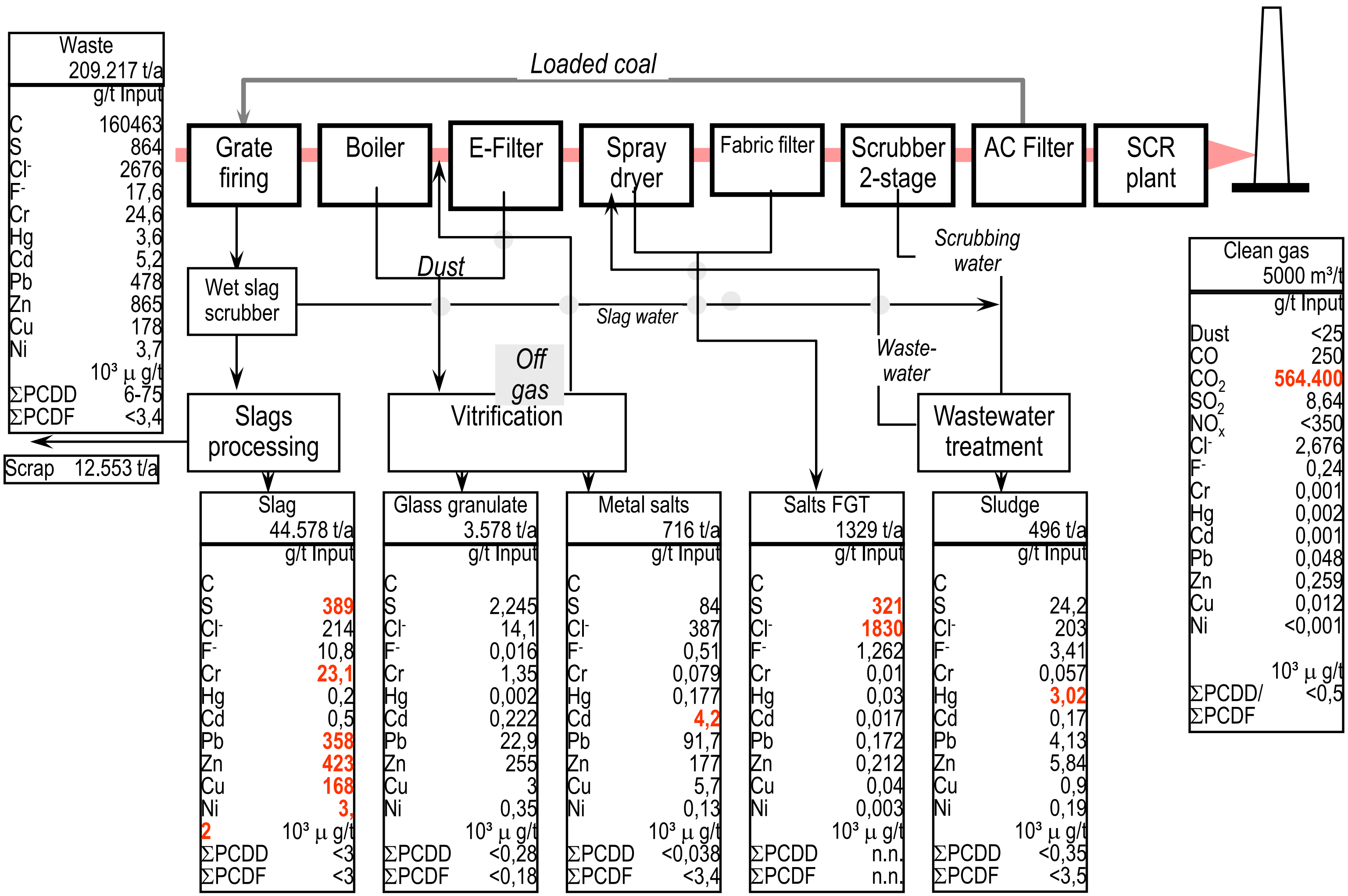
- Flue gas treatment
  - Avoidance of T = 200° to 400 °C („De Novo-Synthesis“)
  - Adsorptive treatment (activated carbon filter)

- Residue treatment
  - Secondary thermal treatment of boiler slag and dust

Dioxin Loads (µg TE/t waste) in WIPs before and after 17. BImSchV



Input/Output Balance of WIPs according to 17. BImschV



Transfer Factors via the Clean Gas

$$\text{clean gas} - \text{transfer factor } (-) = \frac{\text{emission load}}{\text{input load}} = \frac{\text{clean gas volume } (m^3/t \text{ input}) \cdot \text{clean gas concentration } (mg/m^3)}{\text{substance concentration } (mg/t \text{ input})}$$

Example according to Balance Image

Substance	Emission load (mg/t)	Input load (mg/t)	Emission transfer factor
Pb	48	478000	0,010%
Hg	2	3600	0,056%

Waste Amounts from Municipal Waste Incineration

Residue	Emerging amounts (kg/ t incincerated waste)
Slags (grate droppings, grate sifts, boiler slag); raw	250 -350
Slags (processed)	220-260
Ferrous and non-ferrous metals	25 -35
Residues from exhaust gas treatment:	
Filter dust from dust removal	20-40
Wet sorption	8-15
Quasi-dry sorption	15-35
Dry sorption	25-45

For slag utilisation, the LAGA Leaflet „Disposal of Waste from Incineration Plants for Municipal Waste“ 3/1994 must be considered. Improvement and pre-treatment of slags with the following methods:

- Separation of the waste fractions
- Increase of the burnout
- Separate collection (filter dust and boiler slag separate from grate droppings and grate sifts)
- Dewatering, scrap separation, screening
- Ageing (intermediate storage: minimum 3 months), if necessary: scrubbing
- Sintering and melting (for grate plants: subsequently; at high temperature plants integrated into the process).

Utilisation of slags in road construction below water-impermeable top layer according to LAGA leaflet.

Allocation Criteria for Slags according to LAGA Leaflet 3/1994 M 19 and 11/97 M 20 Section II.2.2

Parameter	Dimension	Allocation value	Suitability check	External control	Internal control
Determination in the solids					
Appearance	-	- 1)	+	+	+
Colour	-	- 1)	+	+	+
Smell	-	- 1)	+	+	+
Dry residue	Masse-%	- 1)	+	+	+
Ignition loss	Masse-%	- 1)	+	+	+
TOC	Masse-%	1 2)	+	+	
EOX	mg/kg	3	+	+	
Determination in the eluate					
Colouring	-	- 1)	+	+	+
Diffusion	-	- 1)	+	+	+
Smell	-	- 1)	+	+	+
pH-value	-	7 – 13	+	+	+
el. conductivity	µS	6000	+	+	+
DOC	µg/l	- 3)	+		
Arsenic	µg/l	- 3)	+		1) must be stated
Lead	µg/l	50	+	+	2) for old plants 3
Cadmium	µg/l	5	+	+	3) must be stated-
Chromium total	µg/l	200	+	+	for collection of
Copper	µg/l	300	+	+	experiences
Nickel	µg/l	40	+	+	
Mercury	µg/l	1	+	+	
Zinc	µg/l	300	+	+	
Chloride	mg/l	250	+	+	
Sulfate	mg/l	600	+	+	
Cyanide (easily soluble)	mg/l	0.02	+		