Sewage Sludge Inertisation by Ultrahigh Temperature Pyrolysis

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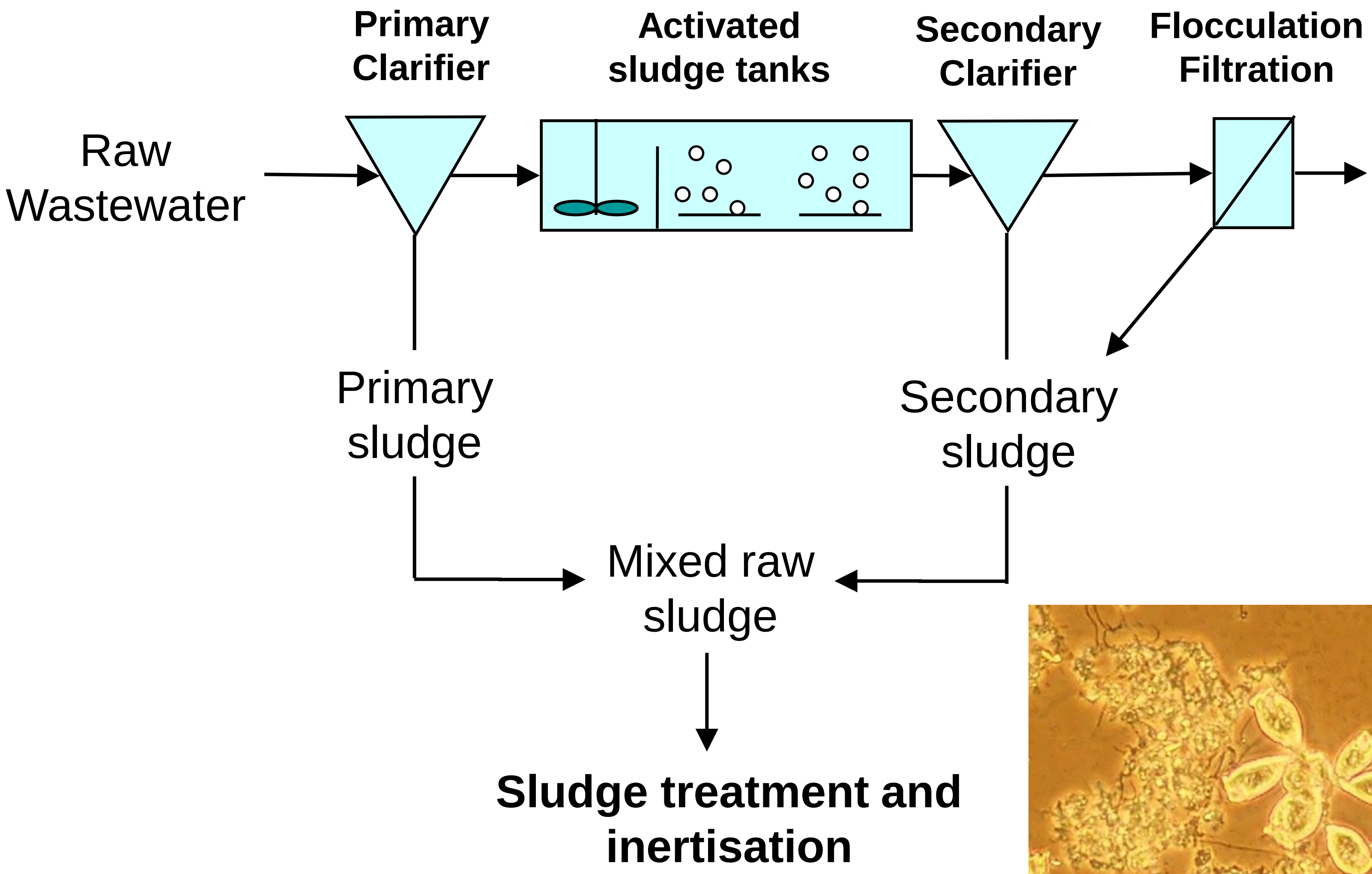
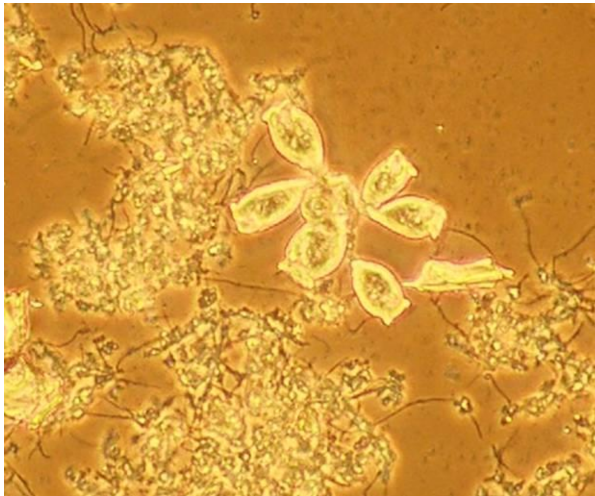
Content

- Sewage sludge treatment and composition
- Pyrolysis process - potential for energy and P reuse
- LCA results - comparison with incineration

Sludge production in WWTP





Sludge treatment

- Stabilization (to reduce mass, volume, odor problems and pathogens as well as gaining energy) with anaerobic digestion

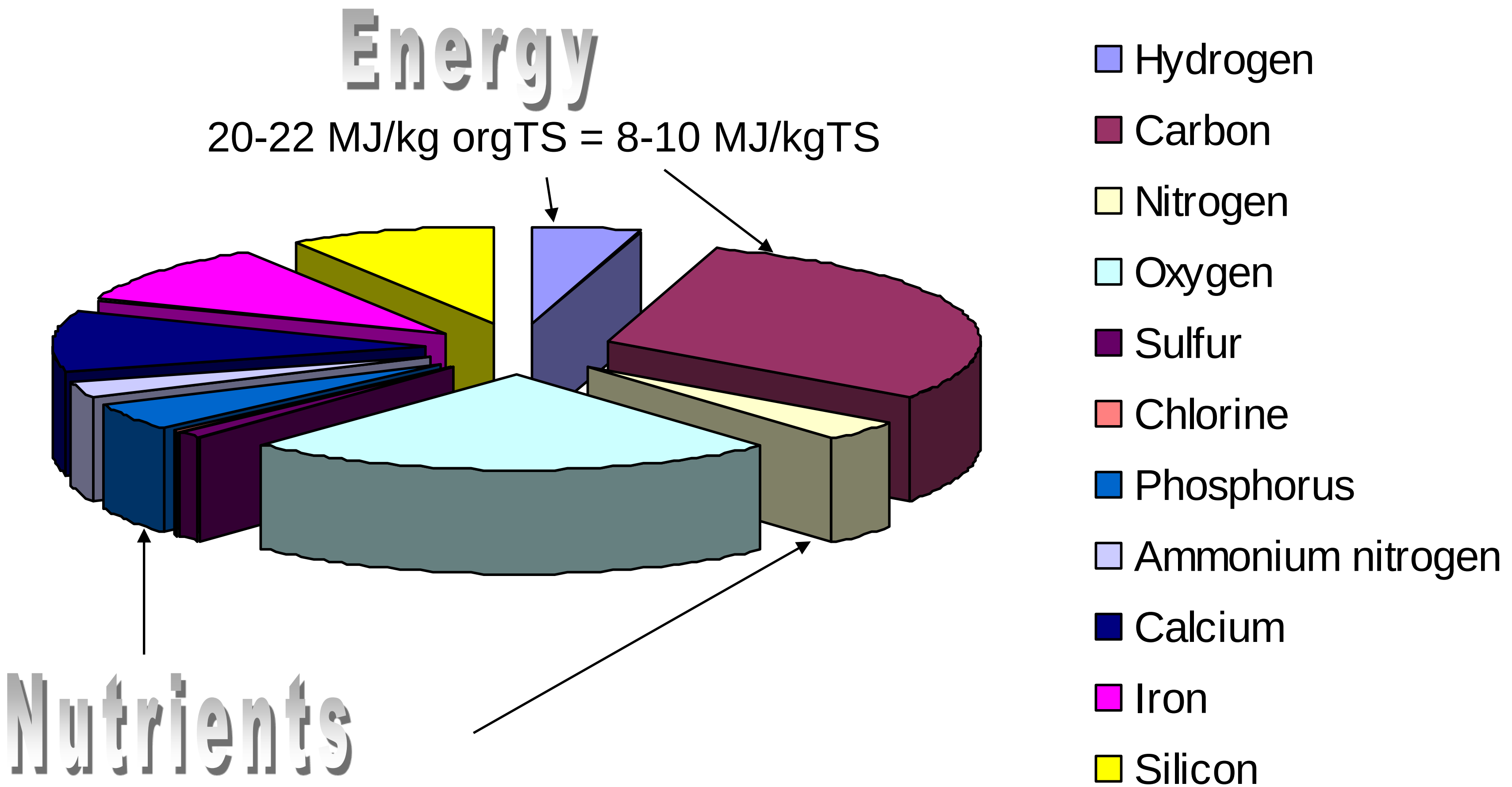
  For agricultural use:

  - Pasteurization (thermophilic pretreatment) or composting
  - Lime treatment (if no stabilization step) and
  - Long time storage in winter

- Dewatering

- Drying

Sludge composition (stabilized sludge)



Nutrient	Nutrients in WW vs. fertilizer consumption %
Nitrogen	12% - 19%
Phosphorus	8% - 21%
Potassium	11% - 24%

Sludge composition (stabilized sludge)

- Heavy metals

	mg/kg
Cd	0.28-2.66
Cr	11.2-192.5
Cu	27.3-448.7
Hg	0.21-2.1
Ni	6.3-63
Pb	9.1-154.7
Zn	99.4-1400

**) Data are for EU member states, Source: Disposal and recycling routes for sewage sludge, Part 3, Europian Comission, October 2001*

- Organic contaminants

Polynuclear aromatic hydrocarbons (PAH)	*Herbicide residues*
Polychlorinated biphenyls (PCB)	*Organo-tin compounds*
Polychlorinated terphenyls	*Phthalate esters*
Phenol	*Petroleum hydrocarbons*
Chlorinated hydrocarbon solvents and phenols	*Surfactants*
Organochlorine insecticides	*Aromatic amines*
Organophosphorus compounds	

- Pathogens?

Sludge disposal and recycling

- ~~Ocean dumping~~ 1980's
- ~~Land filling~~ ? In Switzerland since 2000, in Sweeden since 2005
- ~~Agriculture~~ ? Switzerland, Sweeden, The Netherlands...
- Incineration
- Other methods
- P-Recycling

Novel sludge inertisation processes - reuse of sludge and of its resources

Super Critical Water Oxidation

T > 374°C; p = 22MPa = 220 bar

Wet Oxidation

T = 250-300°C; p = 6-10MPa

Sludge Gasification

T=850°C

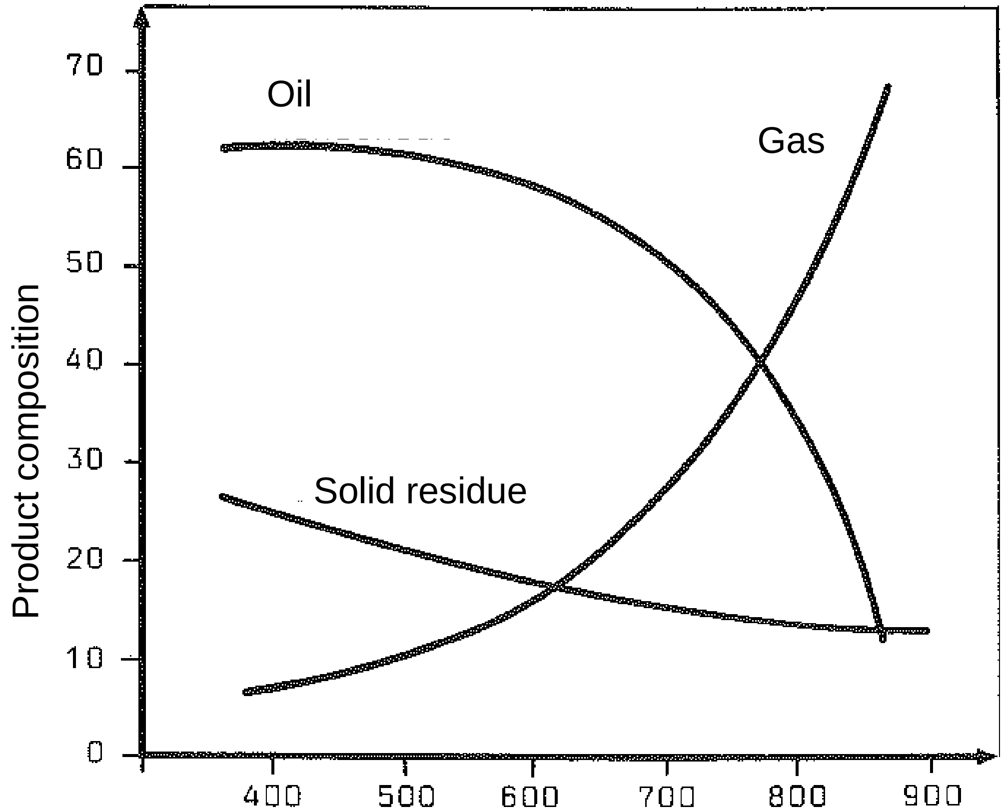
Ultra High Temperature Pyrolysis

T=1200-1400°C

The final result should be:

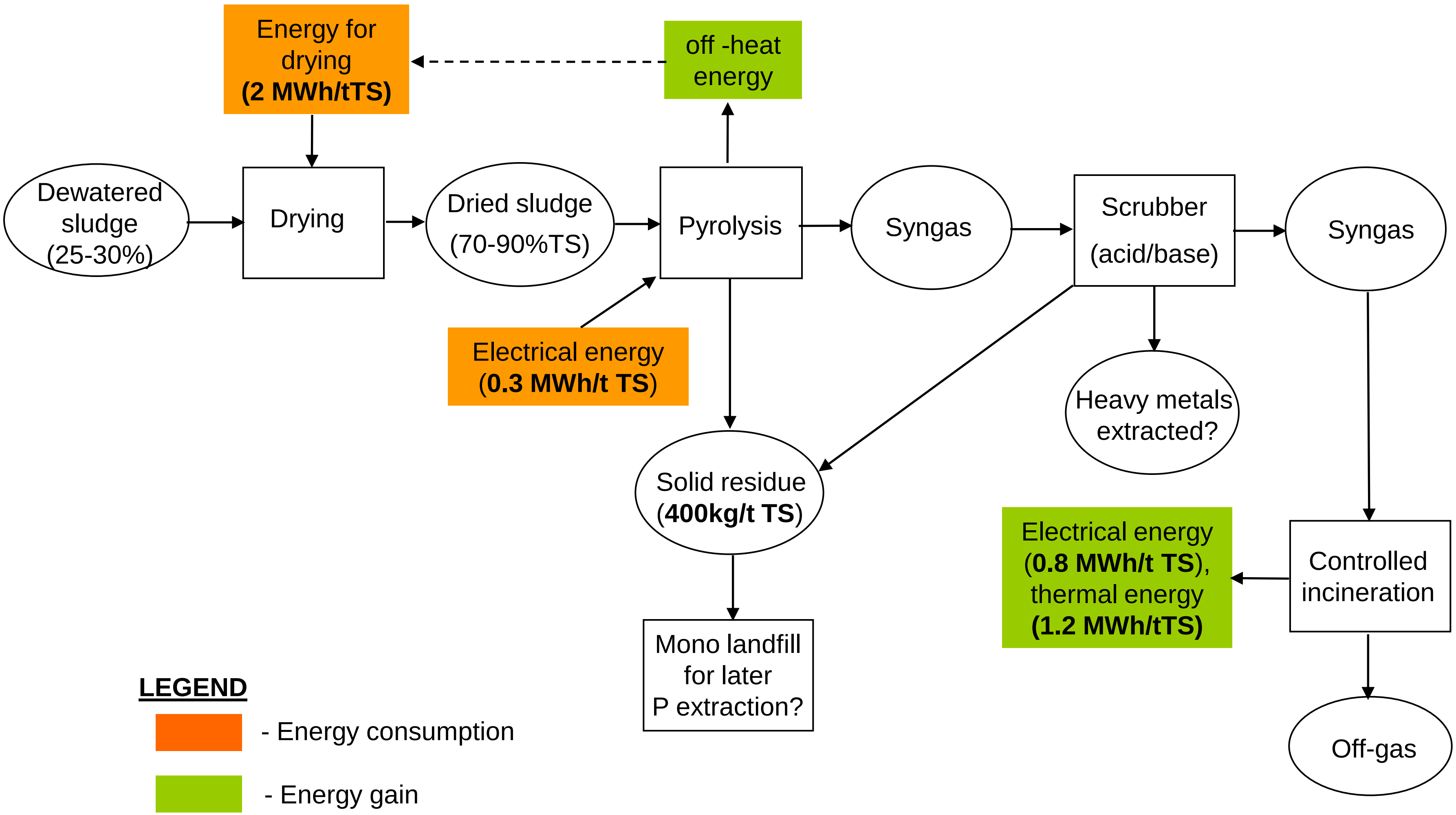
- Sludge reduction, Mineralization of organics
- Elimination or fixation of pollutants
- Recovery of nutrients
- Recovery of energy (not only in form of heat)

High Temperature Pyrolysis (>1’000°C)



- Only two product (solid residue and gas)
- Gas is free of tar but contains heavy metals (gas cleaning?)
- Organic micropollutants are completely destroyed

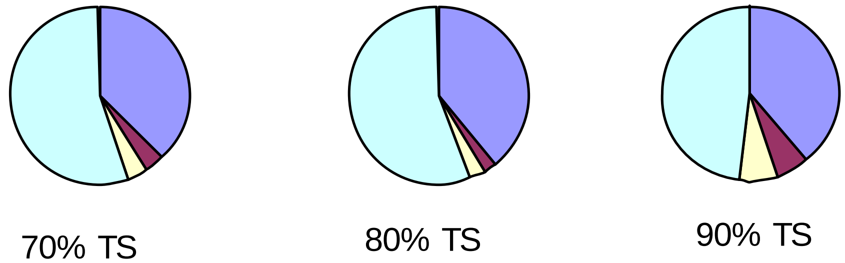
High temperature pyrolysis



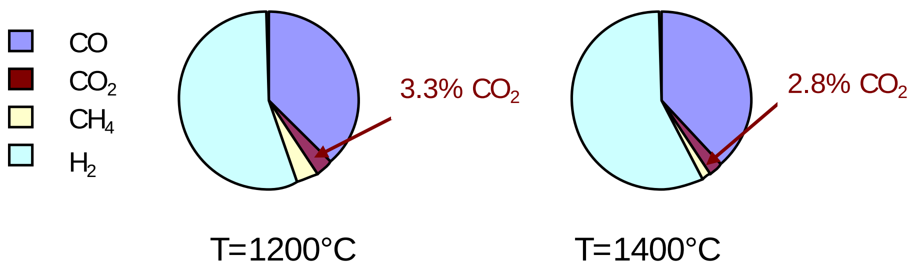
High temperature Pyrolysis, pilot plant Munich

Process gas = Syngas (mainly H_2 and CO)

T=1200°C, t=10min

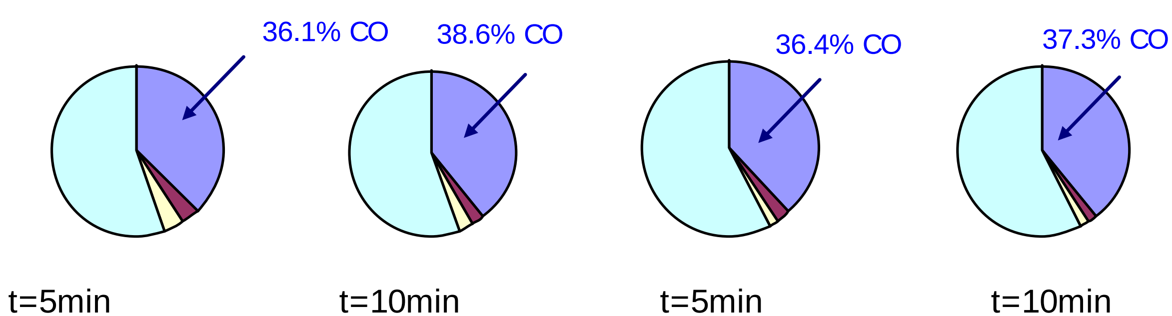


TS = 80%, t = 5min



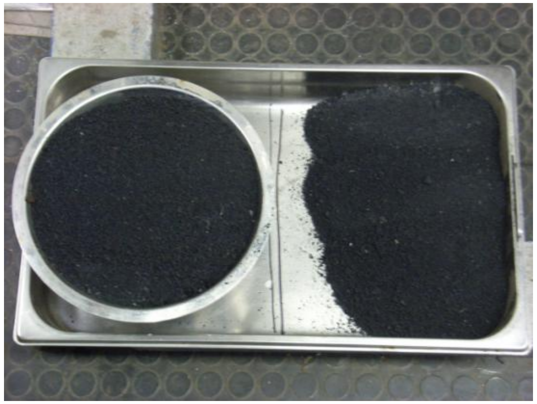
TS = 80%, T = 1200°C

TS = 80%, T = 1400°C



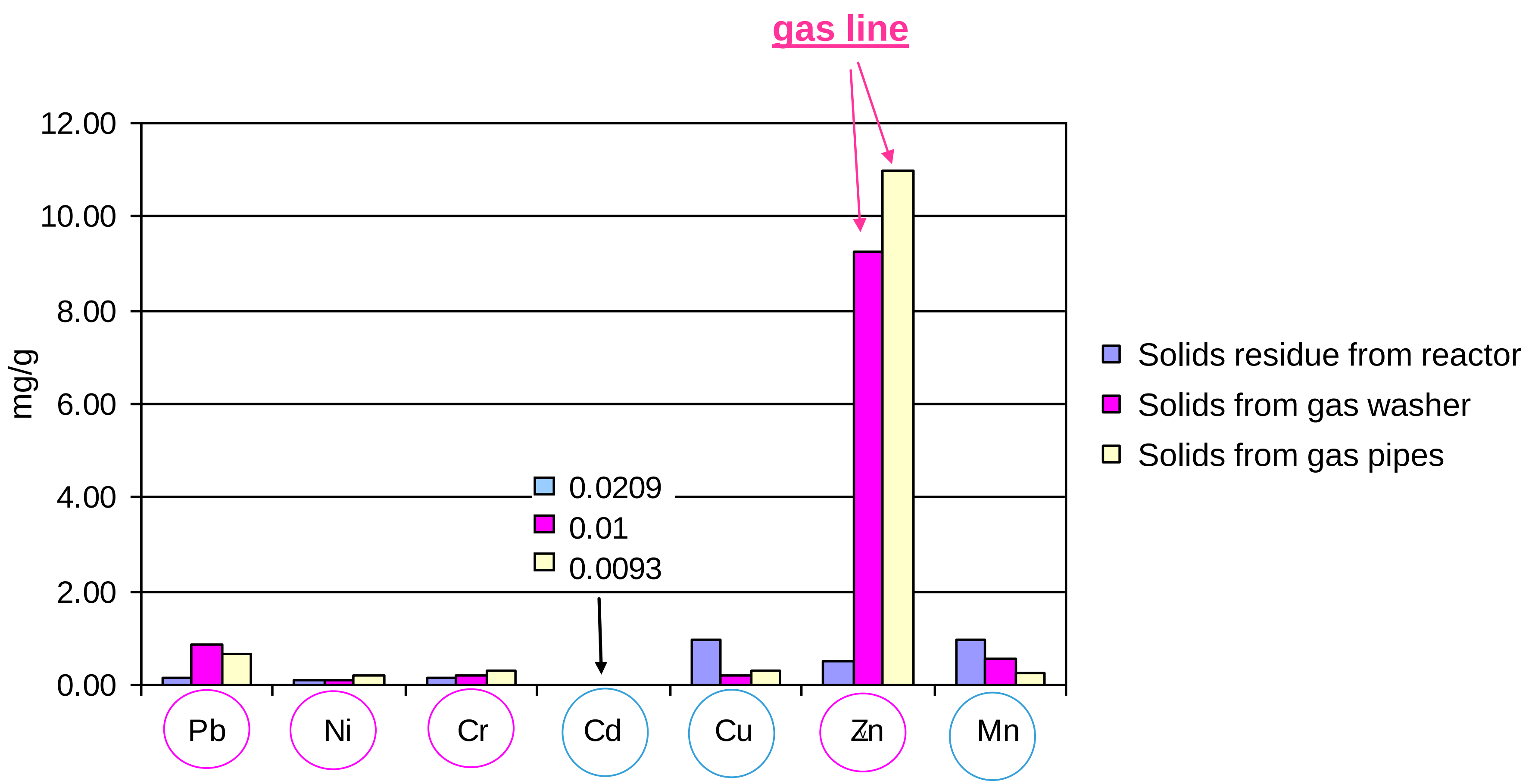
Solid residue in reactor and syngas

- The amount of produced solid residue and syngas depends on process temperature and reaction time
- TS reduction is maximal about 60% (theoretically calculated from the dried sludge composition: Si, Ca, Fe, Al and P oxides)
- TS reduction observed (see Table) was higher probably due to loss in the gas piping system and gas washer (in the reactor 80% of solid residue and in the gas system and washer only 20% was found)

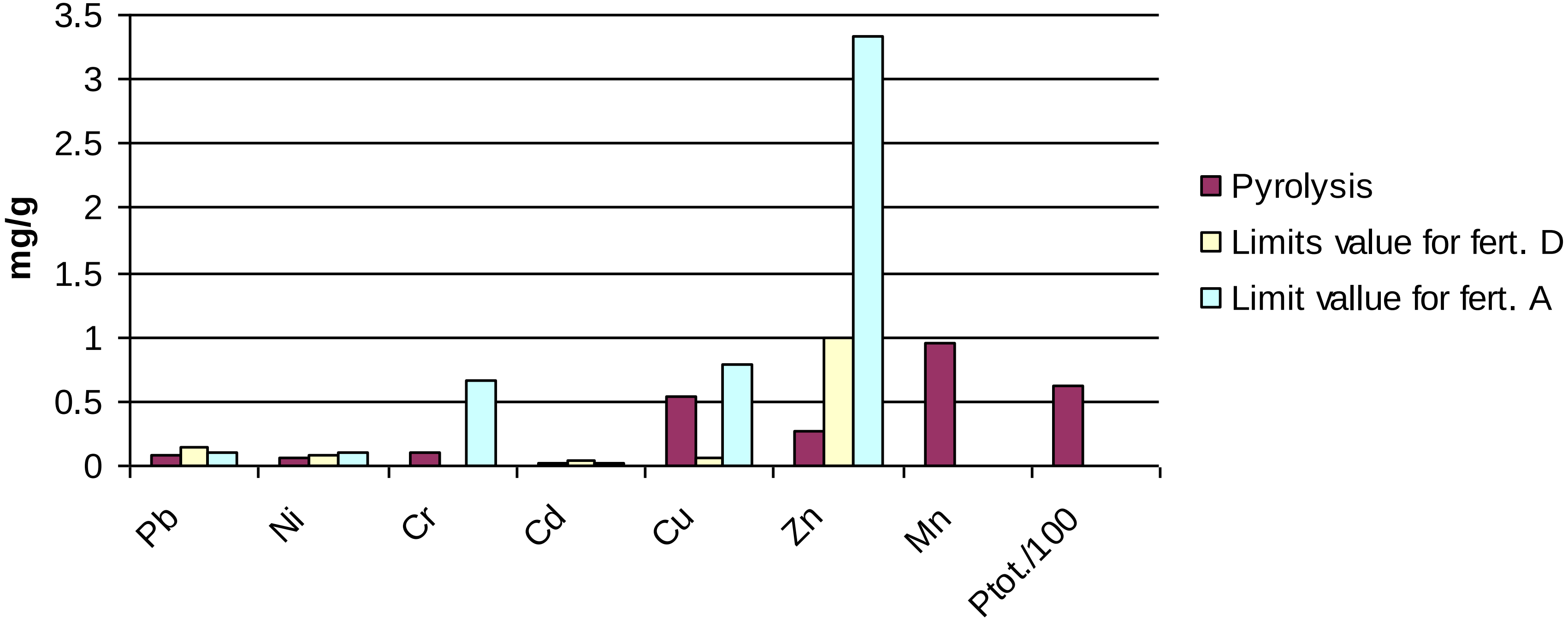


T \ ***t***	***5min***	***10min***
1200°C	62%	81%
1400°C	76%	87%

Heavy metals distribution among solids products (90% TS, T=1200°C, t=10min)



Heavy metals content – comparison with EU limits[1)] for fertilizers



1) Adam et al., (2007) Materials Transactions, 48 (12): 3056-3061

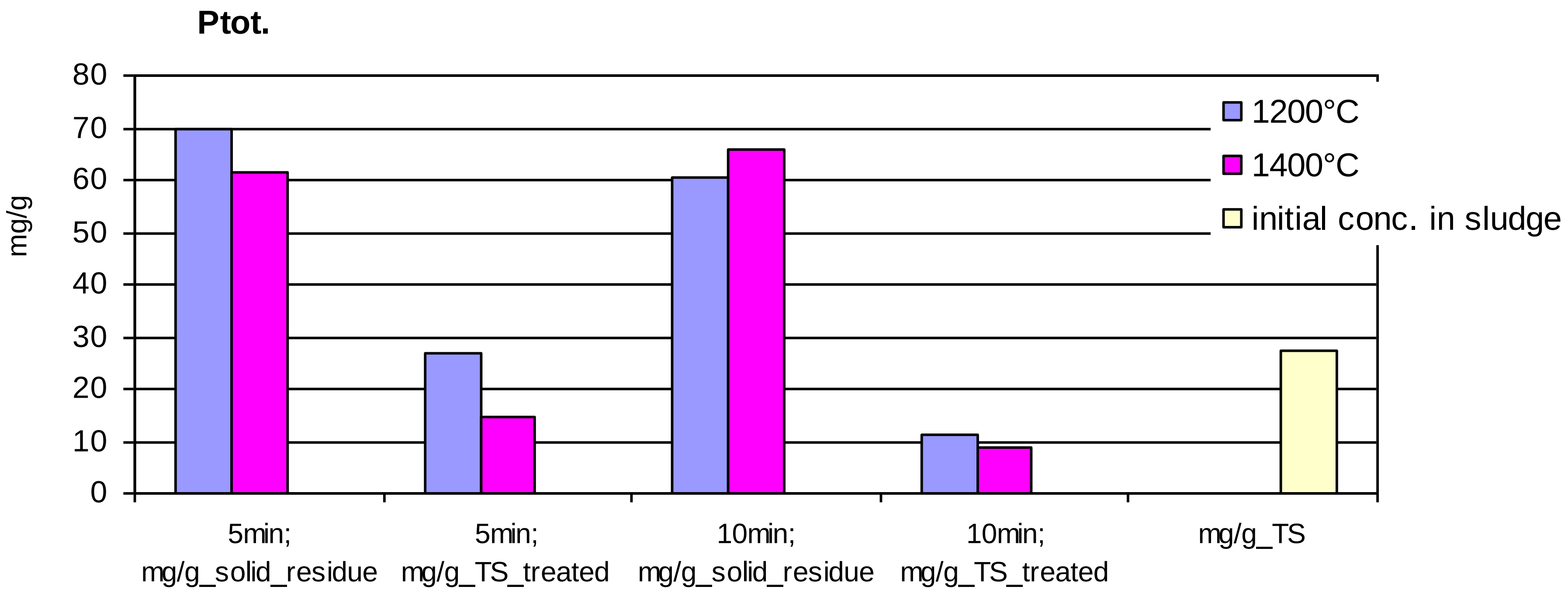
Heavy metals leaching from the solid residue (starting pyrolysis from 80% TS)

- 1g sample was placed in a closed flask suspended in 20ml of deionised water and shaken for 5 days. After filtration the heavy metals content in the liquid was measured and the leached fraction calculated (Table):

T	***time***	***Pb***	***Ni***	***Cr***	***Cd***	***Cu***	***Zn***	***Mn***
1200°C	***5 min***	0.63%	0.15%	0.10%	0.13%	0.04%	0.02%	0.00%
	10 min	1.42%	0.19%	0.13%	0.65%	0.08%	0.05%	0.00%
1400°C	***5 min***	0.77%	0.16%	0.09%	0.16%	0.04%	0.03%	0.01%
	10 min	0.73%	0.19%	0.10%	0.14%	0.04%	0.03%	0.01%

- Neither the temperature nor the residence time influenced the stability of the heavy metals in the solid residue.

Potential for phosphorus recovery



Commercial fertilizer has about 8% P content

Phosphorus bioavailability, (1g in 20ml of 2% citric acid)

	5min		10min		
	init.conc.in res. (mg/g	% leached	init.conc.in res. (mg/g)	% leached	init.conc.in sl. (mg/g)
T					
1200°C	69.9	12.6%	60.6	9.9%	27.4
1400°C	61.4	11.9%	65.6	11.8%	

Conclusion:

Phosphorus bioavailability seems not to depend on the reaction temperature but is slightly reduced with the reaction time.

	Ptot. init. (mg/g)	***Percentage leached***
Incineration ash	58-90	0.07%-0.12%
Wet Oxydation solid residue	81.1	8.9%
Pyrolysis (TS80%, 1200°C, 10min)	60.6	9.9%
Gasification in Balingen	58.6	16.5%

Operating data and costs for full-scale pyrolysis

Pyrolysis process	
Capacity:	7000tTS/year
TS :	70-90%
Electricity consumption:	320kWh/tonTS
Oxygen consumption:	none
Solid mineral out:	250kg/tonTS
Gas out (to the atmosphere)	none
Operato and maintenance:	4men/year
Primary energy gain:	960kWh/tonTS
Investment costs:	9milion € (for 25ton/d unit)
Personal costs	200'000€/year

LCA: Characterization of Pyrolysis scenario

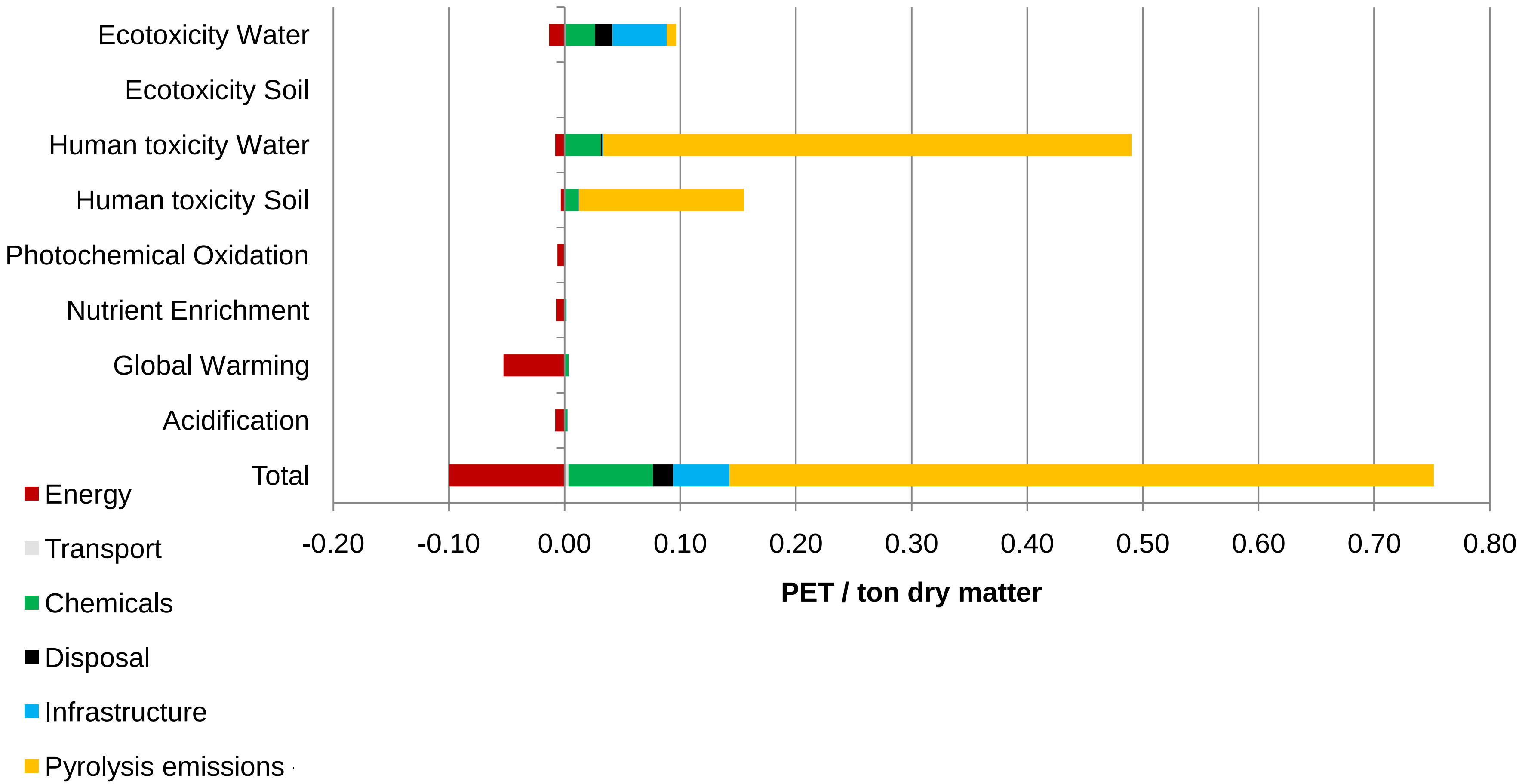
For inventory list of LCA

- Sludge composition of municipal WWTP (European average), thickened to 4% DS, dewatered to 25-30% DM)
- Emissions of heavy metals to air *-> Cd, Cr, Cu, Hg, Ni, Pb, Zn*
- Infrastructure
- Disposal of solid residues
- Chemicals (for off-gas treatment; assumed identical to on-site incineration)
- Transport
- Energy consumption / production

Energy production	Electricity	0.78 MWh/tDM (33% of theoretical yield)
	Heat	1.20 MWht/DM (50% of theoretical yield)
Energy consumption	Electricity	0.34 MWh/tDM (data from Pyromex)
	Heat	1.7-2.2 MWh/tDM (evaporation, 25-30%DM)
Energy balance	Electricity surplus	**0.4 - 0.5 MWh/tDM**
	Heat missing	**0.5 - 1.0 MWh/tDM**

LCA: Impact profile; Pyrolysis - heat drying

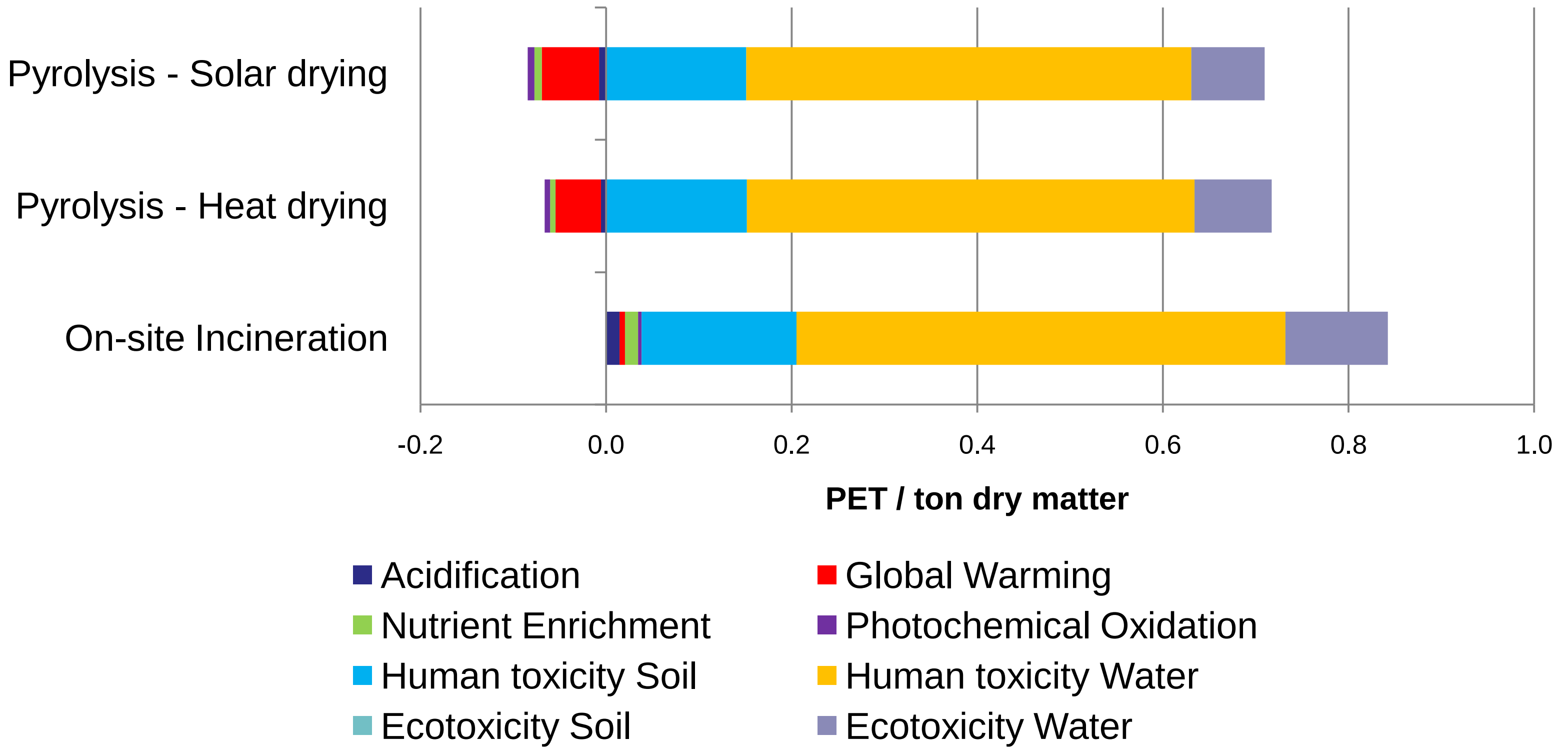
(Normalized and weighted impacts, PET. Weighting factors =1 for all impact categories).



Total (net) = 0,65

The impact of "pyrolysis emissions" is dominated by mercury air emissions

LCA: Comparison of impact profiles;
Pyrolysis and on-site incineration



Total (net): Incineration = 0,84 PET/ton DM

Pyrolysis – heat drying = 0,65 PET/ton DM

Pyrolysis – solar drying = 0,63PET/ton DM

Conclusions

- High temperature pyrolysis avoids oily phase; only solids (free of organics) and syngas.
- Gas is free of tar and expensive cleaning is avoided.
- Solid product in the reactor has low content of heavy metals, ash has probably to be treated to extract heavy metals
- Potential for phosphorus recycling.
- Higher bioavilibity than incineration ash
- Heavy metals are well immobilized
- LCA indicates that high temperature pyrolysis might be more sustainable than incineration due to lower air emissions and better energy balance
- However, the LCA is highly sensitive to heavy metal emissions, mainly mercury?

Acknowledgment

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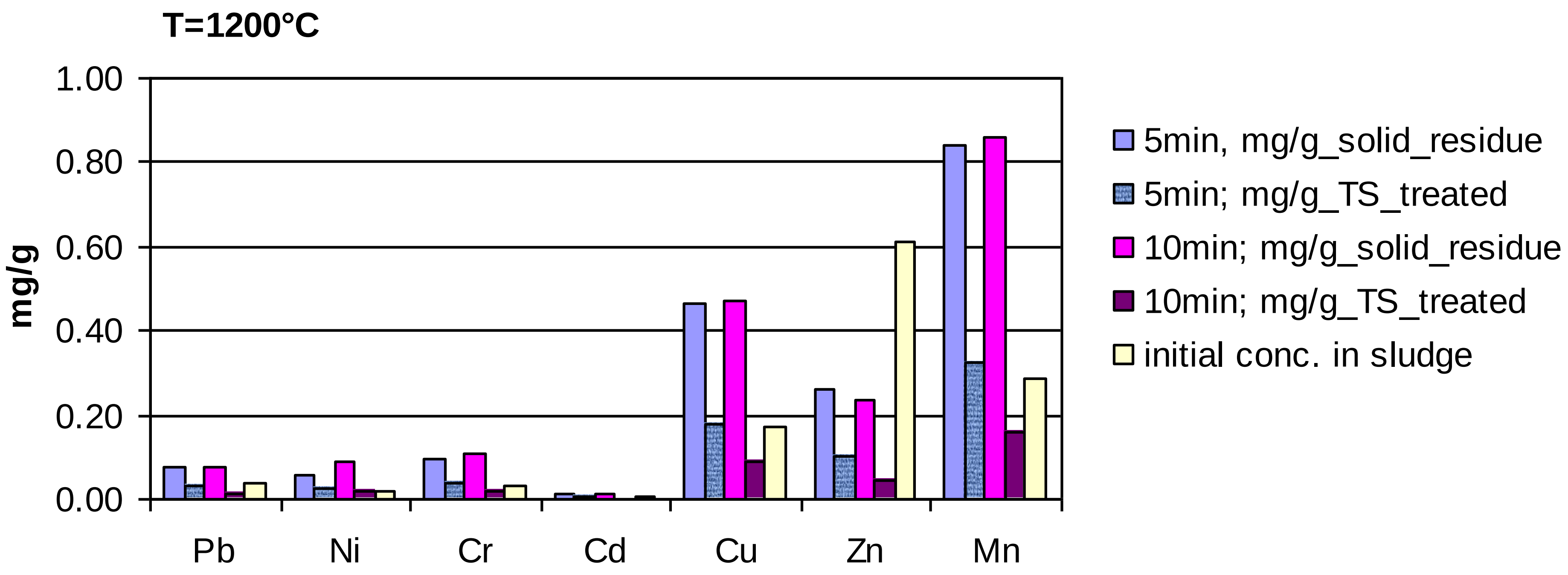
Heavy metals in solids residue of reactor (80% TS, 1200°C, t = 5-10 min)



Heavy metals in solids residue of reactor
(80% TS, 1200-1400°C, t = 10 min)