ABSTRACT: Waste derived material for recycling and energetic utilization is the preferable option in waste management compared to pure disposal in the context of climate change mitigation. Waste-to-energy, e.g. the (co-)incineration of so-called "refuse derived fuel" (RDF) in industrial facilities, is one particularly interesting option for heterogeneous waste, which can not be reused or recycled easily. In order to secure that environmental standards are not being compromised, waste material that may be used as RDF shall be processed to meet certain quality criteria. The required processing demands can potentially be met by the use of sensor-based sorting technologies, which are state-of-the-art for the treatment of separately collected recyclables which are rather homogeneous in their composition. In this work sensor-based sorting is evaluated for its application on heterogeneous wastes on a pilot and a large scale, showing that the technology is generally feasible to gain waste fractions with the required characteristics, if the sensor systems are adjusted to the specific waste stream.

1 BACKGROUND

Appropriate waste management contributes to mitigate greenhouse gas emissions (mainly methane (CH_4) but also carbon dioxide (CO_2)) in order to combat the anthropogenic climate change (e.g. Pomberger et al., 2008) and fulfill the climate-protection commitments within the European Union (EU). Generally, the use of waste derived material for recycling and energetic utilization is the more preferable option in waste management compared to pure disposal in the context of the impact on the climate change (e.g. Ragoßnig et al., 2009) but also environmental pollution (Cleary, 2009). This is also underlined by the European "waste hierarchy" (EP, 2008), aiming at "prevention" over "reuse", "recycling", "recovery" and finally "disposal".

In this regard, "recovery", i.e. waste-to-energy is one particularly interesting option for heterogeneous waste, which is characterized by a highly variable composition and a large portion of impurities (e.g. stones and soil) and can therefore not be reused or material recycled easily, as also mentioned by Hopewell et al. (2009) previously. Waste-to-energy comprises different options, namely the (co-) incineration of so-called "refuse derived fuel" (RDF) or "waste derived fuel" (Rotter et al., 2010) in industrial facilities as well as waste incineration aiming at "thermal disposal".

RDF contains mainly high calorific components that are separated from a waste stream and used as a substitute for fossil fuels in certain industry sectors, e.g. the cement or the pulp and paper industry. The (co-) incineration of this RDF in industrial facilities is preferable over ordinary waste incineration from an economical point of view for the waste contractor (see review in Ragoßnig & Faist, 2009 for the situation in early 2009) and also in the light of the energetic output. However, concerning the environmental pollution by e.g. formed dioxins and furans due to contained chlorine compounds, the use of RDF for co-incineration in industrial facilities is not necessarily more preferable compared to waste incineration which is usually controlled strictly in terms of its pollutant emissions (e.g. Steven & Lahl, 2009).

In order to secure that environmental standards are not being compromised, waste material that may be used as alternative, partly renewable energy source in form of RDF shall (be processed to) meet certain quality criteria, which in Austria are partly determined in the RDF-guideline (Lebensministerium, 2008). In addition to these quality criteria of RDF which address primarily the heavy metal content, the partly renewable nature of RDF gains in importance due to the EU CO_2 emission trading scheme (e.g. Pomberger & Alb, 2008; Pomberger et al. 2008).

In addition to mainly fossil RDF agricultural and industrial biogenic waste is already an important renewable energy resource for heat and power generation. Additional biogenic resources can be gained from heterogeneous wastes by the means of separation of biogenic fractions as well. However, to make the waste stream useable for co-incineration, addressing further contaminants besides chlorine compounds is desireable and sometimes necessary. In the future an increased biogenic content as well as the distinct characterization of the biogenic content along with the heavy metal content will become determining in the energetic recovery especially of heterogeneous waste materials.

Both, the conversion of heterogeneous wastes to RDF as well as the generation of biogenic energy resources, is favorable in the light of the European “renewables” directive (EP, 2009) aiming at increasing the renewable portion in the overall energy consumption to at least 20% in the EU.

In RDF-production, high calorific components are split from the waste stream and used as a substitute for fossil fuels in certain industry sectors as mentioned above. In the production currently rather basic mechanical processing steps (crushing/shredding, classification and ballistic separation, are performed using mainly waste particle size and density as separation criteria (e.g. Thermo Team, 2010; Rotter et al., 2004). The use of material characteristics like pollutant content as separation criteria is not yet widely applied in RDF production, although some research is conducted (e.g. Rotter et al., 2004). This research, however, demonstrates that mechanical processing steps are not sufficient at least for chlorine removal. Additionally, the separation of renewable biogenic from fossil components is a completely new approach towards material specific waste management.

2 AIM AND SCOPE

The feasibility of using material specific characteristics (i.e. molecular characteristics and associated spectroscopic behavior) of heterogeneous waste components to generate a low-pollutant bearing biogenic waste stream and one enriched with fossil waste components is evaluated in the presented research. The required processing demands, i.e. (1) to remove chlorine-containing compounds and (2) separate biogenic from non-biogenic materials, can potentially be met by the use of sensor-based sorting technologies with near infrared spectroscopy (NIR), which is a state-of-the-art technology for the treatment of separately collected recyclables (e.g. plastic and paper). However, it is not yet widely applied for the processing of heterogeneous wastes. Therefore, its technical feasibility for this application is evaluated and results of achieved chlorine- as well as biogenic-components are presented here.

3 SENSOR-BASED SORTING TRIALS

3.1 *Material and Methods*

Two specific waste streams from a mechanical treatment plant, processing commercial solid waste (60 kt/year in 2008), which are destined for the utilization as RDF in the cement industry are considered and were analyzed and characterized regarding their composition: a high calorific fraction (HC, particle size > 120 mm) and a medium calorific fraction (MC, 20 – 120 mm). The respective waste streams contain, amongst others, polymers, paper, cardboard and wooden materials as well as textiles, and are highly variable in their composition (Fig. 1).

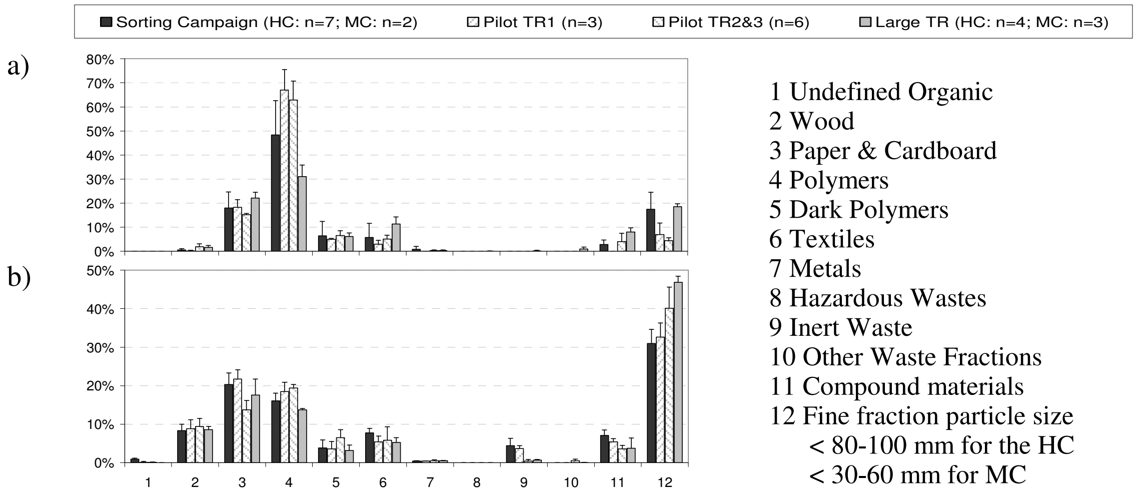

Fig. 1. Characterization of the test material: a) High Calorific Waste Stream (HC); b) Medium Calorific Waste Stream (MC); TR = Test Run. Analysed material in total [kg]: Sorting campaign: HC 340, MC 110; Pilot TR1: HC 60, MC 60; Pilot TR2&3: HC 120, MC 140; Large TR: HC 290, MC 340.

Experiments with a near infrared (NIR) sensor system on a pilot and on a large scale were targeted towards (a) the removal of chlorine compounds followed by (b) the separation of biogenic from non-biogenic materials. Therefore the sensor system was tuned to firstly reject polymers containing polyvinyl chloride (PVC) and secondly remove biogenic materials from this PVC-freed material stream, resulting in three output-streams: (R1) Reject 1: PVC output; (R2) Reject 2: biogenic output; (P2) Passing 2: fossil output.

Parameter configurations (a.o. scanning speed of the sensor-system, pressure of compressed air for ejection, sieving of the material, etc.) were varied in three pilot scale tests, to optimize the quantitative reject of PVC-containing materials (R1) and the quality and quantity of the biogenic reject (R2) in the outcome of HC and MC. Based on these results, a test run at large scale was conducted in order to get first results although the existing plant was optimized for a different type of waste stream and a different sorting task.

The yield (R2) and the purity (R2, P2) were used for the evaluation of the separation of biogenic from fossil materials. The yield represents the rejected mass-proportion of material that is supposed to be rejected. The purity is the mass-proportion of material sorted correctly into R2 or P2. The fine fraction (for particle size see Fig. 1) was excluded from this evaluation and textiles were assumed to be biogenic if found in R2 and assumed to be fossil if found in P2.

Additionally, the removal and final concentration of contaminants (especially chlorine compounds but also other heavy metals) as well as the biogenic content were analyzed by chemical analysis.

3.2 *Results and Discussion*

For the HC as well as the MC waste stream, an optimized parameter configuration of the pressure of compressed air and an appropriate NIR identification scheme were found in the pilot scale test run no. 2 for the assigned problem. Therefore, only the results of the second test run are presented here. Based on the knowledge gained from this test run, the large scale test was conducted, of which the results are presented in the following as well.

The pilot scale tests resulted in mass proportions (Tab. 1, Fig. 2) of the output streams as previously expected and desired based on the characterization of the input material, namely a small output stream for Reject 1, a small to medium output stream for the biogenic materials as Reject 2 and a large output stream for the Passing 2, containing the remaining, mainly fossil, material. A similar distribution of output streams concerning their mass was found for the HC as well as the MC waste stream, whereas the biogenic Reject 2 had a slightly higher mass for the MC waste stream. Concerning the large scale test (Tab. 1, Fig. 2), the mass of Reject 2 was much smaller, only in the range of the proportion of Reject 1 - a result of (1) focusing the purity of R2 rather than the yield (R2) and (2) the fact that the plant used was designed and optimized for a different waste stream and a different sorting task.

The yield of Reject 2 and the purity of Reject 2 and Passing 2 were used for the evaluation of the separation of biogenic from fossil materials as described above and are presented in Tab. 1, based on the characterization of the material regarding its compositions of the fractions mentioned in the legend of Fig. 1. The results of this characterization are displayed in Fig. 2, showing the material classified in five categories as described in the legend of Fig. 2.

Tab. 1. Mass balance (Input = 100%), yield and purity of pilot and large scale tests (mean of n samples).

			HC Pilot (n=3)	HC Large (n=1)	MC Pilot (n=3)	MC Large (n=1)
Mass	Reject 1	wt% $_{OS}$	5.11 ± 0.66	3.38	4.99 ± 1.75	2.65
Mass	Reject 2	wt% $_{OS}$	21.1 ± 6.7	6.20	28.0 ± 7.6	5.01
Yield	Reject 2	wt% $_{OS}$	88.2 ± 4.3	20.2	79.4 ± 0.7	16.7
Purity	Reject 2	wt% $_{OS}$	88.1 ± 3.1	79.1	95.3 ± 0.4	87.4
Mass	Passing 2	wt% $_{OS}$	73.8 ± 6.8	71.2	67.1 ± 9.3	51.8
Purity	Passing 2	wt% $_{OS}$	96.0 ± 2.8	72.7	84.4 ± 0.7	57.8

Mass balance based on ca. 21.7 ± 2.1 kg $_{OS}$ (HC, pilot), 38.6 ± 2.2 (MC, pilot), 7030 (HC, large), 5390 (MC, large). Yield and purity of R2 and P2 based on 20.6 ± 2.0 kg $_{OS}$ (HC, pilot), 36.9 ± 2.1 (MC, pilot), 290 kg $_{OS}$ (HC, large), 340 (MC, large).

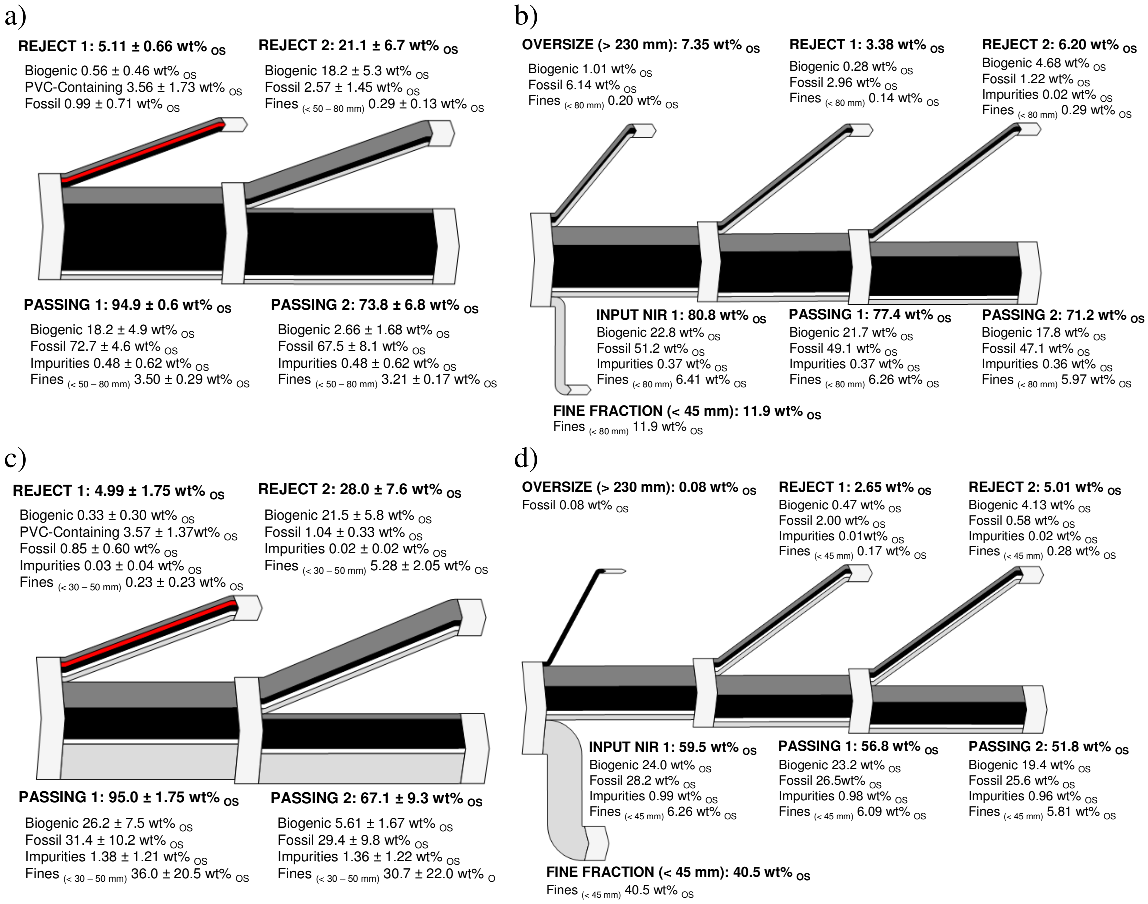

Fig. 2. Material characterisation of output streams. (a) HC pilot, n=3, (b) HC large, (c) MC pilot, n=3, (d) MC large. Based on the legend in Fig. 1, "Biogenic" (marked dark grey) refers to the sum of fractions 1-3 and additionally 6 only if R2 is considered, "Fossil" (black) refers to fractions 4-5, 10-11 and 6 if R1, P1 and P2 are considered, "Impurities" (white) refers to 7, 8, 9 and "Fines" (slight grey) refers to 12. "PVC-containing" (red) is a part of fossil materials of R1 that was detected to contain PVC by a manual NIR sensor. Data (in wt% OS) based on same mass as noted in the heading of Tab. 1.

It needs to be noted, that the fine fraction was excluded from the evaluation of yield and purity whereas the fine fraction is included in the mass balance.

Concerning the biogenic Reject 2 a yield of about 88 wt% $_{OS}$ and purity of about 88 wt% $_{OS}$ for a mass of around 21 wt% $_{OS}$ was achieved on a pilot scale for the HC waste stream (Tab. 1).

The remaining material in Passing 2 (ca. 74 wt% $_{OS}$, P2) had a purity of around 96 wt% $_{OS}$. On a large scale, a lower purity and much lower yield for the biogenic reject (R2) as well as the remaining material (P2) compared to the pilot scale tests was achieved.

Concerning the manual characterization of the MC waste stream, results similar to the HC waste stream were achieved with a yield of ca. 80 wt% $_{OS}$ and purity of ca. 95 wt% $_{OS}$ for the biogenic reject (R2) on a pilot scale; the purity of P2 was around 84 wt% $_{OS}$ (Tab. 1). Comparing the first results on a large scale to the pilot scale results, the purity of R2 was slightly decreased (to 87 wt% $_{OS}$), whereas the purity of P2 was largely decreased (to ca. 58 wt% $_{OS}$). Only a low yield of R2 (ca. 17 wt% $_{OS}$) was achieved similar to the HC waste stream.

Distinct chemical characterization of the output-fractions of the HC and the MC waste stream in regard of their characteristics as RDF (e.g. chlorine content and lower heating value, LHV, see Fig. 3) and also the content of biogenic carbon indicate that the separation of the PVC-containing materials results in very much decreased chlorine content in R2 as well as P2. Furthermore a slightly decreased heating value is achieved in the R2 (due to the increased biogenic content) and an increased heating value in P2 (due to the enrichment of fossil components). Additionally an increased content of biogenic carbon is observed in R2 as could be expected from the results presented in Fig. 2a.

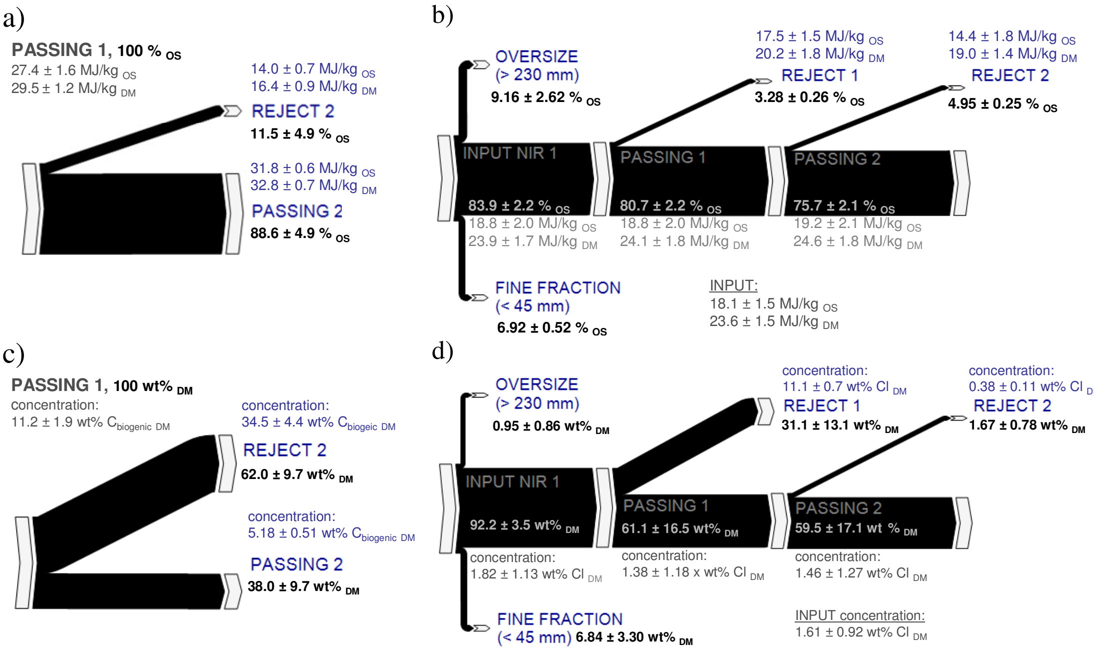

Fig. 3. HC. Energy balance LHV $_{OS}$: (a) for pilot scale (n=3; 20.6 ± 2.0 kg $_{OS}$) and (b) large scale tests (n=4; 7030 kg $_{OS}$ output material); Biogenic carbon balance on a pilot scale (c, n=3) and chlorine balance on a large scale (d, n=3, extreme values excl.).

Combining results for the mass proportions and chemical analysis, for both, the HC as well as the MC waste streams, a chlorine-enriched Reject 1, characterized by a small mass-proportion as well as a small energy-contribution to the overall energy-balance, is achieved. This results in a great decrease in the chlorine content of the desired output streams Reject 2 and Passing 2 coming along with only a slight loss in material mass and energy content as desired.

Especially the low chlorine content in the biogenic enriched Reject 2 is very promising in regard of the required chlorine content of RDF streams of about ≤ 1 wt% Cl $_{DM}$ for specific (co)-incineration facilities, especially in the cement industry (Rotter et al., 2010).

Also the greatly increased biogenic carbon content of around 35 wt% $_{DM}$ in the “biogenic” Reject 2, which equals about 68 wt% $_{DM}$ of the total carbon content compared to the “fossil” Passing 2 with only around 5 wt% $_{DM}$ is very promising. However, mass fractions concerning especially the biogenic reject (R2) have been very small in the large scale test (compare Tab. 1) due to above-mentioned reason that the plant is designed and optimized for a waste stream with different physical characteristics which makes further processing trials necessary for an accurate evaluation.

4 CONCLUSIONS & PERSEPCTIVES

The results of pilot scale and large scale tests presented here show that the sensor-based sorting technology is generally feasible to gain waste fractions with the required characteristics concerning the chlorine as well as the biogenic content, if the sensor systems are adjusted to the specific waste stream. This is also underlined by the purity of the rejected biogenic material on a pilot as well as large scale.

However, mass fractions concerning especially the biogenic reject (R2) have been very small in the large scale test. Due to restrictions that had to be dealt with during the large scale experiment a number of further - mainly construction - issues need to be addressed to allow for a concluding evaluation on the technical feasibility of that treatment concept in regard of mass output.

Therefore, further processing test runs on a large scale with a plant concept, adapted for the specific waste stream and its physical characteristics are recommended and also foreseen.

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REFERENCES

Cleary, J. (2009) Life cycle assessments of municipal solid waste management systems: A comparative analysis of selected peer-reviewed literature. Environment International 35, pp. 1256-1266.

European Parliament (EP) (ed.) (2008) Richtlinie 2008/98/EG des Europäischen Parlaments und des Rates vom 19. November 2008 über Abfälle und zur Aufhebung bestimmter Richtlinien.

European Parliament (EP) (ed.) (2009) Richtlinie 2009/28/EG des Europäischen Parlaments und des Rates vom 23. April 2009 zur Förderung der Nutzung von Energie aus erneuerbaren Quellen und zur Änderung und anschließenden Aufhebung der Richtlinien 2001/77/EG und 2003/30/EG.

Hopewell, J., Dvorak, D. & Kosior, E. (2009) Plastics recycling: challenges and opportunities. Philosophical Transactions of The Royal Society B. Biological Sciences 364, pp. 2115 – 2126.

Lebensministerium (ed.) (2008) Guideline for waste fuels. Federal Ministry of Agriculture, Forestry, Environment and Water management (ed.). Vienna, Austria.

Pomberger, R. & Alb, C. (2008) Mittelkalorische Ersatzbrennstoffe für das HOTDISC-Verfahren. Lorber, K. E., Keindl, G., Menapace, H., Müller, P., Sager, D. & Wruss, K. (ed.), Conference Proceedings 9. DepoTech, Leoben, Austria.

Pomberger, R., Curtis, A. & Scherübl, T. (2008) Climatological relevance of waste management as seen by a collector. Österreichische Wasser- und Abfallwirtschaft 07-08, pp. 113 - 122.

Ragoßnig, A. & Faist, V. (2009) Destination-process-specific Optimization of Waste Processing Using Innovative Treatment Technology. ISWA World Congress 2009, Lisbon, Portual.

Ragoßnig, A. M., Wartha, C. & Pomberger, R. (2009) Climate impact analysis of waste treatment scenarios – thermal treatment of commercial and pretreated waste versus landfilling in Austria. Waste Management Research 27, pp. 914 – 921.

Rotter, V. S., Kost, T., Winkler, J. & Bilitewski, B. (2004) Material flow analysis of RDF-production processes. Waste Management 24, pp. 1005 - 1021.

Rotter, V. S., Lehmann, A. Marzi, T. Möhle, E., Schignitz, D. & Hoffman G. (2010) New techniques for the characterization of refuse-derived fuels and solid recovered fuels. Waste Management & Research, Copenhagen, doi:10.1177/0734242X10364210

Steven, W. & Lahl, U. (2009) Thermal waste treatment – emissions, immission load and assessment of health impact. Müllhandbuch, Thermische Verfahren 3, 1 – 25.

Thermo Team (2010) Produktionsablauf der ThermoTeam-Anlage, online at: http://www.thermoteam.at/cms/front_content.php?idart=3&idcat=4&lang=1