Conference: Mind the Gap! Sink holes in Twente

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Twente University, Enschede

Accumulation of hazardous and valuable substances in incineration ashes – the need for a holistic (risk) assessment and move to a circular economy

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Content of Presentation

- Material and substance flow in industrial countries – role of waste incineration.
- Heavy metals in municipal waste and their fate
- Material and substance flows in waste incineration
- Volumes of ashes and toxic potential
- Potential of releases during ash management and disposal
- More circular approach of ash management or stop MWI?
- Conclusions

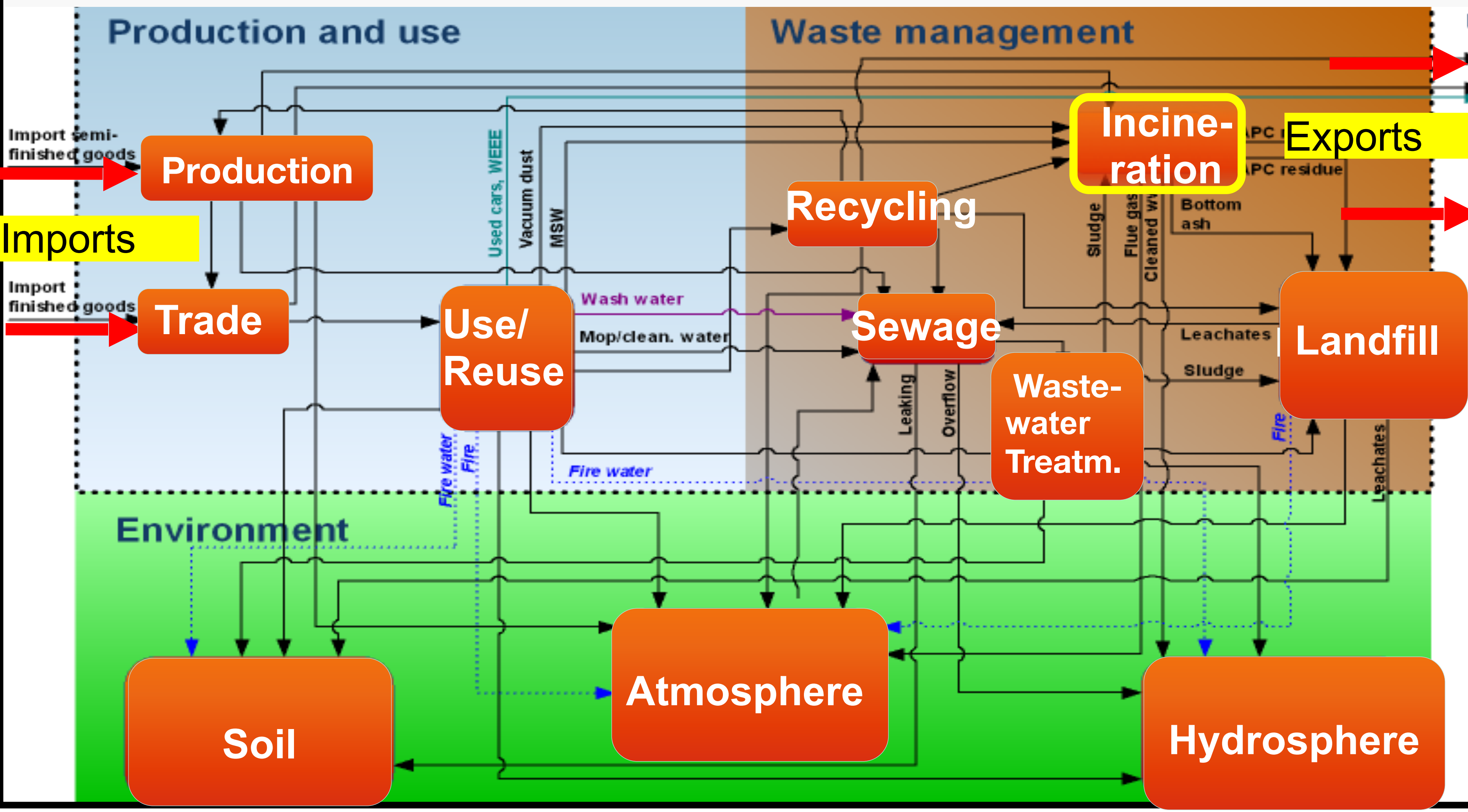
Risk of waste incineration to support non-sustainable linear consumption societies

- The high consumption (and production) in industrial countries is one problem for global sustainable development.
- Here the large resource consumption and the mainly/partly linear material flows of non-renewable resources are major challenges.
- Societies need to move to (more) circular economies (EU strategy).
- Currently waste incineration is rather a part of the linear economy.

Bonnet (ARC+) Circular Economy, saving resources, creating jobs, Green Week Brussels June 2014

Material Flow Analysis: Production/Use - Waste Management - Environment

- In industrial countries with limited space a considerable share of waste/ materials end up in waste incinerators generating related toxic residues.



Morf et al. (2006)

Substances entering waste incinerators

- A range of heavy metals and other non-combustible substances and materials enter municipal waste incinerators in many waste fractions.

		Minimum value	Maximum value	Ratio maximum/minimum	Mean value	Coefficient of variat (cv value)
Input						
Mass-flow	kg h^{-1}	6800	9600	41%	8000	13%
Lower heating value	kJ/kg^{-1} WS	8400	12400	55%	10900	15%
Water content	w %	*n.m.*	*n.m.*	–	–	–
Ash content	w %	27.7	35.7	28%	32.8	8%
Dust content	w %	3.1	3.9	24%	3.6	8%
Carbon	g kg^{-1} WS	193	271	41%	234	12%
Chlorine	g kg^{-1} WS	10.4	14.8	42%	13.2	11%
Sulfur	g kg^{-1} WS	4.2	4.6	11%	4.4	4%
Copper	mg kg^{-1} WS	330	950	183%	640	32%
Zinc	mg kg^{-1} WS	1040	1470	42%	1300	10%
Cadmium	mg kg^{-1} WS	7.6	14.6	93%	11.5	20%
Lead	mg kg^{-1} WS	290	660	127%	430	27%
Combustion						
Temperature	°C	1000	1015	2%	1008	1%
Load	[-]	0.93	1.02	10%	1.00	3%
Dust (flue gas*)	[-]	0.74	1.20	61%	1.00	16%
H_2O (flue gas*)	Vol. %	14.2	16.6	17%	15.2	7%
O_2 (flue gas†)	Vol. %	8.6	9.2	7%	8.9	2%
CO_2 (flue gas†)	Vol. %	9.9	10.8	9%	10.3	2%

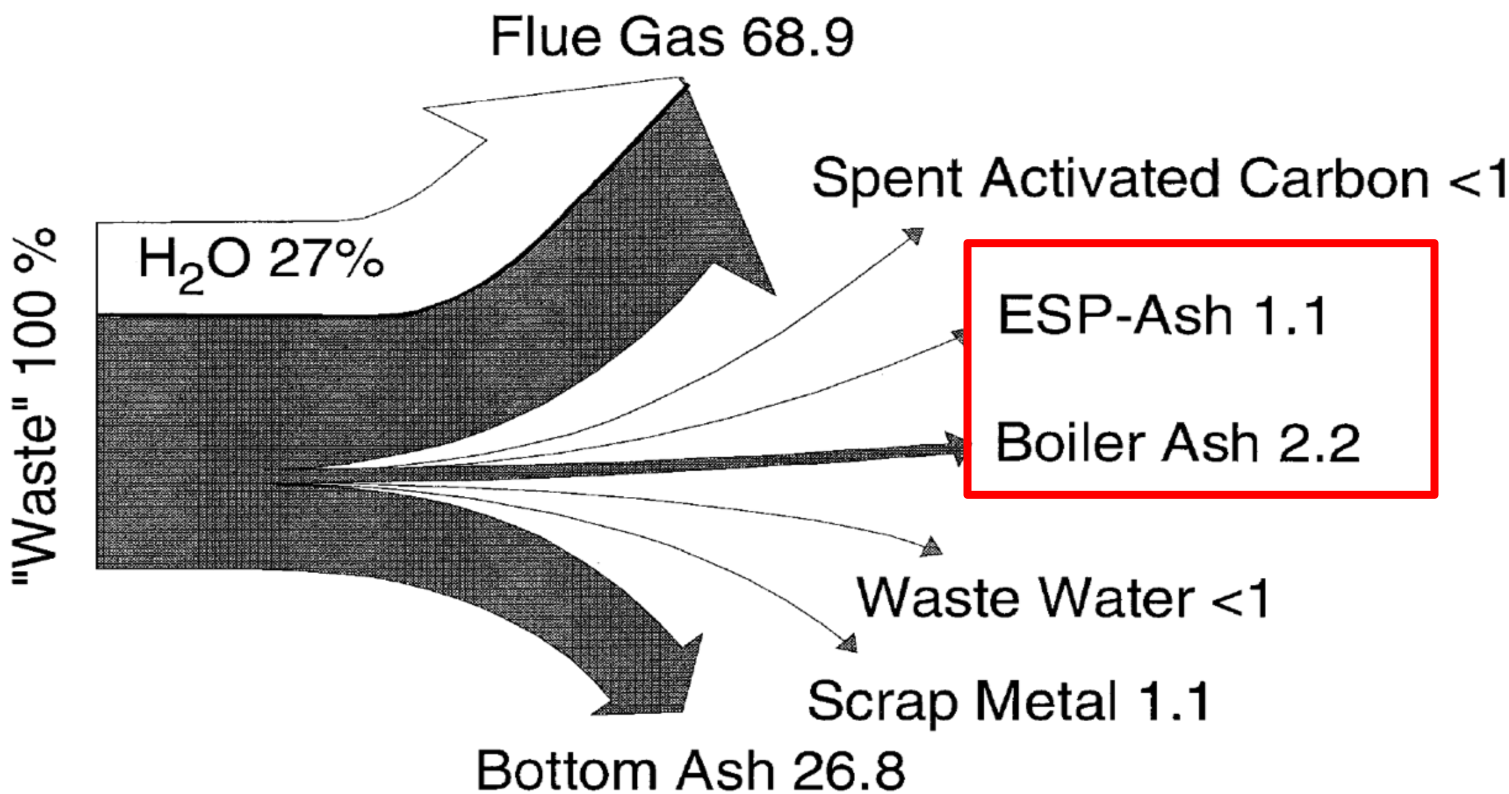
WS, wet substance; *nm*, not measured or calculated; *combustion flue gas, †cleaned flue gas (stack).

Ref.: Morf et al. (2000) Waste Manage Res 18, 4-15.

Material flow within a waste incinerator

Several material flows are generated in a municipal waste incinerator.

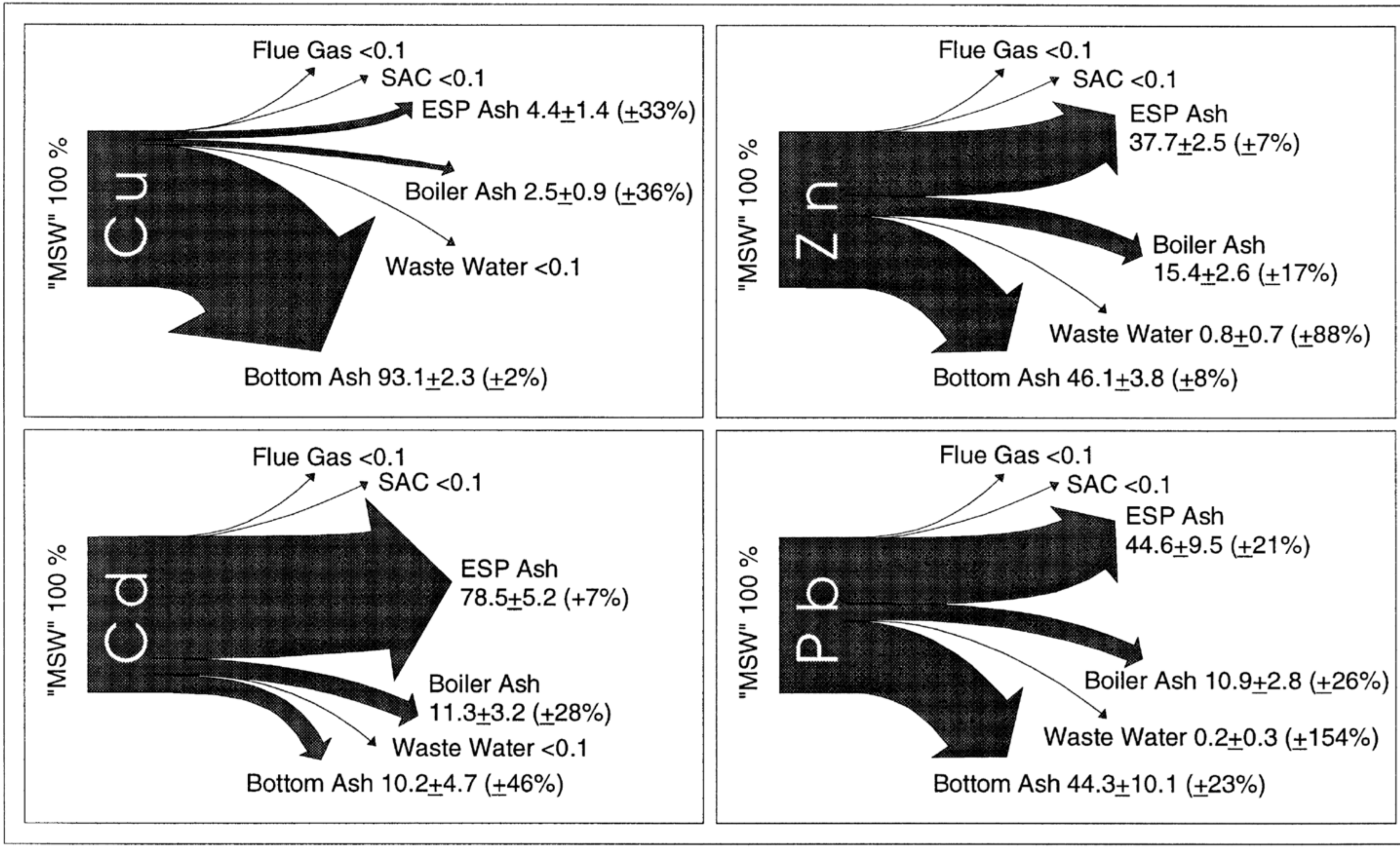
- Approx. 20 to 30 % remain as bottom ash
- Approx. 2 to 4% end up as fly ash (bag-filter/ESP and boiler ash)
- Other wastes (salt from waste water treatment; waste water)



Ref.: Morf et al. (2000) Waste Manage Res 18, 4-15.

Heavy metal substance flow in a waste incinerator

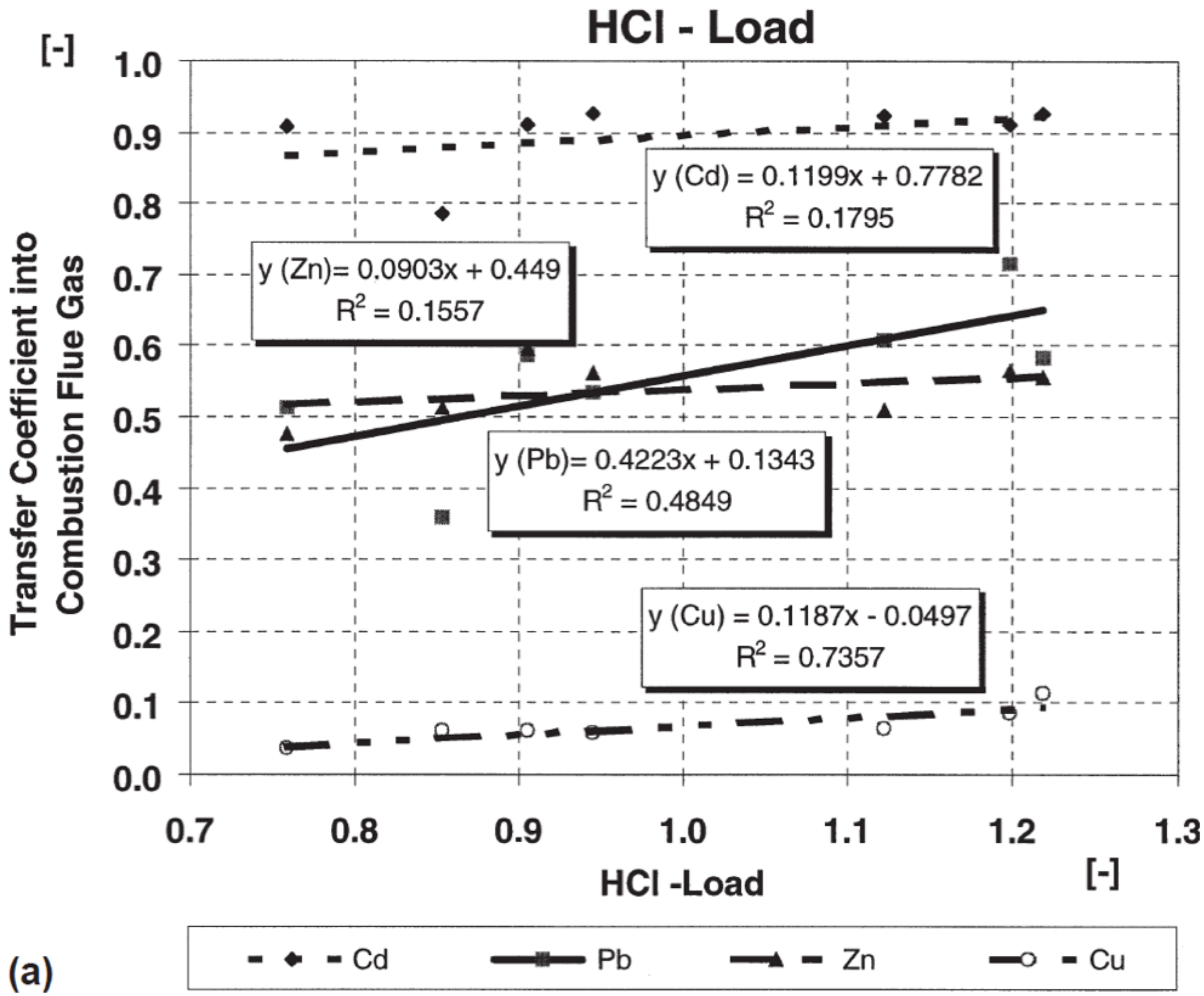
- The substance flow of heavy metals in MWI depends on their properties
- Cadmium, lead, zinc and mercury accumulate to a high share in fly ash.



Ref.: Morf et al. (2000) Waste Manage Res 18, 4-15.

Heavy metal substance flow in a waste incinerator

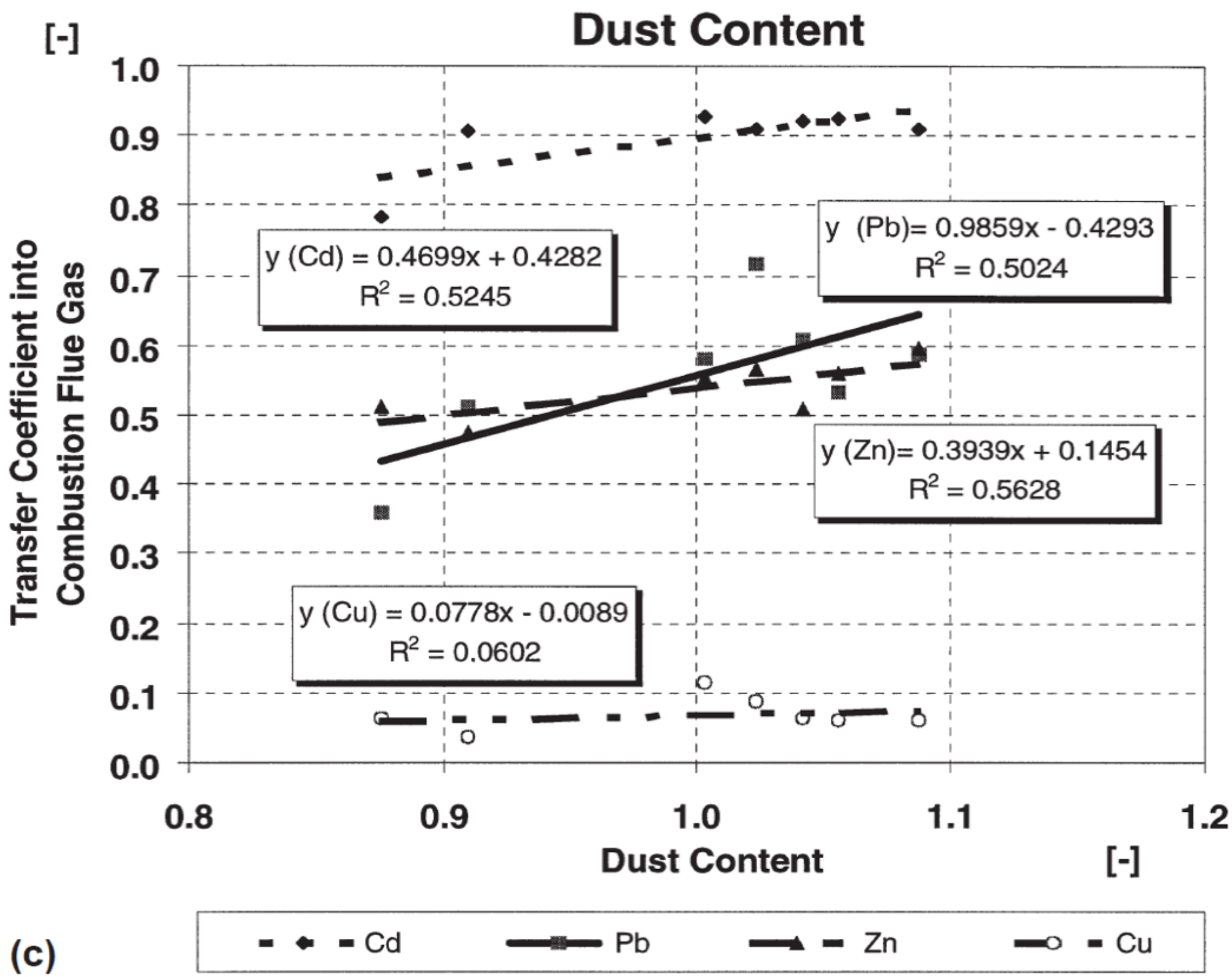
- The transfer coefficient of heavy metals to flue gas/fly ash in MWI depends slightly on parameters such as HCl load (volatile chlorides).



Ref.: Morf et al. (2000) Waste Manage Res 18, 4-15.

Heavy metal substance flow in a waste incinerator

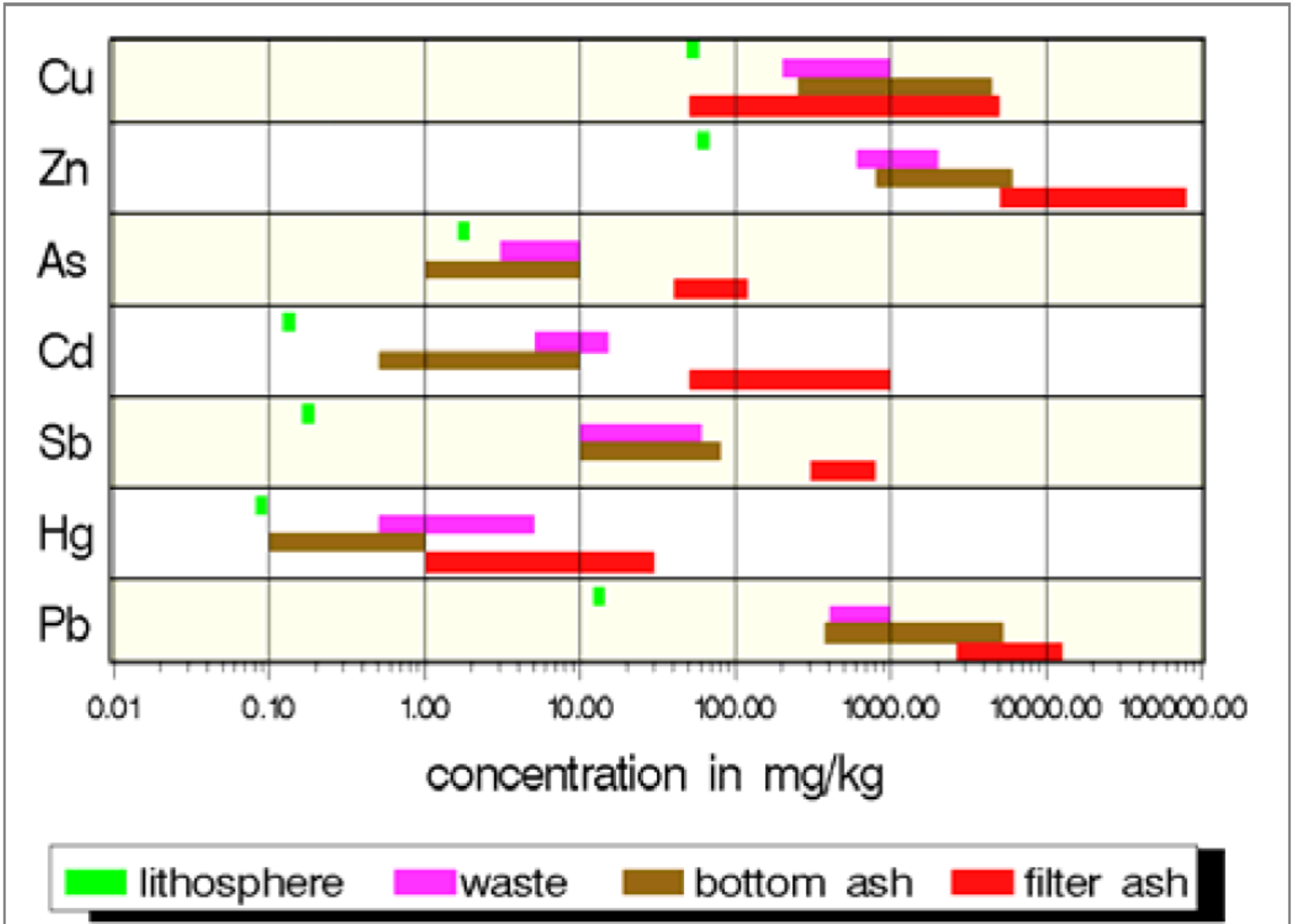
- Also the dust concentration has an impact on the transfer coefficient of heavy metals to flue gas/fly ash in MWI (high for fluidized bed inciner,)



Ref.: Morf et al. (2000) Waste Manage Res 18, 4-15.

Concentration of heavy metals in fly ashes

- High levels of problematic heavy metals and chloride end up in fly ash



Vehlow et al (2012) Waste Management 32, 1156-1162

Concentration of heavy metals in fly ashes - European Directive on Hazardous Waste

Annex 2 (Directive 91/689/EEC).

ANNEX II

CONSTITUENTS OF THE WASTES IN ANNEX I.B. WHICH RENDER THEM HAZARDOUS WHEN THEY HAVE THE PROPERTIES DESCRIBED IN ANNEX III (*)

Wastes having as constituents:

C1 beryllium; beryllium compounds;
C2 vanadium compounds;
C3 chromium (VI) compounds;
C4 cobalt compounds;
C5 nickel compounds;
C6 copper compounds;
C7 zinc compounds;
C8 arsenic; arsenic compounds;
C9 selenium; selenium compounds;
C10 silver compounds;
C11 cadmium; cadmium compounds;
C12 tin compounds;
C13 antimony; antimony compounds;
C14 tellurium; tellurium compounds;
C15 barium compounds; excluding barium sulfate;
C16 mercury; mercury compounds;
C17 thallium; thallium compounds;
C18 lead; lead compounds;
C19 inorganic sulphides;

Compounds in fly ashes listed in Annex 2 of **Directive 91/689/EEC** which defined them as hazardous waste not suitable for direct deposition.

For these elements either the total concentration (aqua regia treatment) or eluate test (1/10 Eluat accoring DEV S4) are above the criteria for deposition on this type of landfill.

From regulatory perspective fly ash residues are hazardous wastes and need special care and appropriate disposal.

Toxicity of cadmium

- The International Agency for Research on Cancer has classified cadmium and cadmium compounds as carcinogenic to humans.
- The **most dangerous form of occupational exposure to cadmium is inhalation of fine dust and fumes, or ingestion of highly soluble cadmium compounds**.
- Occupational exposure to Cd is linked to lung and prostate cancer.
- Inhalation of cadmium-containing fumes can result initially in metal fume fever but may progress to chemical pneumonitis, pulmonary edema, and death.
- Epidemiological studies suggest that intake of cadmium through diet associates to higher risk of endometrial, breast and prostate cancer as well as to osteoporosis in humans.

For an overview see ATSDR Toxicological Profile for Cadmium http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=48&tid=15

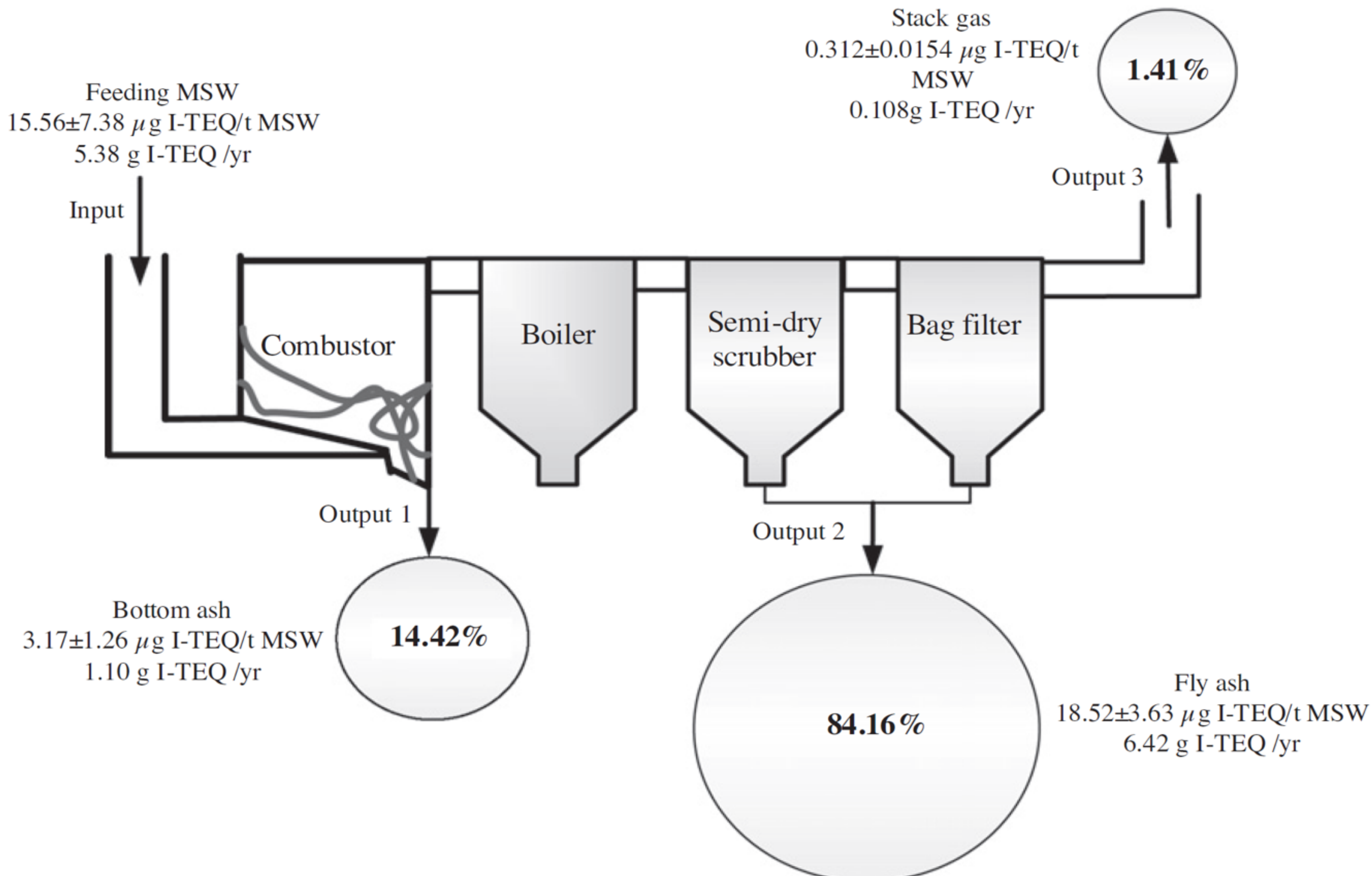
Toxicity of lead

- Lead is a highly poisonous metal (whether inhaled or swallowed), affecting almost every organ and system in the body.
- Elevated blood lead levels (BLL's) in adults can damage the nervous, hematologic, reproductive, renal, cardiovascular, and gastrointestinal systems (USCDC). The main target for lead toxicity is the nervous system, both in adults and children with related antisocial behavior and delinquency.
- U.S. Department of Health and Human Services recommends that BLLs among all adults be reduced to <25 µg/dL. The highest BLL acceptable by standards of the U.S. Occupational Safety and Health Administration is 40 µg/dL. Most cases of adult elevated blood lead levels are workplace-related.

For an overview see ATSDR Toxicological Profile for Lead http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=96&tid=22

Substance flow of PCDD/F in a BAT MWI

- Also the largest share of dioxins (PCDD/F) ends-up in fly ashes.
- Concentration range between 100 to 15000 ng TEQ/kg



Zhang et al (2012) Waste Management 32, 1156-1162

Toxic effects of dioxins (PCDD/PCDF)

- Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F) have a wide range of toxic effects. Relevant for society are the chronic effects.

Acute effects (high dose):

- **Chloracne**
- **Wasting syndrome**
- **Death (animals; humans extreme exposition)**

Chronic effects (also low dose):

- **Tumor promotion**
- **Carcinogenic (2,3,7,8 TCDD; 2,3,4,7,8-PCDF)**
- **Hormone system: Endocrine disruptors**
- **Immune system: Immune suppressors**
- **Developmental toxicity; reproduction; malformations**
- **Diabetes and endometriosis**

Toxicity Review Article: Van den Berg et al. Crit. Rev. Toxicol. 24, 1, (1994)

Levels of hazardous compounds in waste incineration residues

Fly ash, filter ash and boiler dust meet EU hazard criteria

Compound	BF ash	ESP ash	FGC-salts	boiler dust	bottom ash
lead (g/kg)	< 15	1 - 12	0,5 - 1,5	0,3 - 3	1 - 2
zinc (g/kg)	< 60	1 - 30	1 - 5	2 - 20	3 - 4
PAH (mg/kg)	< 30	?	?	< 30	< 30
dioxines* (µg/kg)	3 -10	1 - 5	0,04 - 1	0,03 - 0,4	0,02 - 0,05
6 PCB's (µg/kg)	< 175	< 175	< 175	< 175	< 175
EU-codes	H360 H410	H360 H410		H410	


H360


H410

* TEQ (PCDD/F)

Source: http://www.arbocatalogus-afvalbranche.nl/activiteit/230/1213/1190

Need to consider toxicity of mixtures for ashes

- Fly ashes contain a wide range of hazardous compounds,
- The mentioned heavy metals and the dioxins are only a part of this toxic mixture potential of (fly) ashes.
- An exposure assessment for fly ashes needs to consider the risks from combined exposure to multiple chemicals.
- Challenge: assessing the toxicity of complex mixtures. Ongoing EU activities to assess the toxicity of mixtures in a more holistic way and methodologies for such assessment have been compiled: http://www.efsa.europa.eu/en/efsajournal/pub/3313
- If risk assessments are made for the management of fly ashes such methodologies assessing chemical mixtures need to be included.

Potential amount of fly ashes to be buried in Twente

A large volume of fly ashes (ash from filter; boiler dust; flue gas cleaning salts) are suggested for disposal in the salt caverns.

project phase	***number of caverns***	***amount of fly ashes (t)***
pilot	3	412.500
follow up*	20	2.600.000
optional*	40	5.200.000
totals	**63**	**8.212.500**

* based on 130.000 ton per average cavern of 175.000 m3.

Source: MER PSCT 3.0

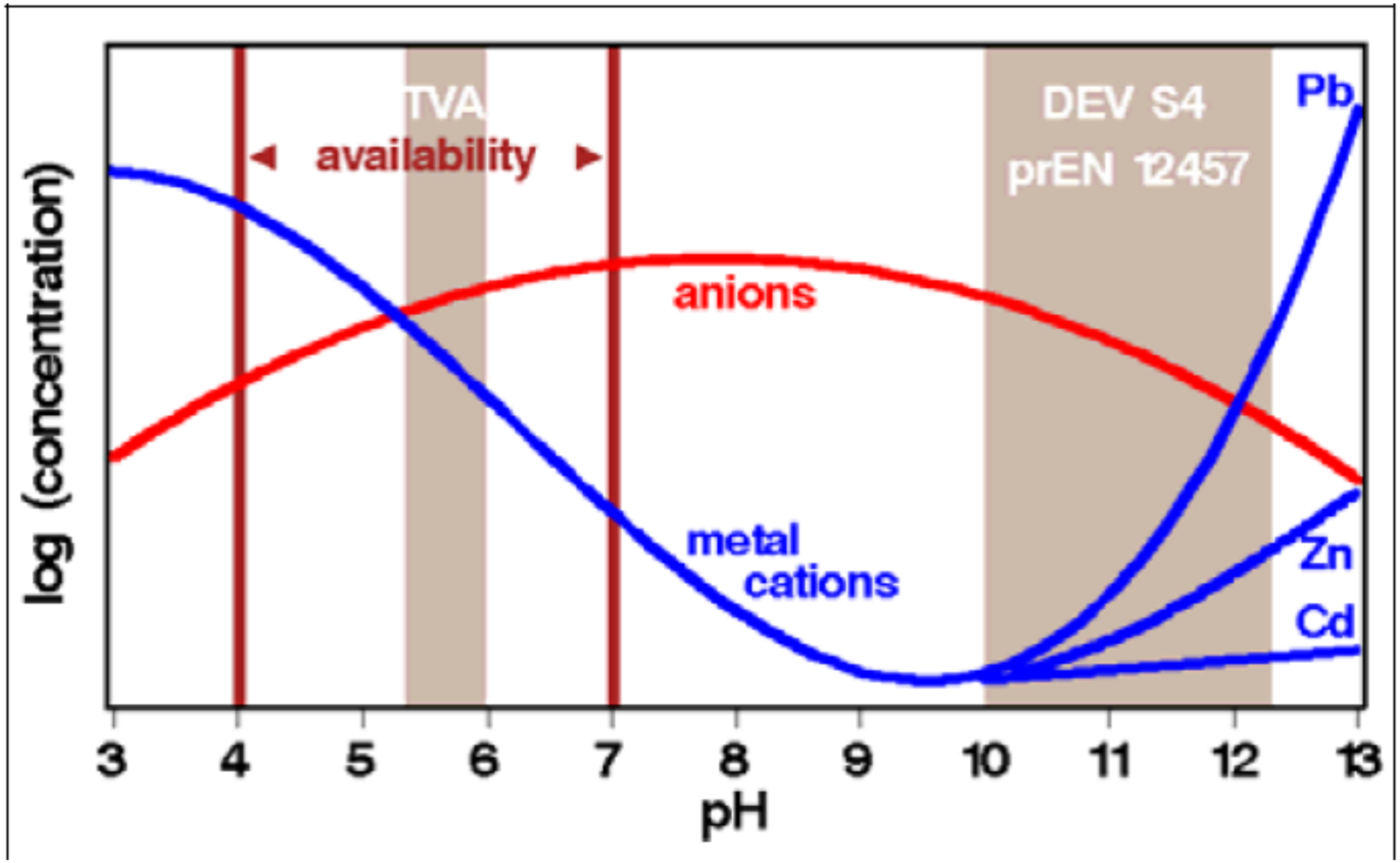
Volume increase of hazardous materials during stabilisation process of an average salt cavern in Twente

During the stabilisation and injection process the volume of hazardous materials is increasing in different processing phases.

Processing phase	***Materials***	***volume (m3)***	***totals (m3)***
supply and storage	***dry ashes***	***130.000***	***130.000***
sludge processing & injection	***ashes + brine***	***175.000***	***175.000***
residual migration	***falling roof material***	***175.000***	***350.000***
re-injection contaminated salt in 4th cavern	***dried salt + brine***	***175.000***	***525.000***

Leaching of heavy metals from the ashes

- Heavy metals in ashes are present in soluble form (high chloride content).
- Heavy metals will partly be leaching into the brine and the brine flowing out from the cavern needs to be treated.
- Here modeling and assessment is needed. Since the brine has a high salt content current leaching tests can not be used for prediction.



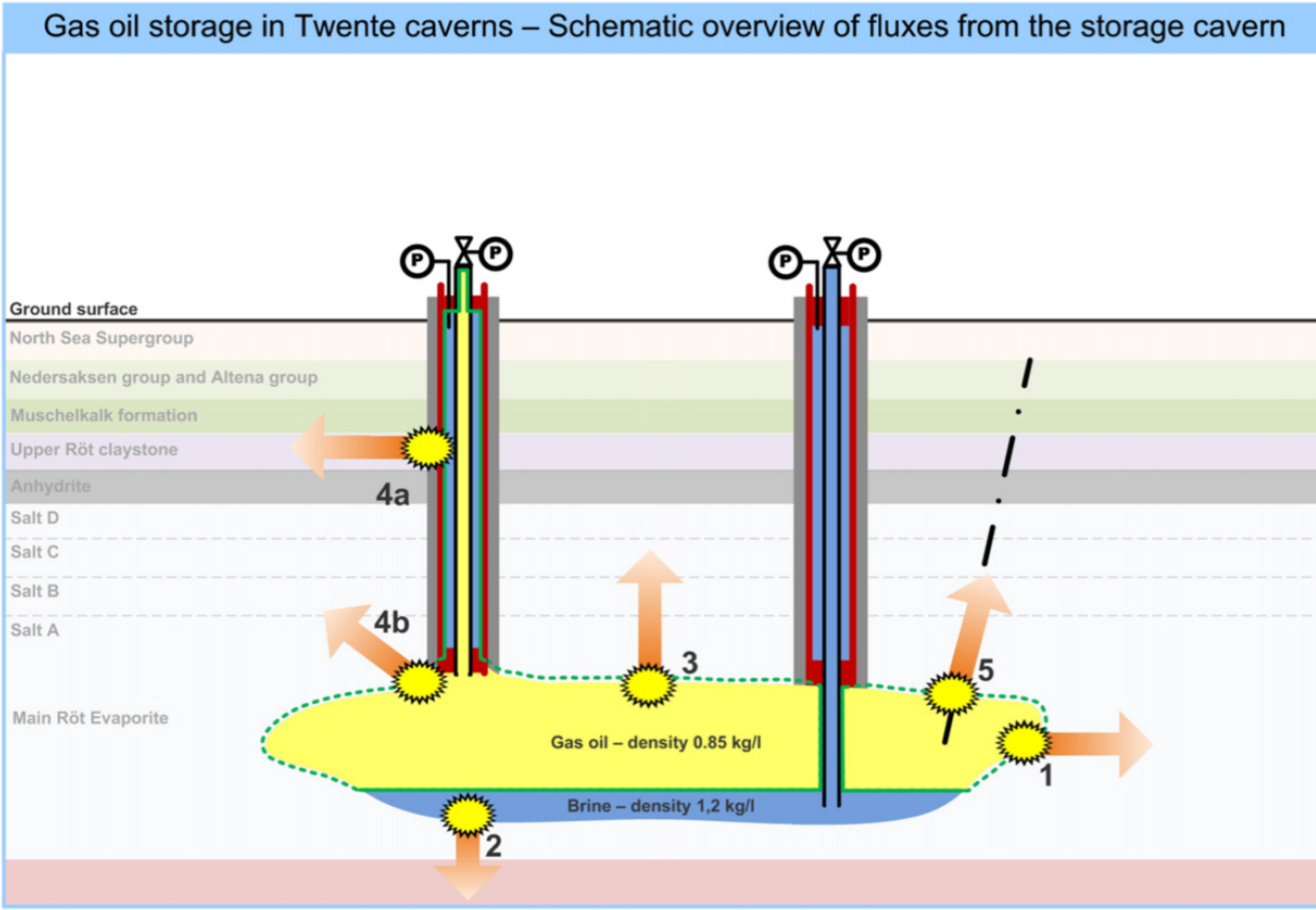
Vehlow et al (2012) Waste Management 32, 1156-1162

Management stages of ashes with potential release and exposure

During the management of the hazardous ashes and during/after the stabilisation process possible release and exposure pathways exist, which need to be assessed and controlled and included in an overall assessment.

	Management stages
1	transport
2	transfer to installation
3	preparation of sludge
4	injection of sludge
5	return flow of brine
6	treatment of return flow of brine
7	re-injection of destilled brine
8	leakage from cavern

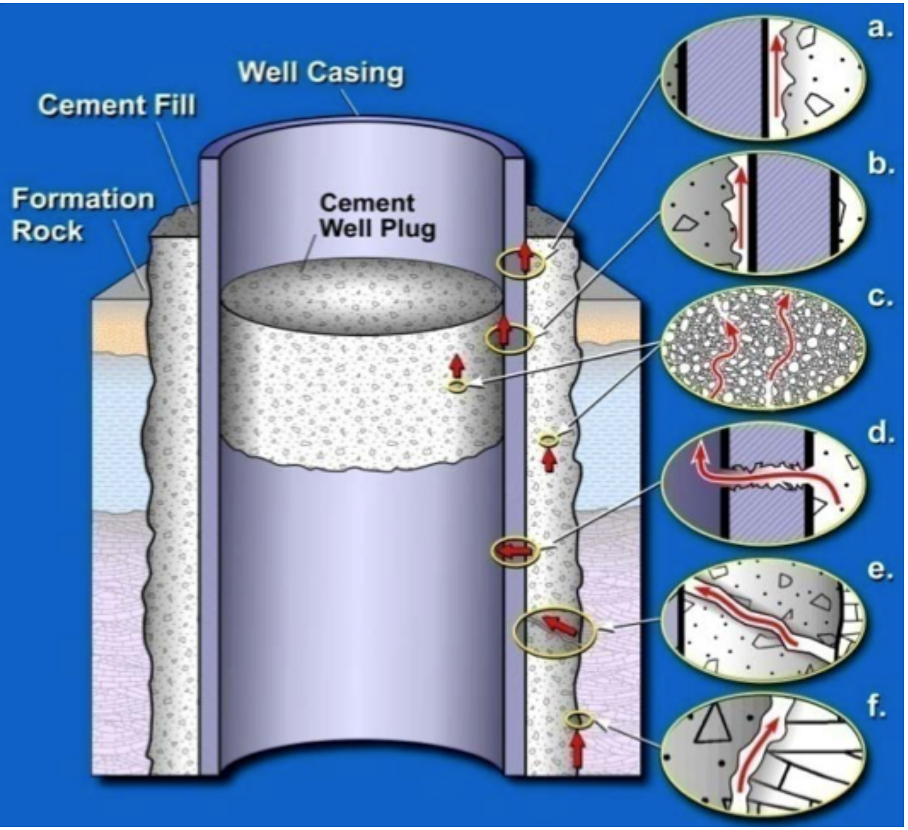
Potential release routes from Twente caverns



Van Tiennen Viesser et al. (2014) Engineering Geology 168, 149–166.

Potential release routes from cavern/casings

Possible leakage pathways from the (50 years old) casings need to be considered and assessed.



Possible leakage pathways along a well

(a)between cement and outside of casing
(b)between cement and inside of casing
(c)through cement
(d)through casing
(e)in cement fractures
(f) between cement and rock

Gasda, S.E., S. Bachu, and M.A. Celia, The Potential for CO2 Leakage from Storage Sites in Geological Media: Analysis of Well Distribution in Mature Sedimentary Basins, Environmental Geology, 46(6-7), 707- 720, 2004.

Possible leaking pathways from casings

The leak tests (possibly) needs an adapted approach to the type of waste.

Maximum Admissible Leak Rate lies between 85 m3 and 160 m3 per year (for liquids).

=> Standard leak rates seem too high for toxic waste.

Pierre Berest, Benoit Brouard, Mehdi Karimi-Jafari, Leo Van Sambeek, 2007, Transient behavior of salt caverns—Interpretation of mechanical integrity tests, International Journal of Rock Mechanics & Mining Sciences 44 (2007) 767–786

Assessment of long-term storage safety

- The long term/“eternity“ storage performance needs to be assessed.
- Currently for German coal mines where waste (including ashes) have been disposed, release risks & long term performance are assessed.
- A Swiss assessment on the use of German salt mines concluded that Switzerland should change their ash management to make efforts to divert from salt mine disposal and include recovery of metals.
- Interesting to follow the developments in Switzerland.

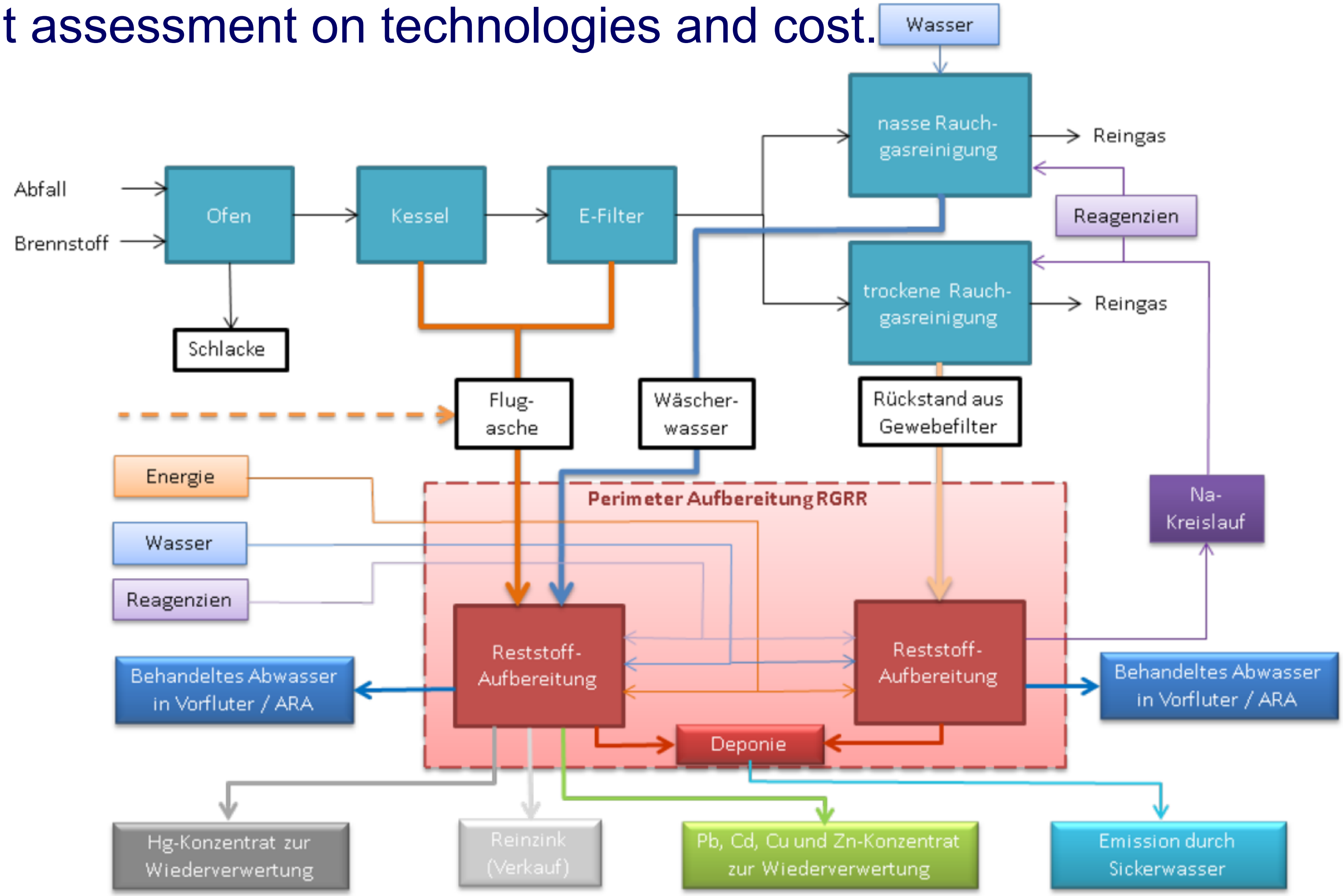
Prüfung möglicher Umweltauswirkungen von Abfall- und Reststoffen zur Bruch-Hohlraumverfüllung in Steinkohlenbergwerken in Nordrhein-Westfalen

Zur Durchführung dieser Prüfung haben das Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz (MKULNV) und das Ministerium für Wirtschaft, Mittelstand und Energie des Landes Nordrhein-Westfalen (MWEIMH) am 16.07.2015 einen Auftrag an ein Gutachterkonsortium unter Federführung der ahu AG Aachen erteilt.

Die Erstellung des Gutachtens wird durch einen Arbeitskreis begleitet. Auf dieser öffentlichen Seite finden Sie Informationen zum Gutachterauftrag und der Arbeit des Arbeitskreises.

Approach of Switzerland: Metal recovery from incineration residues

Precious metals & heavy metals are recovered from incineration ashes.
Current assessment on technologies and cost.



Baudirektion Kanton Zürich; Amt für Abfall, Wasser, Energie und Luft. 06/2014

Potential material value of heavy metals in ash

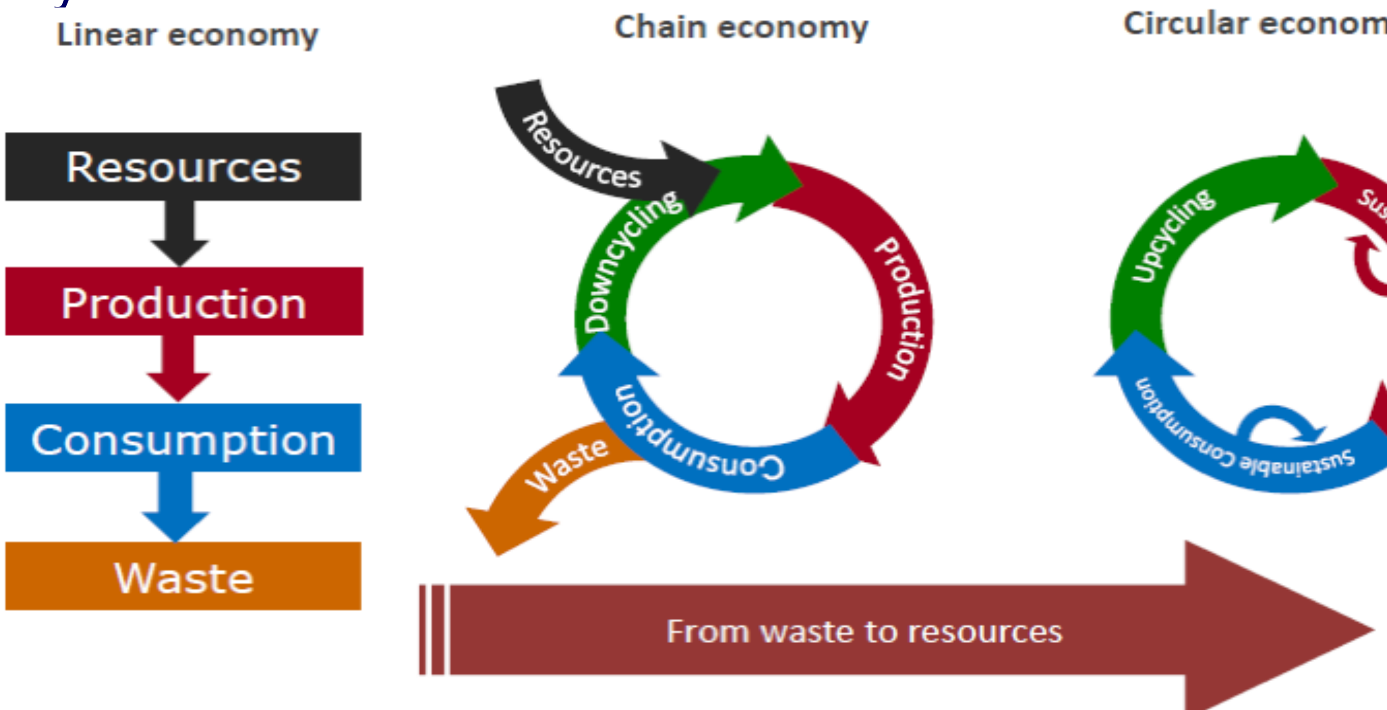
The potential/theoretical material value of heavy metals in the ashes is high if the metals would/could be separated.
⇒ Assessment of Swiss approach to see options & limitations.

compound	g/Kg* Kg/tonne	ton per cavern**	market price (€) per ton***	„value“ per cavern (€)
zinc (Zn)	20	2.600	1.760	4.576.000
lead (Pb)	6	780	1.900	1.482.000
copper (Cu)	0,45	58,5	6.600	386.100
antimony (Sb)	0,40	52	10.500	546.000
cadmium (Ca)	0,25	32,5	1.760	57.200
arsenic (As)	0,07	9,1	1.600	14.560
mercury (Hg)	0,006	0,78	1.700	1.326
totals		**3.532,88**		**7.063.186**

*rounded averages; ** 130.000 tons of fly ashes per average cavern of 175.000m3.
*** based on 5 years averages (except Cd, Hg, As) metalprices.com on 2015-10-10.
Data from: Vehlow et al (2012) Waste Management 32, 1156-1162.

Circular economy – EU & Swiss strategy

- There is a need to move to a (more) circular economy for resource preservation including non-renewable resources such as metals.
- The EU has decided to move towards circular economy and the EU Commission is developing a related strategy (DG Env document) http://ec.europa.eu/environment/circular-economy/index_en.htm
- Attempt of Switzerland to recycle heavy metals from incinerator ashes (also P from sludge incinerator ashes) c/would be part of a circular economy.



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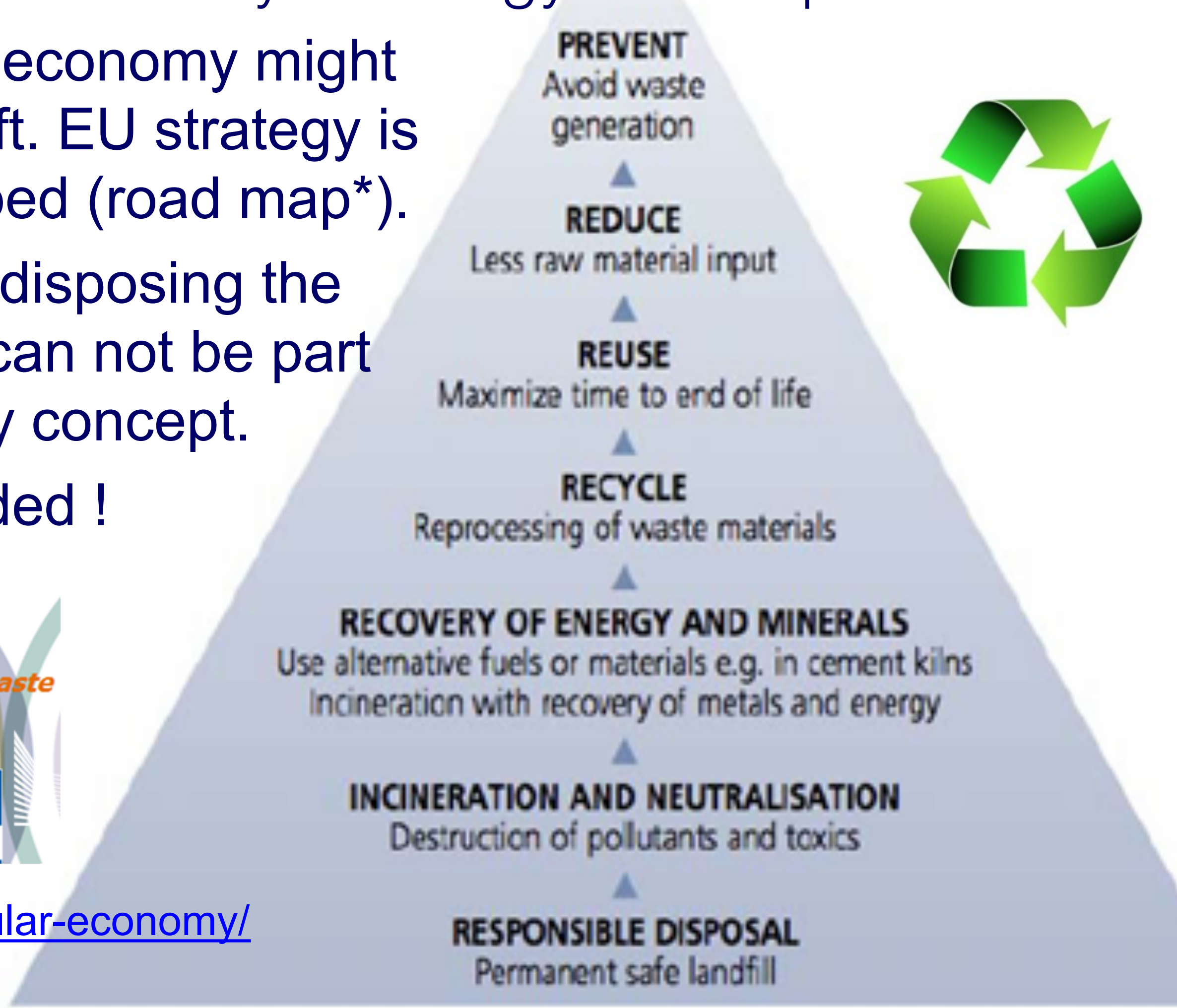
Waste management and circular economy – Substitution of incineration in medium term?

- In the EU the waste management hierarchy is giving priority to reuse and recycle over recovery of energy and disposal.
- The strategy on circular economy might facilitate now such a shift. EU strategy is currently further developed (road map*).
- An incineration concept disposing the ashes including metals can not be part of such a cycle economy concept.

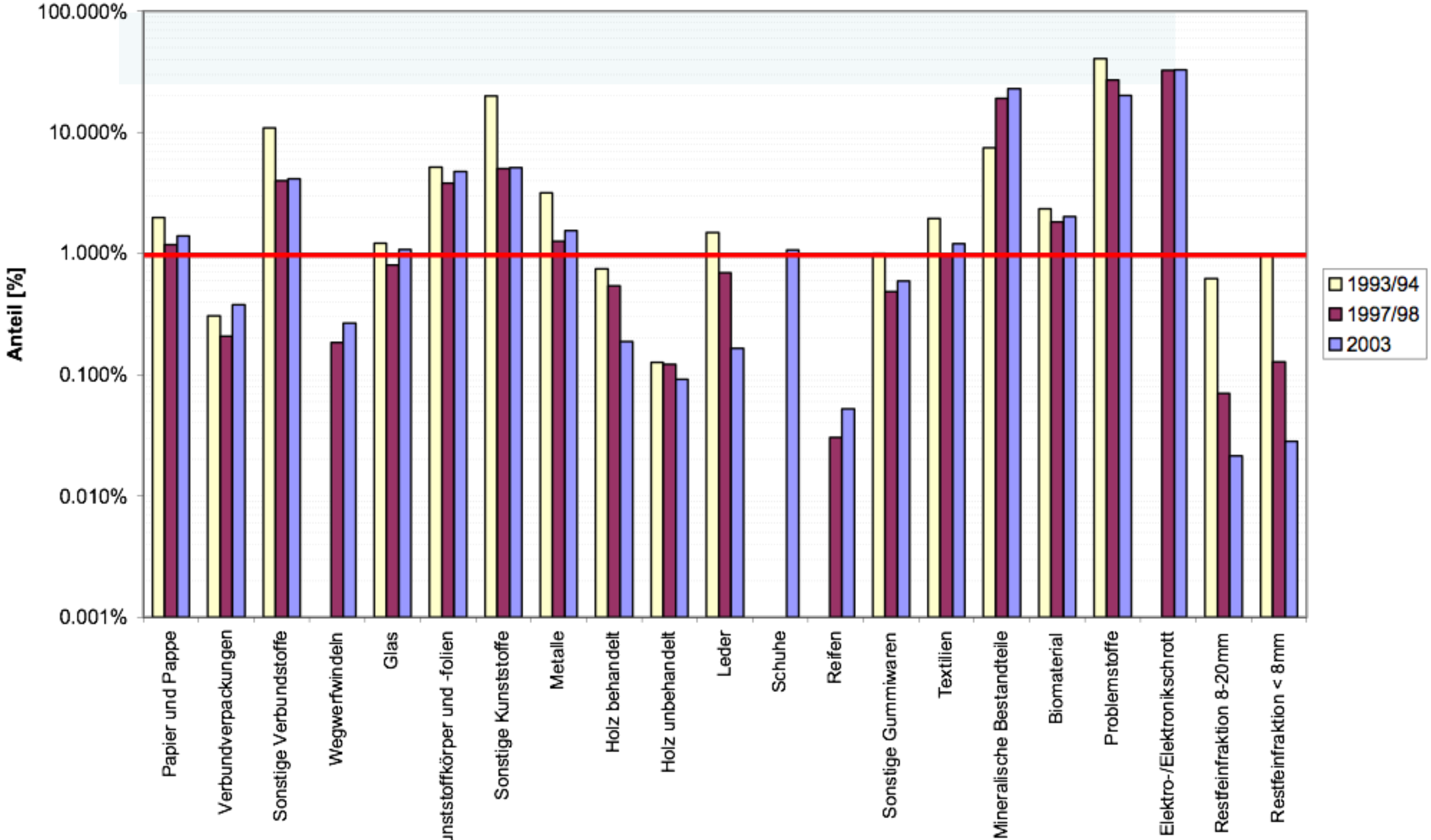
⇒ Therefore changes needed !

http://ec.europa.eu/environment/circular-economy/index_en.htm



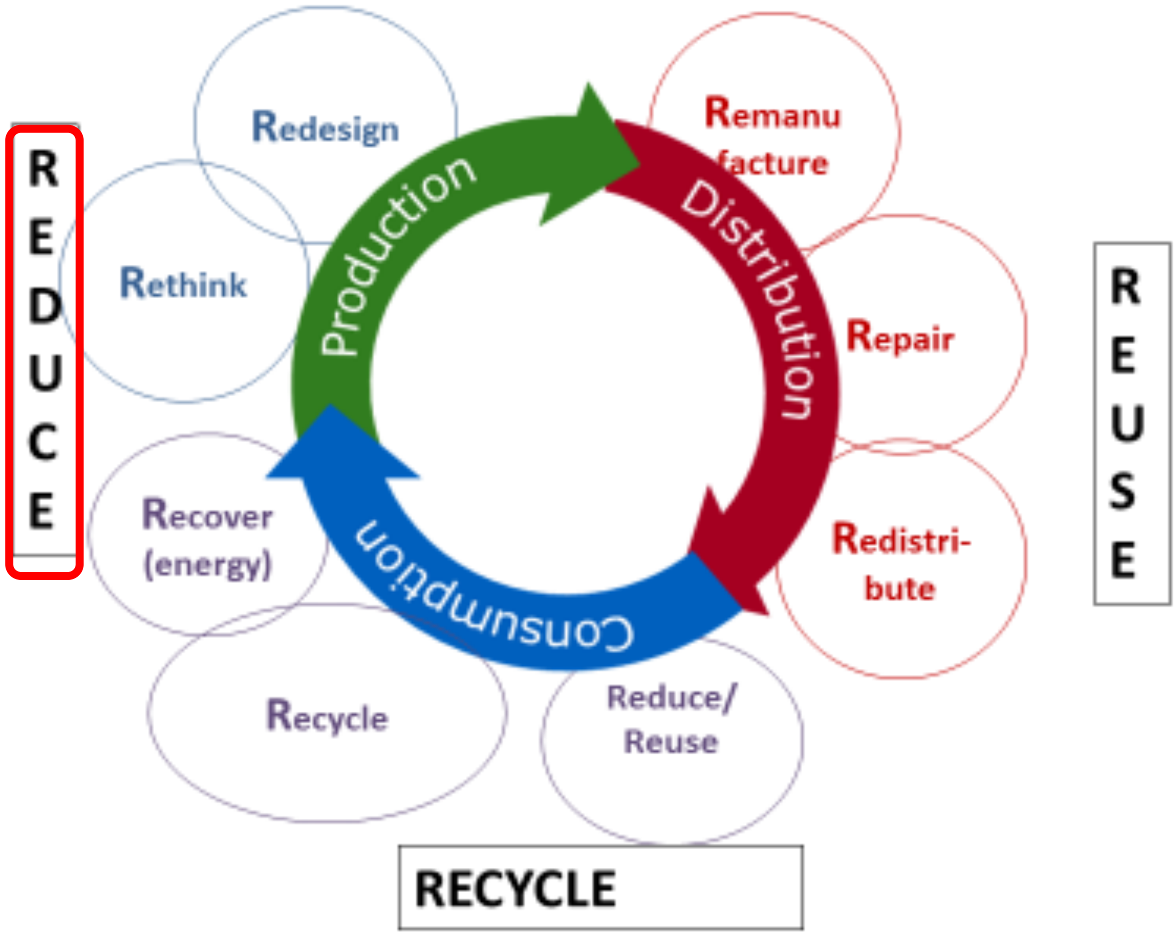
Depollution of products and waste streams

- The strategy of depollution of technosphere by reduction/phase-out of hazardous substances (e.g. RoHS directive) supports the approach of better managing/recycling of waste residues from incineration.
- E.g. due to regulations for EEE, EoL vehicles and batteries, cadmium levels decrease in most waste fractions in the last two decades.



Multi-R approach for moving towards circular economy

For Cycle Economy a “Multi-R approach” is needed including redesign for reuse, recovery and recyclability. The redesign of products will lead to better recyclability. If waste incineration will not SWITCH from disposing ashes (including metals) towards recovery of non-renewables the concept will fail.



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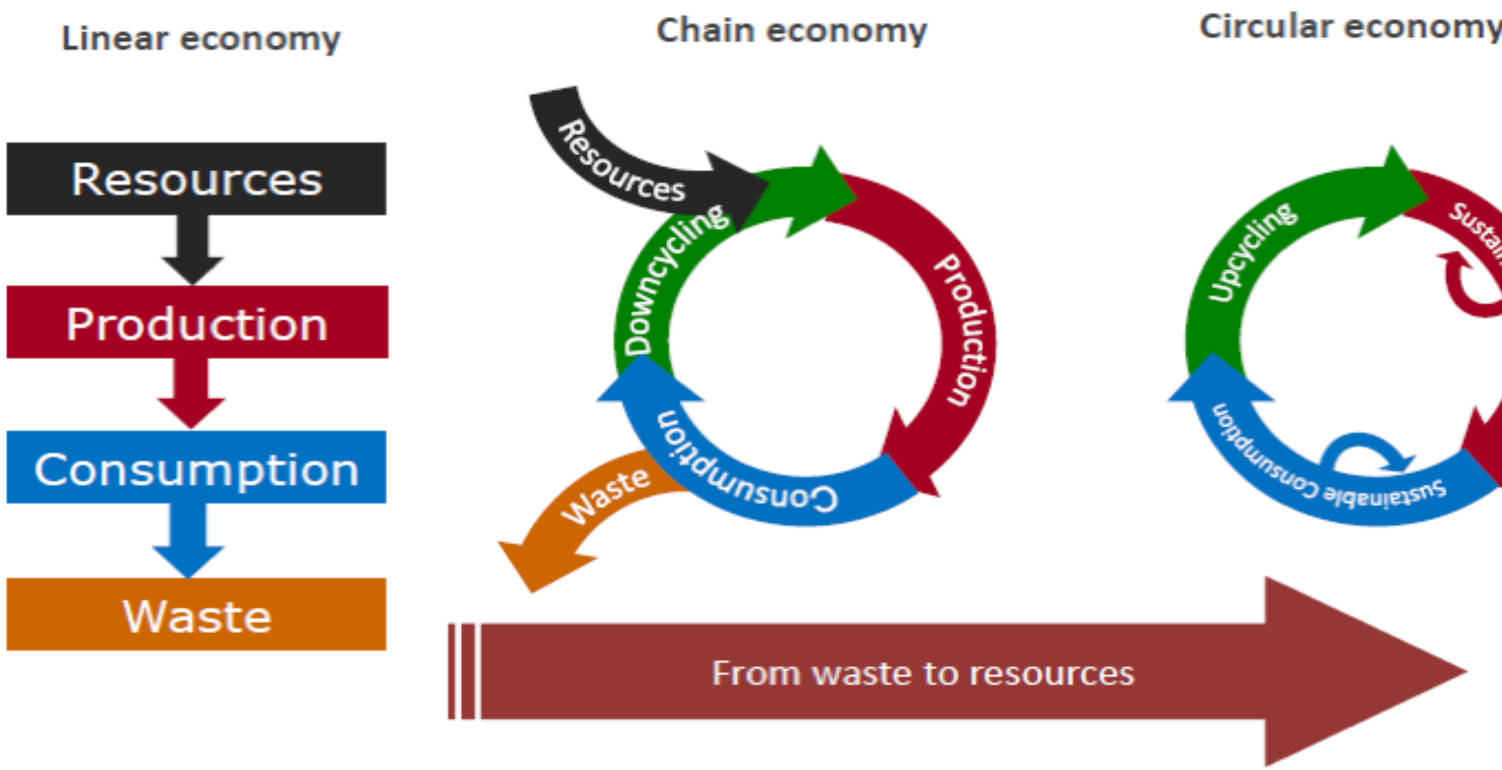
Conclusions

- Heavy metals from a range of sources end up in municipal waste.
- Within the waste incinerator several of toxic heavy metals are transferred to a large share to fly ashes (boiler/filter ashes).
- Also the largest share of PCDD/PCDF and PAHs ends-up in fly ash.
- Therefore fly ash is hazardous waste with a range of toxic compounds
- Processes in the ash management can result in exposure & release.
- Due to the complex mixture of toxic substances an appropriate risk assessment of ashes is challenging and needs specific efforts.
- The further management of this hazardous waste needs particular care for human exposure and long term risk for the environment.
- Assessment of potential recovery of metals from ashes considering the Swiss activities and the European strategy on „circular economy".
- Without such a shift, waste incineration can most likely not be a part of a circular economy concept.

Waste hierarchy priority: Waste prevention!

In addition, consumption societies need to SWITCH to more sustainable production and consumption, including an overall reduction of (resource) consumption.

Thank you for your attention !



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