Electronic Supplementary Material

Greenhouse gas emissions from thermal treatment of non-recyclable municipal waste

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Appendix A—An Inventory Analysis

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A1 Waste-to-Energy Facility

A1.1 Waste composition (RES = residual household waste)

A1.1.1 Expected Average composition of residual waste in the Czech Republic

RES fraction	Content of Particular Components/%	Calor. Value/(MJ·kg^{-1})	Fossil-derived Carbon/(g·kg^{-1})	Biogenic carbon/(g·kg^{-1})
Metal	**2.5**	**0.0**	**0**	**0**
Glass	**5.5**	0.0	0	0
Paper + beverage containers	**8.0**	14.6	73	317
Plastic	**10.0**	34.0	680	0
Electric components	**0.4**	22.9	441	0
Textile	**5.5**	15.0	172	218
Other combustibles	**14.0**	4.4	45	135
Organic waste	**29.0**	4.6	0	160
Hazardous waste	**0.6**	17.0	416	0
Mineral waste	**3.0**	0.0	19	0
Fraction under 40 mm	**21.5**	5.1	46	85
Total	**100***	**8.7****	**104****	**120****

Note: *sum, ** weighted average

A1.2 Medium and large capacity WTE (80–300 kt·year^{-1})

A1.2.1 Supplies / Energy for incineration plant

Natural gas consumption	220	MJ·t^{-1} waste input
Power consumption	105	kWh·t^{-1} waste input
Production of ammonia (liquid)	0.8	kg·t^{-1} waste input
Production of quicklime	1	kg·t^{-1}/t waste input

Production of Sodium hydroxide	6.2	kg·t $^{-1}$ waste input

A1.2.2 Technology/Efficiencies

Boiler efficiency	87.2%
Steam temperature	400°C
Steam pressure	40 bar
Turbine type	extraction condensing
Turbine thermodynamic efficiency	78%

A1.2.3 Residues handling/treatment/recycling

Residues to recycling (Residues from flue gas cleaning, slags)	256	kg·t $^{-1}$ waste input	
Residues to disposal	78	kg·t $^{-1}$ waste input	
Transport of residues to recycling	200	km (round trip)	
Transport of residues to disposal	100	km (round trip)	
Recycling of residue from flue gas cleaning	27.3	kg·t $^{-1}$ waste input	Recycling path: processing to rock filling
Recycling of slag	229	kg·t $^{-1}$ waste input	Recycling path: processing to rock filling, road building and landfill building Assumption: 50% of ferrous metals and 10% of non-ferrous metals are separated
Recycling of iron scrap, separated from slag	8.6	kg·t $^{-1}$ waste input	Recycling path: electric arc furnace
Recycling of non-ferrous scrap, separated from slag	0.8	kg·t $^{-1}$ waste input	Recycling path: aluminium smelter
Disposal of residue from flue gas cleaning	2.7	kg·t $^{-1}$ waste input	Disposal path: inert material landfill
Disposal of slag	76	kg·t $^{-1}$ waste input	Disposal path: inert material landfill

A1.2.4 Credits

A1.2.4.1 Heat and electricity

Heat production Benefit: process heat and district heating (Czech heating mix, see A1.4)

Electricity production Benefit: electricity (Czech electricity mix, see A1.4)

Capacity /(kt·year^{-1}/y)	Heat production /(GJ·year $^{-1}$)	Electricity production /(MWh·year $^{-1}$)	Heat production /(GJ·t $^{-1}$ waste)	Heat production /(GJ·t $^{-1}$ waste)
80	413,211	21,849	5.17	0.27
110	514,781	32,835	4.68	0.30
140	586,209	45,398	4.19	0.32
170	645,941	58,572	3.80	0.34
200	679,395	73,121	3.40	0.37
230	686,410	89,053	2.98	0.39
260	686,410	105,352	2.64	0.41
290	686,410	121,651	2.37	0.42

A1.2.4.2 Credits for metals from residue treatment

Electric steel	6.2	kg·t $^{-1}$ waste input	Benefit: converter steel (oxygen furnace)
Secondary aluminium	0.14	kg·t $^{-1}$ waste input	Benefit: primary aluminium

A1.2.4.3 Credits for residue from flue gas cleaning, slags and ash from residue treatment

Building sand and construction gravel	145	kg·t $^{-1}$ waste input	Benefit: Gravel at mine
Dump material	88	kg·t $^{-1}$ waste input	Benefit: backfill measure

A1.3 Small capacities (10–50 kt·year^{-1})

A1.3.1 Supplies/Energy for incineration plant

Natural gas consumption	220	MJ·t $^{-1}$ waste input
Power consumption	105	kWh· t $^{-1}$ waste input
Production of ammonia (liquid)	0.8	kg·t $^{-1}$ waste input
Production of quicklime	1	kg·t $^{-1}$ waste input
Production of Sodium hydroxide	6.2	kg/·t $^{-1}$ waste input

A1.3.2 Technology/Efficiencies

Boiler efficiency	85.6%
Steam temperature	220°C
Steam pressure	13 bar
Turbine type	backpressure
Turbine thermodynamic efficiency	50%

A1.3.3 Residues handling/treatment/recycling

Residues to recycling (Residues from flue gas cleaning, slags)	256	kg·t $^{-1}$ waste input	
Residues to disposal	78	kg·t $^{-1}$ waste input	
Transport of residues to recycling	200	km (round trip)	
Transport of residues to disposal	100	km (round trip)	
Recycling of residue from flue gas cleaning	27.3	kg·t $^{-1}$ waste input	Recycling path: processing to rock filling
Recycling of slag	229	kg·t $^{-1}$ waste input	Recycling path: processing to rock filling, road building and landfill building Assumption: 50% of ferrous metals and 10% of non-ferrous metals are separated
Recycling of iron scrap, separated from slag	8.6	kg·t $^{-1}$ waste input	Recycling path: electric arc furnace
Recycling of non-ferrous scrap, separated from slag	0.8	kg·t $^{-1}$ waste input	Recycling path: aluminium smelter
Disposal of residue from flue gas cleaning	2.7	kg·t $^{-1}$ waste input	Disposal path: inert material landfill
Disposal of slag	76	kg·t $^{-1}$ waste input	Disposal path: inert material landfill

A1.3.4 Credits

A1.3.4.1 Heat and electricity

Heat production Benefit: process heat and district heating (Czech heating mix, see A1.4)

Electricity production Benefit: electricity (Czech electricity mix, see A1.4)

Capacity/(kt·year ^{1})	Heat production/(GJ·year^{-1})	Electricity production/(MWh·year^{-1})	Heat production/(GJ·t $^{-1}$ waste)	Heat production/(GJ·t^{-1} waste)

10	71,964	1,547	7.20	0.155
20	139,374	3,094	6.97	0.155
30	191,925	4,641	6.40	0.155
40	235,859	6,188	5.90	0.155
50	274,187	7,735	5.48	0.155

A1.3.4.2 Credits for metals from residue treatment

Electric steel	6.2	$kg \cdot t^{-1}$ waste input	Benefit: converter steel (oxygen furnace)
Secondary aluminium	0.14	$kg \cdot t^{-1}$ waste input	Benefit: primary aluminium

A1.3.4.3 Credits for residue from flue gas cleaning, slags and ash from residue treatment

Building sand and construction gravel	145	$kg \cdot t^{-1}$ waste input	Benefit: Gravel at mine
Dump material	88	$kg \cdot t^{-1}$ waste input	Benefit: backfill measure

A1.4 Fuel mix for power and heat industry in the Czech Republic

Power			**Heat**		
Reference	**Share/%**	**CO_2 production/($kg \cdot GJ^{-1}$ of produced power)**	**Reference**	**Share/%**	**CO_2 production/($kg \cdot GJ^{-1}$ of produced heat)**
Coal	51	337	**Coal**	59	112
Natural gas	8	187	**Natural gas**	24	62
Nuclear	30	0	**Other gases**	4	73
Water	1	0	**Renewables**	9	0
Solar	3	0	**Heating oils**	4	85
Wind	1	0	-	-	-
Biomass	6	0			
Total	**100***	**187****	**Total**	**100***	**88****

Note: *sum, ** weighted average

A2. Mechanical biological treatment plant

A2.1 Inlet - Waste composition (RES = residual household waste)

RES fraction	**Content of particular components/%**	**Calor. value/($MJ \cdot kg^{-1}$)**	**Fossil-derived carbon/($g \cdot kg^{-1}$)**	**Biogenic carbon/($g \cdot kg^{-1}$)**
Metal	**2.5**	**0.0**	**0**	**0**
Glass	**5.5**	0.0	0	0
Paper + beverage containers	**8**	14.6	73	317
Plastic	**10**	34.0	680	0
Electric components	**0.4**	22.9	441	0
Textile	**5.5**	15.0	172	218
Other combustibles	**14**	4.4	45	135
Organic waste	**29**	4.6	0	160
Hazardous waste	**0.6**	17.0	416	0
Mineral waste	**3**	0.0	19	0
Fraction under 40 mm	**21.5**	5.1	46	85
Total	**100***	**8.7****	**104****	**120****

Note: *sum, ** weighted average

A2.2 Supplies / Energy for MBT

Covering power demand	175	$MJ \cdot t^{-1}$ waste input
Covering heat demand	60	$kWh \cdot t^{-1}$ waste input
Covering mechanic energy demand	30	$kg \cdot t^{-1}$ waste input
Supply and combustion of natural gas	160	$kg \cdot t^{-1}$ waste input

A2.3 Overall material balance:

Inlet = RES	100%
Outlet 1 - stabilized landfilled fraction	41%
Outlet 2 - high calorific fraction for RDF production	32%
Outlet 3 - losses (drying, degassing)	20%
Outlet 4 - glass and metal material recovery	8%
Exhaust air	5500 $Nm^3 \cdot t^{-1}$ waste
Methane emission in exhaust air	5.8 $mg \cdot Nm^{-3}$ flue gas
Dinitrogen monoxide emission in exhaust air	6 $mg \cdot Nm^{-3}$ flue gas

A2.4 Mass fraction percentual distribution of inlet RES in MBT (with RDF production) in detail

Paper fraction in inlet RES/%	**Plastic fraction in inlet RES/%**	**Organic fraction in inlet RES/%**	**Electric components fraction in inlet RES/%**	**Metal fraction in inlet RES/%**	**Mineral waste fraction in inlet RES/%**	**Hazardous waste fraction in inlet RES/%**	**Glass fraction in inlet RES/%**	**Other combustibles fraction in inlet RES/%**	**Textile fraction in inlet RES/%**	**Fraction under 40 mm in inlet RES/%**			
10.0%	10.0%	29.0%	0.4%	2.5%	3.0%	0.6%	5.5%	14.0%	5.5%	21.5%	→	100%	
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓		**% of outlets**	**MBT outlet**
0	0	0	0	0	0	0	0	0	0	0	→	0	Paper
0	0	0	0	0	0	0	0	0	0	0	→	0	Plastic
0	0	0	0	93	0	0	0	0	0	0	→	2.3	Metal
0	0	0	0	0	0	0	94	0	0	0	→	5.2	Glass
0	0	0	0	0	0	0	0	0	0	0	→	0	Compost (useable)
80	80	2	67	0	0	67	0	75	70	10	→	32.2	RDF
10	10	63	33	7	100	33	6	15	10	67	→	41	Stabilized fraction
10	10	35	0	0	0	0	0	10	20	23	→	19.4	Losses (drying, degassing)
100	100	100	100	100	100	100	100	100	100	100		100	Sum

A2.5 Transport of output fractions

Metals	100 km	Round trip (loaded and empty run)
Impurities	50 km	Round trip (loaded and empty run)
stabilized landfilled fraction	without transport	
RDF	not included	

A2.6 Credits from metal recycling

Electric steel	1.9	$kg \cdot t^{-1}$ waste input	Benefit: converter steel (oxygen furnace)
Secondary aluminium	0.4	$kg \cdot t^{-1}$ waste input	Benefit: primary aluminium

A2.7 Composition of RDF produced

RDF fraction	**Content of Particular Components/%**	**Calor. Value/(MJ·kg^{-1})**	**Fossil-derived Carbon/(g·kg^{-1})**	**Biogenic carbon/(g·kg^{-1})**
Metal	0	0	0	0
Glass	0	0	0	0
Paper + beverage containers	22.8	14.6	73	317
Plastic	26.8	34	680	0
Electric components	0.9	22.9	441	0
Textile	11	15	172	218
Other combustibles	30	4.4	45	135
Organic waste	3	4.6	0	160
Hazardous waste	1.3	17	416	0
Mineral waste	0	0,0	19	0
Fraction under 40 mm	4.2	5.1	46	85
In Total	**100***	**16.2****	**243****	**145****

Note: *sum, ** weighted average

A2.8 Credits from RDF utilization

not included, credits relevant to WTE utilizing RDF fuel

A3. Landfilling

A3.1 Inlet - Waste composition (RES = residual household waste)

RES fraction	**Content of Particular Components/%**	**Calor. value/(MJ·kg^{-1})**	**Fossil-derived carbon/(g·kg^{-1})**	**Biogenic carbon/(g·kg^{-1})**
Metal	**2.5**	**0.0**	**0**	**0**
Glass	**5.5**	0.0	0	0
Paper + beverage	**8.0**	14.6	73	317

containers				
Plastic	**10.0**	34.0	680	0
Electric components	**0.4**	22.9	441	0
Textile	**5.5**	15.0	172	218
Other combustibles	**14.0**	4.4	45	135
Organic waste	**29.0**	4.6	0	160
Hazardous waste	**0.6**	17.0	416	0
Mineral waste	**3.0**	0.0	19	0
Fraction under 40 mm	**21.5**	5.1	46	85
Total	**100***	**8.7****	**104****	**120****

Note: *sum, ** weighted average

A3.2 Energy, auxiliary and operating materials

Covering power consumption	7.2	MJ·t $^{-1}$ waste input	Czech electricity mix
Covering heat consumption	1.6	MJ·t $^{-1}$ waste input	District heating from Czech heating mix
Covering mechanic energy demand	1.6	MJ·t $^{-1}$ waste input	Diesel, burned in building machine

A3.3 Landfilling/Landfill gas capture and utilization

Landfill gas	210 m³·t^{-1} waste input
Landfill leachate	13.5 kg·t^{-1} waste input
Diffuse emissions of landfill gas	40% of total landfill gas
Collected landfill gas	60% of total landfill gas
Electricity demand for collecting landfill gas	540 kJ·m^{-3} landfill gas
Heating value of landfill gas	5.75 kWh·m^{-3} in MJ
Landfill gas to torch	21 % of total collected landfill gas
Landfill gas to gas motor Electrical efficiency: 30 %, Thermal efficiency: 0 %, Benefit: electricity (Czech electricity mix)	79% of total collected landfill gas
Landfill leachate purification	
Diffuse emissions of landfill leachate	60% of total landfill leachate
Collected landfill leachate	40% of total landfill leachate

A3.4 Credits from gas utilization

Electric power generated in gas motor and cogeneration unit	357 MJ·t $^{-1}$ waste input	Net delivery to the public electricity network. Benefit: electricity (Czech electricity mix