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Final Report

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ENERGY WASTE

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Summary:

The selection of the characterization methods to be employed to the samples collected during Action3.2 is determined by the two following goals: 1) to fully determine the properties necessary for classifying the produced fuel according to CEN/TC 343 and 2) to determine attributes that are important for the design and operation of the pilot gasifier, as well as the evaluation of the gasification and combustion performance. Therefore, the proximate and elementary analysis of each sample is to be performed, along with the determination of chlorine and heavy metal concentrations.

Fuel characterization is considered essential in order to find the potential applications of the produced RDF/SRF fuel. According to CEN/TC 343, a number of parameters are obligatory to be specified, e.g. moisture and ash content, calorific value and chlorine content. Other parameters, while not obligatory for specification, provide a more accurate description of the fuel's properties and render it more attractive for prospective end-users.

The purpose of this deliverable is to present the detailed analyses on the collected samples for all the obligatory parameters, as well as certain key non-obligatory ones.

For this reason, the following analyses, which are necessary for the characterisation of RDF properties, were carried out:

- Proximate analysis (water, ash volatiles, fixed carbon),
- Ultimate Analysis (C,H,N,O,S,Cl)
- Heating value
- Heavy metals analysis (Sb, As, Cd, Cr, Co, Cu, Pb, Mn, Hg, Ni, Tl, V)
- Particle size distribution (PSD analysis)
- Biogenic content analysis
- Manual Sorting Analysis

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1 Introduction

1.1 Scope

This deliverable concerns the analysis and classification of the non-recyclable waste stream produced in WATTs' Material Recovery Facility. More specifically in this work package the main target set is the characterization of important fuel properties according to the emerging CEN/TC 343 [1] standard, and classification according to the aforementioned standard. The conformation of the sampling procedure according to the European Standard is also a significant aspect for the completion of the work program. In this report the analyses of two consecutive years of sampling are presented.

1.2 Need for fuel analysis

CEN/TC 343 is an emerging standard for the characterization and classification of solid recovered fuels. Standardization is considered as a key for the acceptance of SRF in fuel markets. By the standardized monitoring of key properties, SRF fuels can be classified and a preliminary assessment of their combustion and environmental performance is achievable. Classified SRF may serve as a substitute fuel in many sectors, i.e. fossil fuel power production, cement factories, etc.

According to CEN/TC 343, a number of parameters are obligatory to be specified, e.g. moisture and ash content, calorific value and chlorine content. Other parameters, while not obligatory for specification, provide a more accurate description of the fuel's properties and render it more attractive for prospective end-users. Especially regarding the determination of the biogenic fraction of the produced fuel, although it is not considered obligatory by CEN/TC 343, the analysis is essential in determining the CO_2 emission contribution from the combustion of the produced RDF/SRF and is therefore vital input for Life Cycle Assessment.

The following table (Table 1) presents the parameters measured for some or all of the received samples, as well as the standards used.

Table 1: Standards used for Refuse Derived Fuel analysis

Measured parameters	**European Standard**
Moisture Content: Reference Method	EN 15414-1:2010 [2]
Ash content	EN 15403:2011 [3]
Volatile matter	EN 15402:2011 [4]
Elementary analysis (C,H,N,S)	EN 15407-8:2011 [5]
Chlorine	EN 15408:2011 [6]
Calorific Value	EN 15400:2011 [7]
Heavy metals (Sb, As, Cd, Cr, Co, Cu, Pb, Mn, Hg, Ni, Tl, V)	EN 15411:2011 [8]
PSD determination	EN 15415:2011 [9]
Biogenic Fraction	EN 15440:2011 [10]

1.3 Sampling Procedure

For the collection of samples for analysis, standard EN 15442:2011 [11] was followed. The aforementioned standard describes step to step the procedures needed, in order to design and implement the sampling procedure as it was described in “Deliverable 3.2: RDF/SRF sampling protocol”. The following figure (Figure 1) sums up the complete sampling plan along with the calculated sizes.

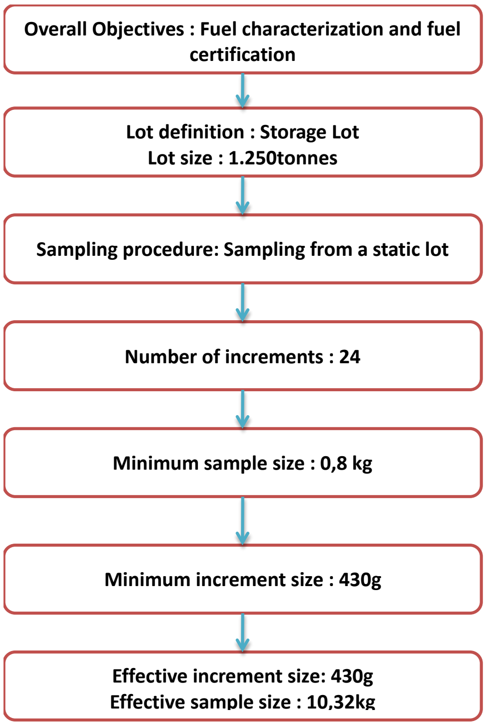

Figure 1: Flow chart on the steps for the development of the sampling plan

1.4 Sample Pre-treatment

For the long term storage of each increment, till the lot is complete, the samples undergo thermal treatment, as described in the standard EN 15443:2011 [12]. After the sample is completed and formed, it is afterwards grinded according to analysing equipment requirements.

1.4.1 Drying

Sample pre-treatment and especially drying can be considered as the most important part for the long term storage of the sample. According to the sampling procedure one sample for analysis was determined to be completed in a period of 4 weeks. For that reason it was found necessary to dry the increments, in order to avoid any decomposition effects due to increased moisture and biogenic content. Pre-drying took place at 40 ^{o}C in order to avoid the evaporation of Mercury (Hg) which is one of the important heavy metals that need to be analysed for the final classification of RDF. After the drying, the increments are air-tight sealed, so as to avoid the absorption of moisture through the air due to capillary phenomena.

In the following figures (figures 2, 3) the equipment acquired in ENERGYWASTE, for the drying procedure is presented. More specifically a precision balance KERN (KERN EBS 2000-2) and an air drying oven (NUVE FN-500) were used for that purpose.

Figure 2: KERN EBS 2000-2

Figure 3: NUVE FN-500

1.4.2 Comminution

Most of the analytical equipment has a requirement for particle size that is smaller than the one that WATTs' material recovery facility produces, so the sample was grinded to the needed size (<250 μm) with the cutting mill Fritsch Pulverisette 19. For the reason that RDF is a mixed material, with both hard and soft parts, a cyclone (figure 4) was used in order to help the procedure and to cool the mill.

Figure 4: Cyclone for the mill

1.4.3 Methodology of lab scale analysis

The methodologies followed for the analysis of WATTs' RDF lot samples have been made according to the European standards mentioned in *Paragraph 1.2*. The steps for theses analysis have been described in Deliverable 4.1 “Report on RDF/SRF gasification properties” [Available from www.energywaste.gr]. In table 2 a quick guide is given on the description of the analyses that can be found in D.4.1.

Table 2: Analyses described in ENERGYWASTE Deliverable 4.1.

Chapter	**Analysis Description**
2.1.1	Proximate Analysis (Moisture, Volatiles, Ash, Fixed Carbon)
2.1.2	Ultimate Analysis (C, H, N, S, O, Cl)
2.1.3	Heating Value Determination
2.2.	Thermogravimetric Analysis

2 Lab Analyses

2.1 Sampling Dates

For the classification and complete analysis of WATTs' RDF, the sampling procedure lasted for more than a year. This occurred in order to identify the seasonality of RDF's properties. And by seasonality, we mean a set of factors such as weather, customs, climate, as well as unforeseen factors such as large scale events (long-term strikes etc.). In the following tables (table 3a and 3b) the sampling period of each lot is presented.

Table 3a: Sampling period of each lot

Week	Sampling Period		Lot	Week	Sampling Period		Lot
	From	To			From	To	
-	30/05/11	03/06/11	RDF 0 (06.2011) June 2011	31	30/01/12	05/02/12	RDF 8 (02.2012) February 2012
-	06/06/11	10/06/11		32	06/02/12	12/02/12	
-	13/06/11	17/06/11		33	13/02/12	19/02/12	
-	20/06/11	24/06/11		34	20/02/12	26/02/12	
-	27/06/11	01/07/11		35	27/02/12	04/03/12	RDF 9 (03.2012) March 2012
1	04/07/11	10/07/11	RDF 1 (07.2011) July 2011	36	05/03/12	11/03/12	
2	11/07/11	17/07/11		37	12/03/12	18/03/12	
3	18/07/11	24/07/11		38	19/03/12	25/03/12	
4	25/07/11	31/07/11		39	26/03/12	01/04/12	
5	01/08/11	07/08/11	RDF 2 (08.2011) August 2011	40	02/04/12	08/04/12	RDF 10 (04.2012) April 2012
6	08/08/11	14/08/11		41	09/04/12	15/04/12	
7	15/08/11	21/08/11		42	16/04/12	22/04/12	
8	22/08/11	28/08/11		43	23/04/12	29/04/12	
9	29/08/11	04/09/11	RDF 3 (09.2011) September 2011	44	30/04/12	06/05/12	RDF 11 (05.2012) May 2012
10	05/09/11	11/09/11		45	07/05/12	13/05/12	
11	12/09/11	18/09/11		46	14/05/12	20/05/12	
12	19/09/11	25/09/11		47	21/05/12	27/05/12	
13	26/09/11	02/10/11		48	28/05/12	03/06/12	
14	03/10/11	09/10/11	RDF 4 (10.2011) October 2011	49	04/06/12	10/06/12	RDF 12 (06.2012) June 2012
15	10/10/11	16/10/11		50	11/06/12	17/06/12	
16	17/10/11	23/10/11		51	18/06/12	24/06/12	
17	24/10/11	30/10/11		52	25/06/12	01/07/12	
18	31/10/11	06/11/11	RDF 5 (11.2011) November 2011	53	02/07/12	08/07/12	RDF 13 (07.2012) July 2012
19	07/11/11	13/11/11		54	09/07/12	15/07/12	
20	14/11/11	20/11/11		55	16/07/12	22/07/12	
21	21/11/11	27/11/11		56	23/07/12	29/07/12	
22	28/11/11	04/12/11	RDF 6 (12.2011) December 2011	57	30/07/12	05/08/12	
23	05/12/11	11/12/11		58	06/08/12	12/08/12	RDF 14 (08.2012) August 2012
24	12/12/11	18/12/11		59	13/08/12	19/08/12	
25	19/12/11	25/12/11		60	20/08/12	26/08/12	
26	26/12/11	01/01/12		61	27/08/12	02/09/12	
27	02/01/12	08/01/12	RDF 7 (01.2012) January 2012	62	03/09/12	09/09/12	RDF 15 (09.2012) September 2012
28	09/01/12	15/01/12		63	10/09/12	16/09/12	
29	16/01/12	22/01/12		64	17/09/12	23/09/12	
30	23/01/12	29/01/12		65	24/09/12	30/09/12	

Table 3b: Sampling period of each lot

Week	Sampling Period		Lot
	From	To	
66	01/10/12	7/10/12	RDF 16 (10.2012) October 2012
67	08/10/12	14/10/12	
68	15/10/12	21/10/12	
69	22/10/12	28/10/12	
70	29/10/12	04/11/12	
71	05/11/12	11/11/12	RDF 17 (11.2012) November 2012
72	12/11/12	18/11/12	
73	19/11/12	25/11/12	
74	26/11/12	02/12/12	
75	03/12/12	09/12/12	RDF 18 (12.2012) December 2012
76	10/12/12	16/12/12	
77	17/12/12	23/12/12	
78	24/12/12	30/12/12	
79	31/12/12	06/01/13	RDF 19 (01.2013) January 2013
80	07/01/13	13/01/13	
81	14/01/13	20/01/13	
82	21/01/13	27/01/13	
83	28/01/13	03/02/13	
84	04/02/13	10/02/13	RDF 20 (02.2013) February 2013
85	11/02/13	17/02/13	
86	18/02/13	24/02/13	
87	25/02/13	03/03/13	

Week	Sampling Period		Lot
	From	To	
88	04/03/13	10/03/13	RDF 21 (03.2013) March 2013
89	11/03/13	1703/13	
90	18/03/13	24/03/13	
91	25/03/13	31/03/13	
92	01/04/13	07/04/13	RDF 22 (04.2013) April 2013
93	08/04/13	14/04/13	
94	15/04/13	21/04/13	
95	22/04/13	28/04/13	
96	29/0413	05/05/13	RDF 23 (05.2013) May 2013
97	06/05/13	12/05/13	
98	13/05/13	19/05/13	
99	20/05/13	26/05/13	
100	27/05/13	02/06/13	
101	03/06/13	09/06/13	RDF 24 (06.2013) June 2013
102	10/06/13	16/06/13	
103	17/06/13	23/06/13	
104	24/06/13	30/06/13	

In each week daily samples were gathered, which underwent the drying procedure in order to be stored until the completion of the lot and/or in case any further future analyses are need. After the completion of the lot increments, a sample was sent for analysis.

From January 2012 to August 2012, WATTs' materials recovery facility produced RDF with changes in the setup of the plant by trying to reduce the moisture content. Therefore every sampling day the plant operated in two different setups: normal and positive sorting setup. In this deliverable the results of the normal setup will be given in order to complete the database needed for the classification of RDF. Rest results will be presented in Deliverable 3.4 "Report on comparison of produced RDF/SRF with technical specifications and suggested modifications". Moreover this database will be used for further reference during the gasification tests.

2.2 RDF Proximate Analysis

Proximate analysis is necessary in order to determine two very important parameters for the gasification process, namely the total moisture and the ash content of the input fuel stream. Proximate analysis was carried out according to standards EN 15402:2011 [4], EN 15403:2011 [3] and EN 15414-3:2011 [2]. In the following table (table 4) the proximate analysis of the sampling lots gathered from the produced WATTs RDF is presented:

Table 4: Proximate Analysis of RDF

	Proximate analysis (%w.t. as received)				**Proximate analysis (%w.t. dry)**		
	Moisture	Ash	Volatiles	Fixed Carbon	Ash	Volatiles	Fixed Carbon
RDF 0 June 2011	17.55	12.30	63.18	6.97	14.92	76.62	8.46
RDF 1 July 2011	24.84	10.99	63.41	0.77	14.62	84.36	1.03
RDF 2 August 2011	26.76	5.91	64.92	2.40	8.07	88.65	3.28
RDF 3 September 2011	23.56	8.66	63.36	4.42	11.33	82.89	5.78
RDF 4 October 2011	39.85	6.03	51.13	3.00	10.02	85.00	4.98
RDF 5 November 2011	31.74	6.46	54.09	7.70	9.47	79.25	11.29
RDF 6 December 2011	29.10	7.24	56.92	6.74	10.22	80.28	9.51
RDF 7 January 2012	20.32	10.32	62.74	6.62	12.95	78.74	8.30
RDF 8 February 2012	23.83	8.38	63.26	4.53	11.00	83.05	5.95
RDF 9 March 2012	31.15	8.94	56.11	3.80	12.98	81.50	5.52
RDF 10 April 2012	27.60	9.45	57.75	5.20	13.06	79.76	7.18
RDF 11 May 2012	23.19	7.61	64.04	5.16	9.91	83.37	6.72
RDF 12 June 2012	19.49	6.80	65.96	7.76	8.44	81.92	9.63
RDF 13 July 2012	32.98	12.14	51.54	3.34	18.12	76.90	4.98
RDF 14 August 2012	27.42	10.94	56.98	4.66	15.07	78.52	6.42
RDF 15 September 2012	27.51	11.45	59.35	1.69	15.80	81.87	2.33
RDF 16 October 2012	25.02	7.19	64.99	2.79	9.59	86.68	3.72
RDF 17 November 2012	22.18	6.71	61.11	10.00	8.62	78.53	12.85

RDF 18 December 2012	23.44	10.08	63.83	2.64	13.17	83.38	3.45
RDF 19 January 2013	24.75	10.94	62.03	2.28	14.53	82.43	3.03
RDF 20 February 2013	24.88	11.34	58.86	4.93	15.09	78.35	6.56
RDF 21 March 2013	19.16	13.74	61.76	5.34	16.99	76.40	6.61
RDF 22 April 2013	21.96	7.77	67.19	3.08	9.96	86.09	3.94
RDF 23 May 2013	21.52	8.32	63.66	6.50	10.60	81.11	8.29
RDF 24 June 2013	19.96	9.24	65.68	5.11	11.55	82.06	6.39
Mean Value	25.19	9.16	60.95	4.70	12.24	81.51	6.25
Standard Deviation	4.94	2.14	4.36	2.15	2.77	3.15	2.76
Median	24.75	8.94	62.74	4.66	11.55	81.87	6.39

Ash content varies from 8.07 to 18.12 % in dry basis, with a mean value of 12.24%. This percentage of ash content is not expected to create technical difficulties during the gasification process. Volatiles content in dry basis ranges from 76.40 to 88.65% with an average of 81.51%. Moisture varies from 17.55 to 39.85% with a mean value of 25.19%. These three parameters play an important role in the thermal utilization schemes of RDF. Increased moisture and ash content in RDF may cause technical difficulties in terms of lowering Net calorific value and creating fouling on the pipes of thermal plants. On the other hand, high volatiles concentration is an indicator of ignitability.

Moisture Variance

As mentioned before, each increment was pre-dried before storing. The moistures measured for a whole year are presented in figure 5. This can depict the seasonality of one RDF parameter that highly affects both the quality of the RDF and the produced syngas.

In figure 5, moisture percentage variance in function with dates is presented in bars, weekly average moisture is presented in red lines and lot average moisture is presented in different color horizontal lines. During the sampling procedure it was found that average moisture rises on winter months while it shows smaller values during hot summer months. Moreover certain “spikes” in moisture content can be clearly distinguished. These two facts may be occurring due to the following main reasons. These reasons can be classified as human and non-human factors:

a) Input waste for treatment in WATTs’ MRF may contain lots of organics due to falsified source separation in blue bins

b) Input waste for treatment during winter months, may absorb rain water in case that the bins are left open from the citizens
c) Input waste for treatment may contain higher amount of paper in contrast with the content in plastic, which can in turn absorb more moisture
d) Comparing wet winter months with hot summer months, ambient air has more moisture, so in that case paper can withhold more water due to capillary phenomena

More specifically the maximum moisture measured in an increment was 48.56% and the minimum was 6.13%. The great variation among each increment shows the strong effect of the aforementioned factors. Moreover the maximum moisture measured in a lot was 39.85% and the minimum 17.55%. Respectively weekly maximum moisture was 39.35% and minimum 11.05%.
On average, moisture content is within limits set by other companies and in only few cases it was measured to be high enough so that it will obstruct RDFs' thermal utilization. Generally in few cases the moisture exceeded 25% which is an acceptable value according to European Recovered Fuel Organization (ERFO) [14].

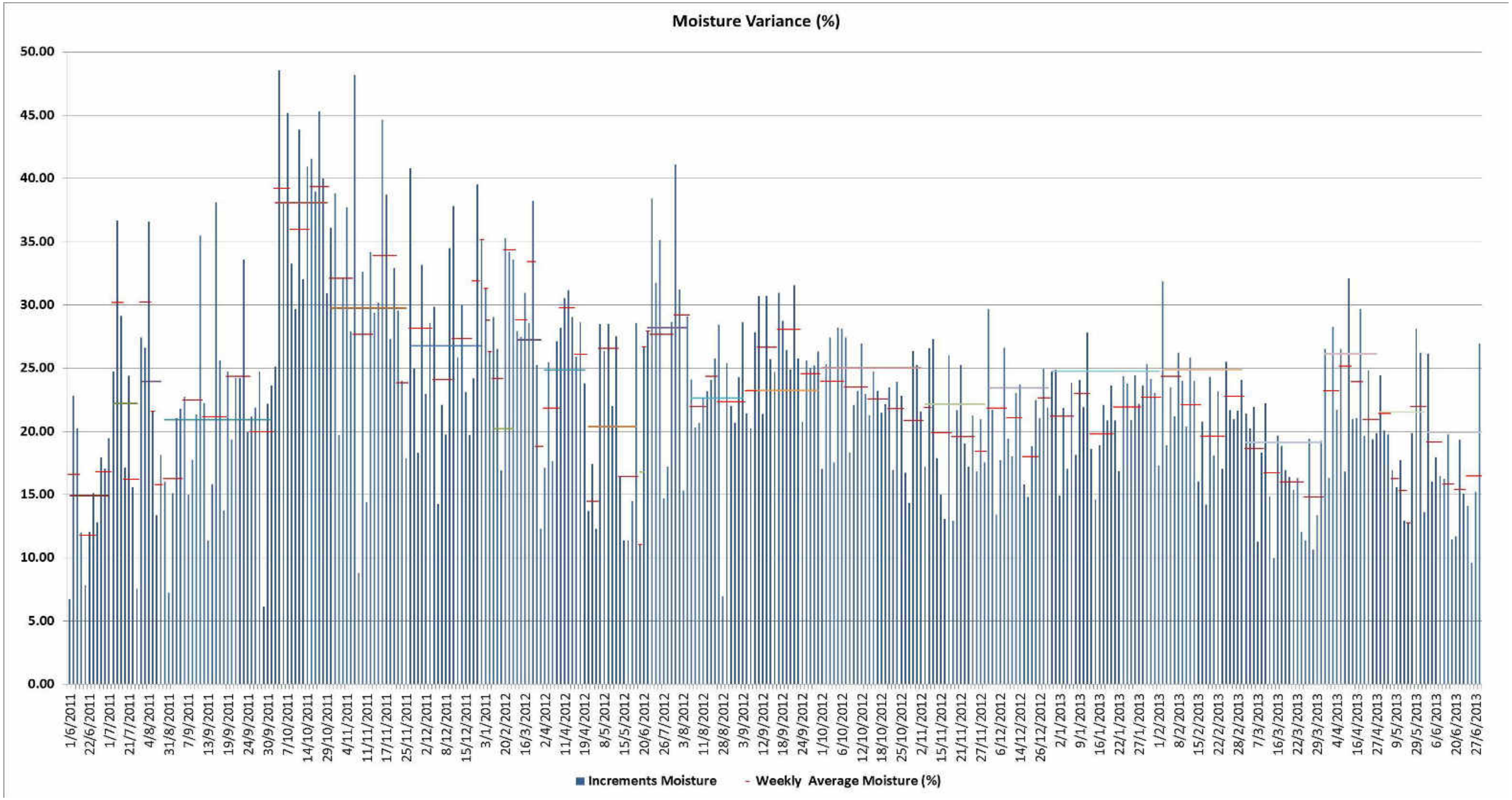

Figure 5: Moisture Variance during sampling period

2.3 RDF Ultimate Analysis

Another important factor for a complete RDF characterization is elementary analysis. Moreover according to standards CEN 343, chlorine is an element obligatory to be measured for the final classification of RDF and at the same time it is a technological indicator which depicts the possible corrosion risk for the RDF thermal utilization plant. The analyses were carried out according to standards EN 15407:2011 [5] and EN 15408:2011 [5]. In tables 5, 6 the ultimate analysis of the gathered lots is given. More specifically chlorine in dry basis is used for the classification of RDF.

Table 5: Ultimate Analysis of RDF

Ultimate Analysis (% as received)								
	C (% wt.)	H (% wt.)	N (% wt.)	S (% wt.)	O (% wt.)	Cl (% wt.)	Ash (% wt.)	Moisture (% wt.)
RDF 0 June 2011	33.66	4.42	0.97	0.24	30.57	0.28	12.30	17.55
RDF 1 July 2011	42.86	6.28	0.90	0.36	13.29	0.48	10.99	24.84
RDF 2 August 2011	34.36	4.56	0.90	0.21	26.99	0.31	5.91	26.76
RDF 3 September 2011	38.90	4.80	0.39	0.13	23.18	0.37	8.66	23.56
RDF 4 October 2011	28.24	3.62	1.14	0.07	20.77	0.29	6.03	39.85
RDF 5 November 2011	34.56	4.53	1.28	0.25	21.03	0.16	6.46	31.74
RDF 6 December 2011	36.72	4.59	0.86	0.05	21.31	0.13	7.24	29.10
RDF 7 January 2012	36.81	4.51	0.25	0.00	27.62	0.17	10.32	20.32
RDF 8 February 2012	42.06	6.95	0.52	0.49	17.00	0.78	8.38	23.83
RDF 9 March 2012	33.97	5.16	0.65	0.25	19.37	0.50	8.94	31.15
RDF 10 April 2012	37.36	6.03	0.60	0.42	18.07	0.46	9.45	27.60
RDF 11 May 2012	44.10	6.91	0.77	0.41	16.45	0.57	7.61	23.19
RDF 12 June 2012	38.90	6.00	0.35	0.24	28.11	0.11	6.80	19.49
RDF 13 July 2012	32.52	4.77	0.62	0.09	16.43	0.45	12.14	32.98
RDF 14 August 2012	34.49	5.14	0.86	0.21	20.51	0.43	10.94	27.42
RDF 15 September 2012	39.77	6.15	1.01	0.64	11.14	0.13	11.04	30.12
RDF 16 October 2012	32.75	5.96	0.90	0.53	27.52	0.12	7.19	25.02
RDF 17 November 2012	34.55	6.67	0.55	0.17	28.70	0.47	6.71	22.18
RDF 18 December 2012	38.32	6.58	1.48	0.41	19.14	0.54	10.08	23.44
RDF 19 January 2013	32.61	6.33	0.49	0.10	24.24	0.55	10.94	24.75
RDF 20 February 2013	34.64	5.27	1.41	0.32	22.04	0.11	11.34	24.88
RDF 21 March 2013	40.74	4.93	0.36	0.44	20.32	0.31	13.74	19.16
RDF 22 April 2013	39.82	5.71	1.38	0.16	19.34	0.11	7.36	26.13
RDF 23 May 2013	32.74	5.18	0.92	0.32	30.86	0.13	8.32	21.52
RDF 24 June 2013	41.14	6.75	0.26	0.35	21.72	0.57	9.24	19.96
Mean Value	36.66	5.51	0.79	0.27	21.83	0.34	9.13	25.46
Standard Deviation	3.83	0.91	0.35	0.16	5.11	0.19	2.13	4.98
Median	36.72	5.27	0.86	0.25	21.03	0.31	8.94	24.84

Table 6: Ultimate Analysis of RDF

Ultimate Analysis (% dry ash free)						
	C (% wt.)	H (% wt.)	N (% wt.)	S (% wt.)	O (% wt.)	Cl (% wt.)
RDF 0 June 2011	47.99	6.30	1.39	0.34	43.58	0.40
RDF 1 July 2011	66.78	9.79	1.41	0.56	20.71	0.75
RDF 2 August 2011	51.03	6.77	1.34	0.32	40.09	0.47
RDF 3 September 2011	57.40	7.08	0.58	0.19	34.20	0.55
RDF 4 October 2011	52.18	6.68	2.10	0.12	38.37	0.54
RDF 5 November 2011	55.92	7.32	2.07	0.40	34.02	0.27
RDF 6 December 2011	57.68	7.21	1.36	0.08	33.47	0.20
RDF 7 January 2012	53.08	6.50	0.36	0.00	39.82	0.24
RDF 8 February 2012	62.05	10.25	0.76	0.72	25.08	1.15
RDF 9 March 2012	56.70	8.62	1.09	0.43	32.33	0.84
RDF 10 April 2012	59.36	9.58	0.95	0.67	28.71	0.72
RDF 11 May 2012	63.73	9.98	1.11	0.59	23.78	0.82
RDF 12 June 2012	52.78	8.14	0.47	0.33	38.14	0.15
RDF 13 July 2012	59.27	8.68	1.12	0.17	29.93	0.82
RDF 14 August 2012	55.95	8.34	1.40	0.34	33.28	0.69
RDF 15 September 2012	67.59	10.45	1.72	1.09	18.93	0.21
RDF 16 October 2012	48.32	8.79	1.32	0.79	40.61	0.18
RDF 17 November 2012	48.59	9.38	0.77	0.24	40.36	0.67
RDF 18 December 2012	57.64	9.90	2.22	0.62	28.80	0.82
RDF 19 January 2013	50.71	9.84	0.75	0.15	37.69	0.85
RDF 20 February 2013	54.31	8.26	2.22	0.49	34.55	0.18
RDF 21 March 2013	60.72	7.35	0.54	0.65	30.29	0.46
RDF 22 April 2013	59.87	8.59	2.07	0.23	29.07	0.17
RDF 23 May 2013	46.67	7.38	1.31	0.46	43.99	0.19
RDF 24 June 2013	58.11	9.53	0.37	0.50	30.68	0.80
Mean Value	56.18	8.43	1.23	0.42	33.22	0.53
Standard Deviation	5.56	1.27	0.57	0.25	6.61	0.29
Median	56.70	8.59	1.31	0.40	33.47	0.54

According to the ultimate analysis of RDF, the average values of carbon and hydrogen measured are closer to the concentration of paper. The respective average values are 56.18% and 8.43%. Therefore, this indicates that the paper quantity in RDF should be significantly higher than plastic percentage. Regarding nitrogen, the measured value is believed to mainly derive from Polyamide (PA). More specifically the measured dry ash free mean value was 1.23%.

Regarding chlorine, the concentration calculated is believed to originate mainly from PVC. The average value measured was 0.53% dry-ash free with a standard deviation of 0.29%. The maximum value for chlorine content measured in dry-ash free basis is 1.15% and the minimum value was 0.15%.

2.4 RDF Heating Value Analysis

Heating value analysis is essential for the classification of the fuel. It is the factor that shows the thermal quality of the produced fuel. The analyses were made according to the instructions of standard EN 15400:2011 [7]. In the following table (table 7) the results of the analyses for each lot are given.

Table 7: Heating Value of RDF

Heating Value			
	High Heating Value (kJ/kg)	Lower Heating Value (kJ/kg) (dry)	Lower Heating Value (kJ/kg) (as reveived)
RDF 0 June 2011	19,150.17	17,981.00	14,396.58
RDF 1 July 2011	24,462.17	22,638.63	16,409.16
RDF 2 August 2011	19,281.75	17,925.00	12,473.60
RDF 3 September 2011	20,391.35	19,021.51	13,964.57
RDF 4 October 2011	21,493.84	20,182.89	11,166.75
RDF 5 November 2011	23,986.45	22,540.27	14,609.63
RDF 6 December 2011	19,744.30	18,333.01	12,286.80
RDF 7 January 2012	17,129.30	15,894.69	12,168.24
RDF 8 February 2012	22,330.01	20,340.68	14,910.74
RDF 9 March 2012	18,493.28	16,857.32	10,844.96
RDF 10 April 2012	20,330.06	18,513.05	12,728.37
RDF 11 May 2012	22,731.67	20,770.70	15,388.01
RDF 12 June 2012	16,643.95	15,018.90	11,615.93
RDF 13 July 2012	16,459.86	14,908.97	9,185.99
RDF 14 August 2012	18,982.81	17,438.46	11,985.96
RDF 15 September 2012	22,444.57	20,525.04	13,606.41
RDF 16 October 2012	23,810.06	22,075.94	15,939.88
RDF 17 November 2012	20,766.28	18,896.92	14,163.73
RDF 18 December 2012	18,051.45	16,175.55	11,810.85
RDF 19 January 2013	21,258.15	19,423.70	14,011.00
RDF 20 February 2013	24,019.38	22,490.31	16,287.80
RDF 21 March 2013	23,975.45	22,644.87	17,836.87
RDF 22 April 2013	17,180.38	15,494.26	10,806.34
RDF 23 May 2013	21,955.16	20,515.52	15,574.81
RDF 24 June 2013	20,054.92	18,216.10	14,091.64
Mean Value	20,605.07	18,992.93	13,530.58
Standard Deviation	2,440.28	2,407.17	2,060.06
Median	20,391.35	18,896.92	13,964.57

As observed in the table above (table 7), the calculated high heating value of RDF on dry basis is 20.61 MJ/kg and the lower heating value on dry basis is 18.99 MJ/kg. However the as received lower heating value is calculated to be 13.53 MJ/kg. The significant difference observed is due to the moisture content present in the produced RDF. The standard deviation measured is 2.06 MJ/kg as received which is about $1/7^{th}$ of the mean value of lower heating value.

2.5 Heavy Metals Analysis

Heavy metals analysis and especially Mercury is crucial for the characterization of RDF as an environmental parameter and is one of the factors that indicate RDFs' final classification. According to EN 15359:2011 [13] a set of 12 heavy metals is obligatory to be analyzed. More specifically the content of each heavy metal separately as well as the sum thereof as mentioned in Waste Incineration Directive shall be specified on dry basis according to EN 15411:2011 [8]. The heavy metals are antimony, arsenic, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, thallium and vanadium. Cadmium, mercury and thallium are not included in the sum.

Table 8: Heavy Metals Analysis of RDF

Heavy metals analysis (mg/kg as received)													
	Antimony (Sb)	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Cobalt (Co)	Copper (Cu)	Lead (Pb)	Manganese (Mn)	Mercury (Hg)	Nickel (Ni)	Thallium (Tl)	Vanadium (V)	SUM
RDF 0 June 2011	<15 ppb	n.a.	4.35	10.44	1.74	20.01	13.92	53.08	1.37	9.57	<5 ppb	0.00	110.46
RDF 1 July 2011	<15 ppb	n.a.	4.91	22.10	0.00	34.37	9.82	36.01	0.09	26.19	<5 ppb	0.00	130.07
RDF 2 August 2011	<15 ppb	n.a.	4.28	16.79	12.08	125.51	235.13	43.06	0.26	20.20	<5 ppb	0.00	454.33
RDF 3 September 2011	<15 ppb	6.92	1.62	44.97	9.05	8.16	5.38	36.20	0.15	12.27	<5 ppb	4.98	128.72
RDF 4 October 2011	<15 ppb	6.81	0.87	39.20	0.89	8.10	7.39	18.75	0.48	7.32	<5 ppb	4.48	93.64
RDF 5 November 2011	<15 ppb	9.50	0.22	18.07	1.21	17.52	6.56	27.79	0.81	27.66	<5 ppb	4.29	113.36
RDF 6 December 2011	<15 ppb	6.75	0.25	24.81	0.98	17.64	6.29	18.24	0.32	84.45	<5 ppb	4.74	164.65
RDF 7 January 2012	<15 ppb	27.09	2.25	0.00	4.09	22.93	11.59	24.68	0.25	56.09	<5 ppb	4.93	152.23
RDF 8 February 2012	<15 ppb	0.00	0.61	13.24	1.72	20.02	6.07	26.16	1.73	10.74	<5 ppb	5.36	84.11
RDF 9 March 2012	<15 ppb	11.24	0.28	28.11	1.40	12.49	6.97	22.55	0.08	17.00	<5 ppb	4.97	105.48
RDF 10 April 2012	<15 ppb	10.19	1.27	21.52	3.17	18.18	6.77	24.06	0.11	17.89	<5 ppb	4.64	107.19

RDF 11 May 2012	<15 ppb	23.03	0.91	12.43	0.87	27.15	11.21	28.49	0.34	5.34	<5 ppb	4.96	114.28
RDF 12 June 2012	<15 ppb	27.08	1.24	30.40	0.64	29.44	8.99	42.51	0.18	5.27	<5 ppb	1.60	146.76
RDF 13 July 2012	<15 ppb	11.28	0.78	127.01	1.32	119.12	10.25	99.40	0.11	21.37	<5 ppb	1.57	392.05
RDF 14 August 2012	<15 ppb	22.19	1.23	109.02	3.82	102.69	8.97	85.06	0.54	23.43	<5 ppb	1.70	357.64
RDF 15 September 2012	<15 ppb	14.31	1.09	118.80	1.20	39.01	12.19	26.80	0.15	9.97	<5 ppb	1.25	224.27
RDF 16 October 2012	<15 ppb	15.31	3.23	58.44	3.14	66.47	6.23	70.93	0.19	65.54	<5 ppb	5.46	292.33
RDF 17 November 2012	<15 ppb	5.56	2.42	5.25	0.43	9.05	12.17	38.40	0.32	32.56	<5 ppb	3.56	107.78
RDF 18 December 2012	<15 ppb	3.44	2.07	10.34	1.78	49.38	9.97	43.25	0.30	63.90	<5 ppb	5.06	187.93
RDF 19 January 2013	<15 ppb	22.10	1.31	73.14	0.09	56.09	13.19	25.70	0.33	64.02	<5 ppb	4.26	259.40
RDF 20 February 2013	<15 ppb	22.81	1.92	30.75	1.91	57.70	10.86	59.35	1.02	51.84	<5 ppb	0.74	236.77
RDF 21 March 2013	<15 ppb	0.36	2.64	75.22	5.01	55.80	10.07	38.70	0.38	61.21	<5 ppb	1.66	248.86
RDF 22 April 2013	<15 ppb	0.23	1.85	17.32	0.30	49.42	8.01	72.06	0.19	72.06	<5 ppb	2.67	222.85
RDF 23 May 2013	<15 ppb	25.26	0.87	24.71	0.15	40.13	10.55	55.03	0.67	18.01	<5 ppb	2.45	177.10
RDF 24 June 2013	<15 ppb	0.53	2.32	38.55	3.46	51.60	10.09	21.01	0.47	11.87	<5 ppb	5.01	142.94
Mean Value	n.a.	10.98	1.79	38.82	2.42	42.32	18.35	41.49	0.43	31.83	n.a.	3.21	190.21
Standard Deviation	n.a.	9.37	1.26	34.78	2.78	32.14	44.31	21.21	0.40	24.18	n.a.	1.88	96.92
Median	n.a.	9.50	1.31	24.81	1.40	34.37	9.97	36.20	0.32	21.37	n.a.	4.26	152.23
80th percentile	n.a.	22.69	2.59	70.20	3.74	57.38	12.05	58.49	0.64	63.36	n.a.	4.98	257.29

*n.a.: not available

Table 9: Heavy Metals Analysis of RDF

Heavy metals analysis (mg/kg dry)													
	Antimony (Sb)	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Cobalt (Co)	Copper (Cu)	Lead (Pb)	Manganese (Mn)	Mercury (Hg)	Nickel (Ni)	Thallium (Tl)	Vanadium (V)	SUM

RDF 0 June 2011	<15 ppb	n.a.	5.16	12.38	2.06	23.73	16.51	62.95	1.62	11.35	<5 ppb	0.00	130.00
RDF 1 July 2011	<15 ppb	n.a.	6.21	27.95	0.00	43.48	12.42	45.55	0.11	33.13	<5 ppb	0.00	164.53
RDF 2 August 2011	<15 ppb	n.a.	5.51	21.61	15.55	161.55	302.64	55.43	0.34	26.00	<5 ppb	0.00	584.78
RDF 3 September 2011	<15 ppb	8.64	2.03	56.25	11.31	10.20	6.72	45.28	0.18	15.33	<5 ppb	6.23	160.96
RDF 4 October 2011	<15 ppb	9.67	1.23	55.70	1.26	11.51	10.49	26.65	0.68	10.39	<5 ppb	6.37	133.04
RDF 5 Novembe r 2011	<15 ppb	12.68	0.30	24.12	1.62	23.40	8.75	37.11	1.09	36.90	<5 ppb	5.73	151.31
RDF 6 December 2011	<15 ppb	8.82	0.33	32.49	1.28	23.10	8.23	23.89	0.42	110.47	<5 ppb	6.20	215.48
RDF 7 January 2012	<15 ppb	32.85	2.73	0.00	4.96	27.82	14.05	29.95	0.31	68.01	<5 ppb	5.99	184.63
RDF 8 February 2012	<15 ppb	0.00	0.77	16.67	2.16	25.21	7.63	32.94	2.18	13.50	<5 ppb	6.75	105.87
RDF 9 March 2012	<15 ppb	15.07	0.37	37.80	1.88	16.80	9.34	30.32	0.11	22.79	<5 ppb	6.68	141.68
RDF 10 April 2012	<15 ppb	13.19	1.65	27.88	4.10	23.56	8.76	31.18	0.15	23.15	<5 ppb	6.01	138.84
RDF 11 May 2012	<15 ppb	28.70	1.14	15.51	1.08	33.88	13.97	35.55	0.43	6.66	<5 ppb	6.18	142.52
RDF 12 June 2012	<15 ppb	32.65	1.49	36.69	0.77	35.50	10.84	51.26	0.21	6.35	<5 ppb	1.93	176.99
RDF 13 July 2012	<15 ppb	15.43	1.07	174.41	1.81	162.86	14.01	135.90	0.15	29.21	<5 ppb	2.15	536.77
RDF 14 August 2012	<15 ppb	28.89	1.60	142.50	4.97	133.72	11.68	110.76	0.70	30.51	<5 ppb	2.22	466.25
RDF 15 Septembe r 2012	<15 ppb	19.03	1.45	158.52	1.59	52.05	16.22	35.76	0.20	13.26	<5 ppb	1.66	299.09
RDF 16 October 2012	<15 ppb	19.36	4.08	73.95	3.97	84.11	7.88	89.76	0.24	82.85	<5 ppb	6.90	369.78
RDF 17 November 2012	<15 ppb	6.86	2.98	6.48	0.53	11.18	15.01	47.43	0.40	40.17	<5 ppb	4.39	133.05
RDF 18 December 2012	<15 ppb	4.30	2.58	12.92	2.22	61.70	12.45	54.05	0.37	79.76	<5 ppb	6.32	234.72

RDF 19 January 2013	<15 ppb	27.96	1.66	92.67	0.12	71.07	16.69	32.56	0.41	80.98	<5 ppb	5.39	328.43
RDF 20 February 2013	<15 ppb	28.85	2.43	38.94	2.42	73.06	13.74	75.16	1.29	65.56	<5 ppb	0.94	299.67
RDF 21 March 2013	<15 ppb	0.43	3.17	90.52	6.02	67.15	12.11	46.57	0.45	73.58	<5 ppb	2.00	299.38
RDF 22 April 2013	<15 ppb	0.29	2.37	22.19	0.39	63.32	10.25	92.34	0.24	92.20	<5 ppb	3.42	285.40
RDF 23 May 2013	<15 ppb	30.99	1.07	30.34	0.18	49.29	12.95	67.58	0.82	22.10	<5 ppb	3.01	217.45
RDF 24 June 2013	<15 ppb	0.64	2.81	46.79	4.19	62.63	12.23	25.51	0.57	14.39	<5 ppb	6.07	173.45
Mean Value	n.a.	15.70	2.25	50.21	3.06	54.08	23.42	52.86	0.55	40.34	n.a.	4.10	242.96
Standard Deviation	n.a.	11.30	1.56	46.38	3.51	42.33	57.06	28.00	0.50	30.55	n.a.	2.41	128.06
Median	n.a.	14.13	1.66	32.49	1.88	43.48	12.23	45.55	0.40	29.21	n.a.	5.39	184.63
80th percentile	n.a.	28.87	3.13	87.20	4.81	72.66	14.82	73.64	0.80	78.52	n.a.	6.30	322.68

*n.a.: not available

In the analyses as presented in the tables above, high standard deviation values are observed which are comparable with the mean values of the concentration of each heavy metal. It must be noted that the procedure for the analysis of heavy metals in Refuse Derived Fuels is an extensive procedure with many consecutive steps. It has been observed that the sample preparation procedure plays an important role in the results' sensitivity. Moreover equally important for the outcome of the results is the principle upon which the measuring instruments work. The non-detected values are below the detection limit of the measurement principle. The analyses for these specific samples will be rerun, with a technique with higher resolution and will be resubmitted as an update to the Deliverable.

The concentration of Mercury (Hg) which is an environmental factor for all alternative fuels is given in figure 6. As observed, three out of fifteen values are significantly higher than the rest and the mean value, therefore are rejected from the statistical analysis. The reasons for measuring high concentrations in these samples may vary. The most possible is the non-removal as a part of source separation system, waste that may contain high concentrations in mercury. Such types of waste are batteries, thermometers, thermostats, lighting and electrical applications, pharmaceuticals and pesticides, high intensity headlights and ABS braking systems etc.

Comparing to other Refuse Derived Fuels produced in Europe, the values for mercury are at an acceptable level.

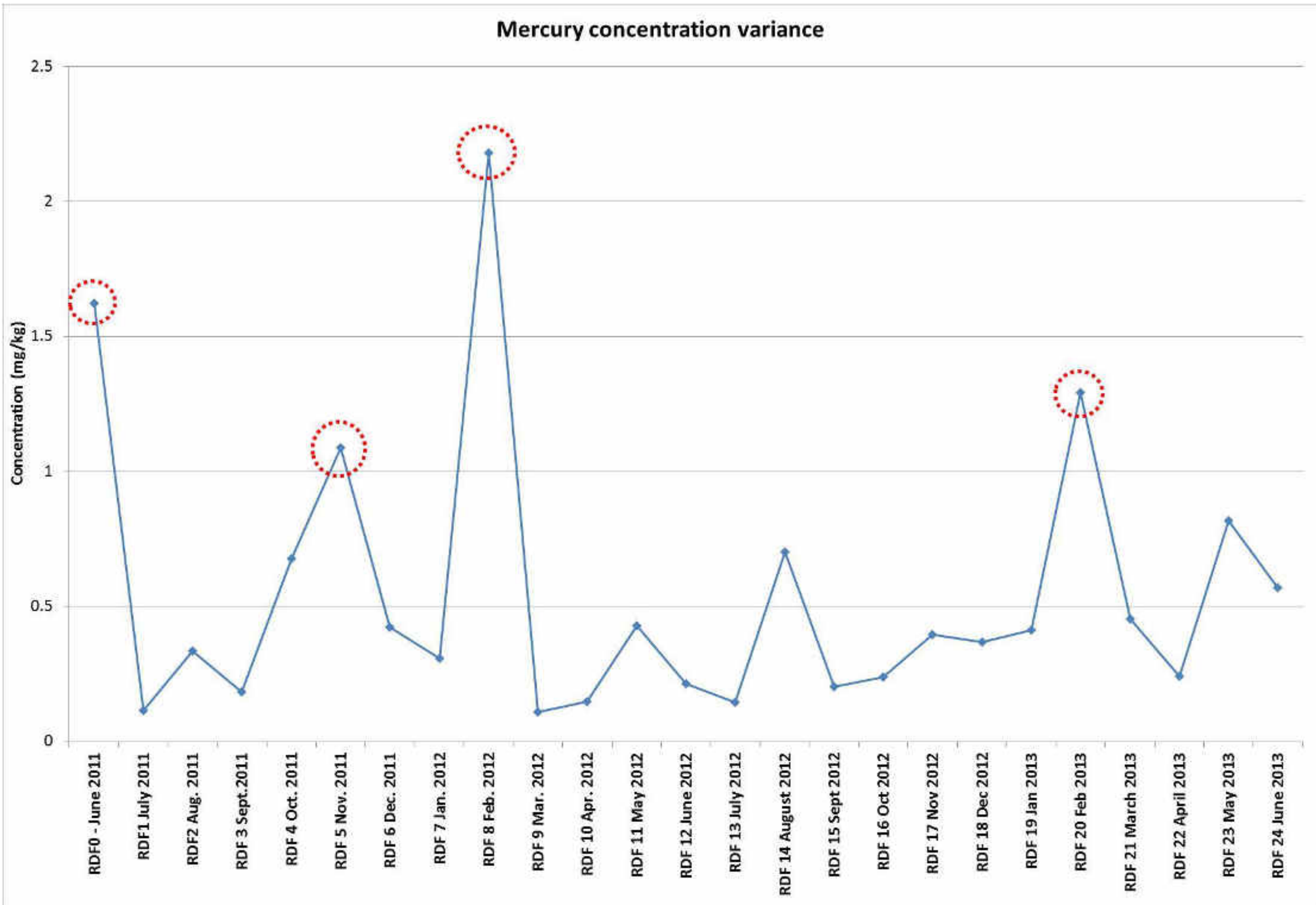

Figure 6: Mercury concentration variance

2.6 Particle Size Distribution (PSD)

A necessary parameter to be identified for the gasification process is the particle size distribution. This parameter indicates the diameter of the particle that enters the fluidized bed reactor and influences the time of the procedure. In order to estimate the size of the particles that would be used as a fuel for gasification. A particle size distribution analysis was made to the RDF as received from the shredder of WATTs' MRF according to EN 15415-1:2011. The analysis was made for two lots April 2012 and May 2012. Five samples of each lot were analyzed and the mean value of these analyses is presented. The data presented below have been analyzed according to linear-linear coordinate system analysis.

Data for April 2012 – Normal Setup

The following table (table 10) presents the mean values of the mass percentage held from a sieve of a certain diameter and the cumulative mass percentage passing from a sieve. Figures 7 and 8 present the respective diagrams.

Table 10: Mean values of particle size distribution analysis

Sieve diameter (mm)	Mass percentage held larger than sieve diameter (%)	Cumulative mass percentage passing from sieve (%)
50	0	100 %
25	4.72 %	95.28 %
12.5	44.60 %	50.67 %
6.3	33.01 %	17.67 %
3.15	12.43 %	5.24 %
Residue	5.24 %	0

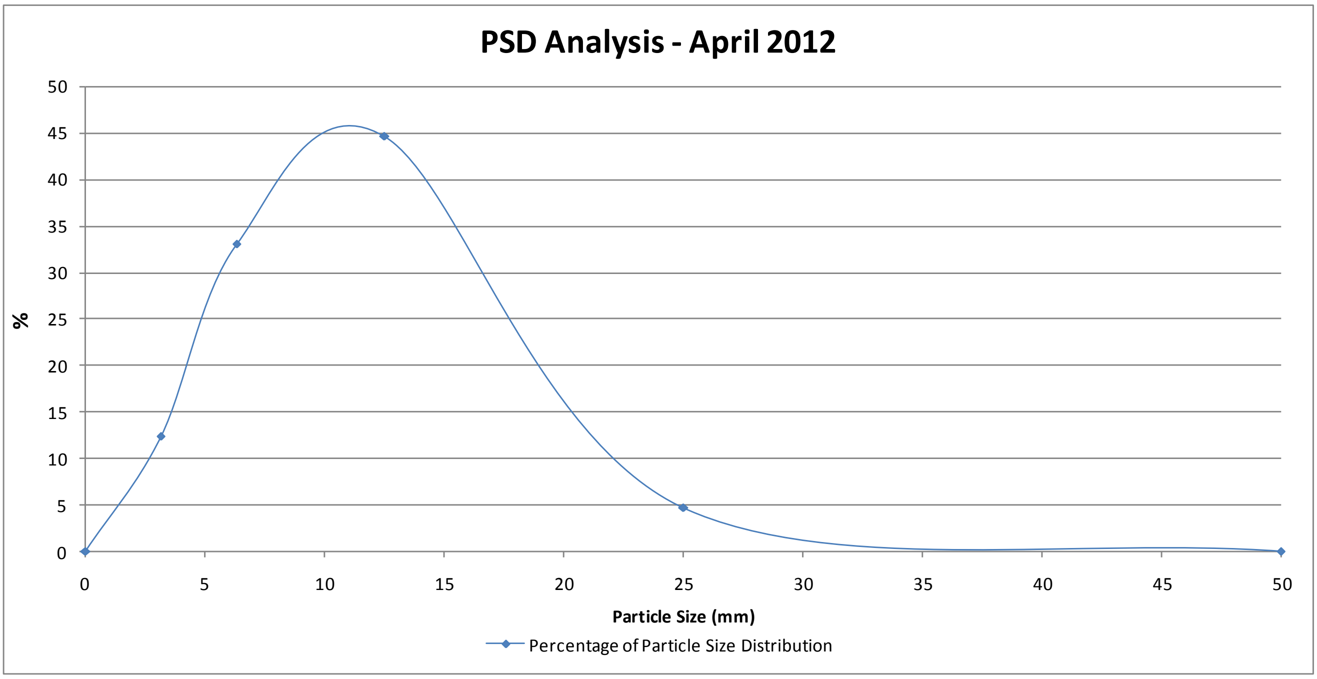

Figure 7: Particle Size Distribution Analysis – April 2012

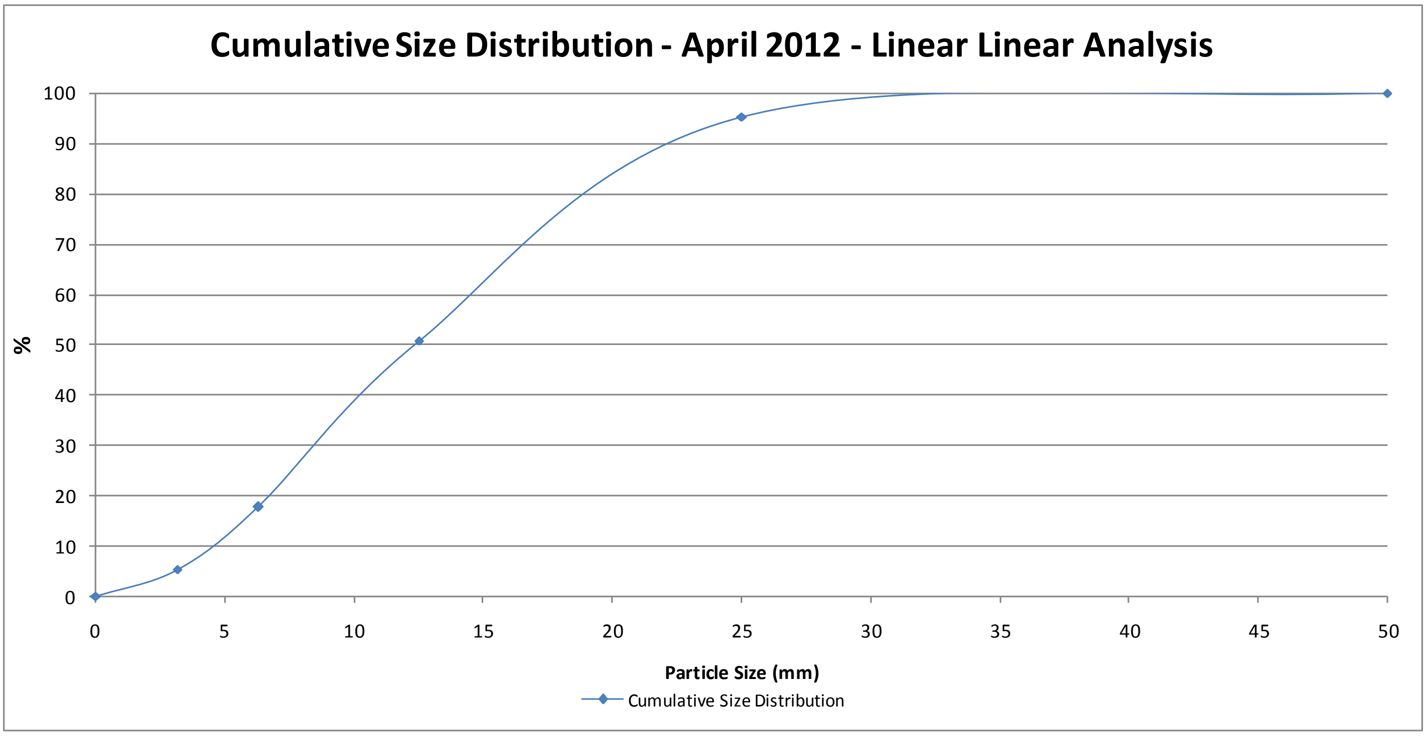

Figure 8: Cumulative Size Distribution – April 2012

As seen in figures 7 and 8. 90% of the particles are with a diameter below ≈22 mm. while the majority of the particles are of about 10-12mm.

<u>Data for May 2012 – Normal Setup</u>

The following table (table 11) presents the mean values of the mass percentage held from a sieve of a certain diameter and the cumulative mass percentage passing from a sieve. Figures 9 and 10 present the respective diagrams.

Table 11: Mean values of particle size distribution analysis

Tray diameter (mm)	Mass percentage held larger than tray diameter (%)	Cumulative mass percentage passing from tray (%)
50	0	100%
25	8.36%	91.64%
12.5	44.66%	46.99%
6.3	34.75%	12.24%
3.15	8.53%	3.71%
Residue	3.71%	0

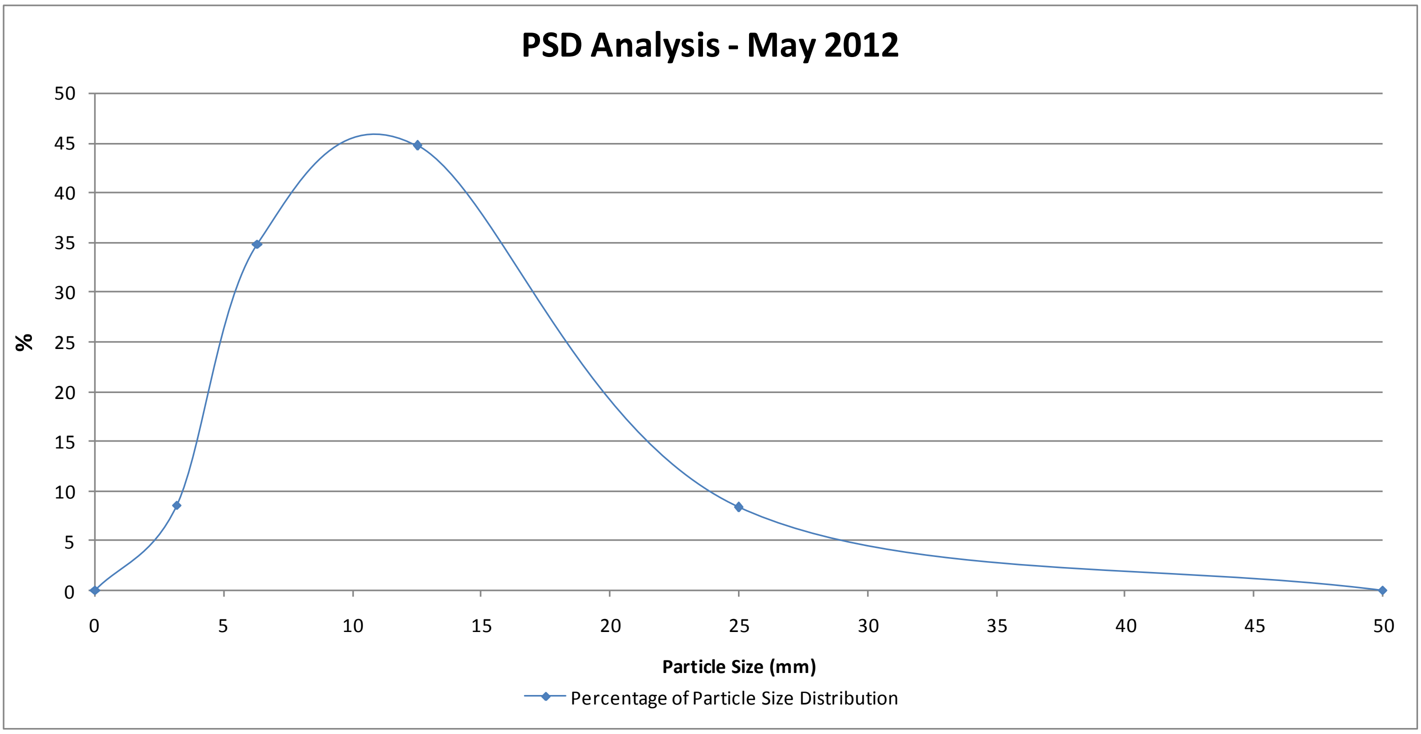

Figure 9: Particle Size Distribution Analysis – May 2012

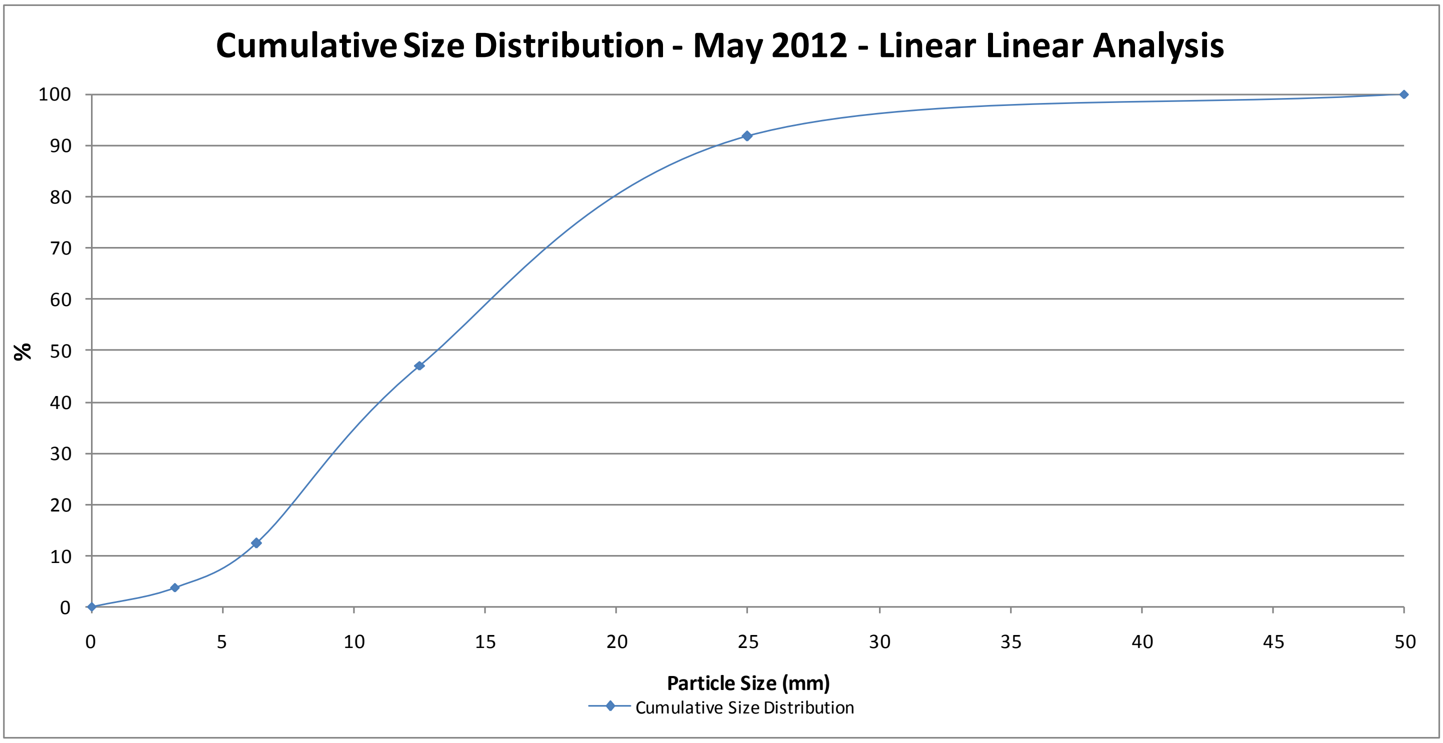

Figure 10: Cumulative Size Distribution – May 2012

As shown in figures 9 and 10, 90% of the particles are with a diameter below ≈24 mm. while the majority of the particles are of about 11-12mm.

Concluding, both of the normal setup samples have particle sizes with d_{90} below 24mm. This kind of size is not expected to cause any operational problems during the gasification process.

2.7 Manual sorting

The produced RDF in WATT although it is mainly consisted of plastic and paper. it contains other material such as wood, leather, textiles etc. These “contaminants” cannot be fully separated from the produced RDF during the sorting procedure due to mechanical limitations.

For the needs of LIFE ENERGY WASTE and for the best possible characterization of the produced RDF two campaigns of manual sorting have taken place for the determination of RDF composition. In the figure bellow (figure 11) the types of materials RDF was divided into are presented.

Figure 11: Materials chosen for RDF breakdown

In table 12 the percentages of RDF composition is presented.

Table 12: Manual sorting RDF composition

	Manual Sorting Campaign #1	Manual Sorting Campaign #2	Average
Plastic	30.45%	34.72%	32.59%
Paper	30.77%	22.22%	26.50%
Organics	9.61%	14.35%	11.98%
Textiles	6.41%	6.48%	6.45%
Wood-leather	5.13%	3.70%	4.42%
Glass-metals	9.94%	7.41%	8.67%
Fines	7.69%	11.11%	9.40%
Total	**100.00%**	**100.00%**	

2.8 Biogenic Content

For the biogenic content determination three samples were chosen; specifically these of March, April and May 2012. The reasoning behind this choice was the ash content, which mainly derives from paper and with its turn paper represents the highest percentage of the biogenic content in RDF. Therefore, in order to have a typical biogenic content value three samples were chosen with ash content close to the mean value. The analyses were carried out according to EN 15440:2011 – Determination of biomass content using the selective dissolution method. The results are given in the following table (table 13).

Table 13: WATTs' RDF Biogenic Content

Biogenic Content			
	Biomass content (%)	Non-biomass content (%)	Ash content (%)
RDF 9 – Mar. 2012	51.12	34.21	14.67
RDF 10 – April 2012	56.10	28.71	15.18
RDF 11 – May 2012	47.89	39.86	12.25
Average	51.70	34.26	14.00
Standard Deviation	4.14	5.57	1.57

The average value for biogenic content in the produced RDF is 51.70% with a standard deviation of 4.14%. The low value of standard deviation comparing to the average value indicates that the biogenic content present in the RDF does not have great variations and that the average value measured can be indicative for all samples.

2.9 Analyses Overview

The following figure (figure 12) presents an overview of the proximate and ultimate analysis, as well as the heating value analysis.

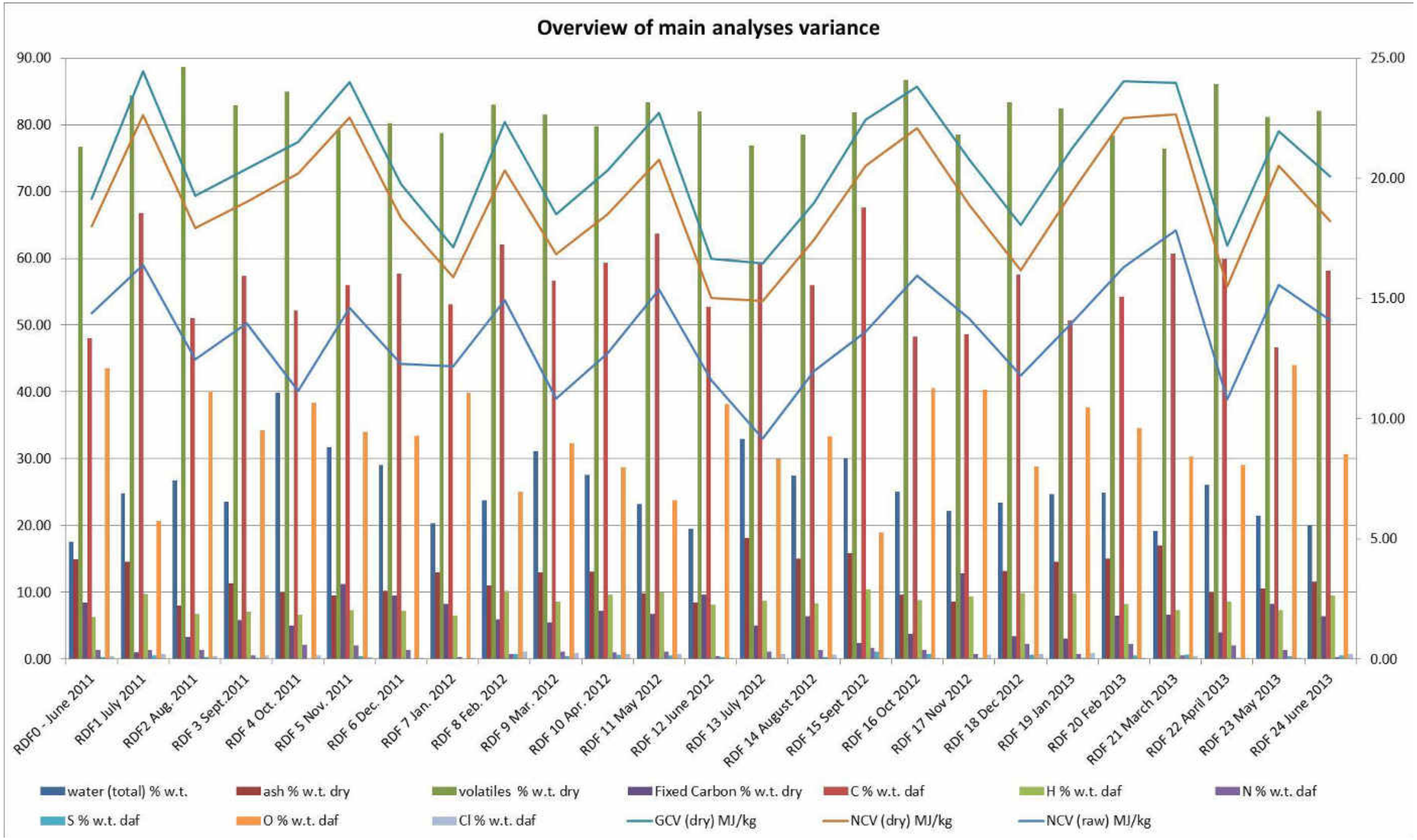

Figure 12: Overview of analyses variance

3 Conclusions

- Regarding ash content, it is found that it varies from 8.07 to 18.12 % in dry basis with an average of 12.01%. This percentage is assumed that will not create significant technical difficulties during the gasification process.
- During the sampling procedure it was found that average moisture rises on winter months while it shows smaller values during hot summer months. This may occur due to the following main reasons which can be classified as human and non-human factors:
    - Input waste for treatment in WATTs' MRF may contain lots of organics due to falsified source separation in blue bins
    - Input waste for treatment during winter months, may absorb rain water in case that the bins are left open from the citizens
    - Input waste for treatment may contain higher amount of paper in contrast with the content in plastic, which can in turn absorb more moisture
    - Comparing wet winter months with hot summer months, ambient air has more moisture, so in that case paper can withhold more water due to capillary phenomena
- On average, moisture content is within limits set by other companies and in only few cases it was measured to be high enough so that it will obstruct RDFs' thermal utilization.
- According to the ultimate analysis of RDF, the average values of carbon and hydrogen measured are closer to the ones of paper. This indicates that the paper quantity in RDF should be significantly higher than plastic percentage. Regarding nitrogen, the measured value is believed to mainly derive from Polyamide (PA) and for chlorine, the concentration calculated is believed to originate mainly from PVC.
- Regarding the heating value content, the impact of moisture is clearly indicated by the reduction in the Net Calorific Value calculated in dry basis and as received. The average net calorific value on dry basis is 18.99 MJ/kg and on as received it is 13.53 MJ/kg.
- Regarding heavy metals concentration; high standard deviation values are observed which are comparable with the mean values of the concentration of each heavy metal. The procedure for the analysis of heavy metals in RDF is an extensive procedure with many consecutive steps where the sample preparation procedure plays an important role in the results' sensitivity..
- The concentration of Mercury (Hg) which is an environmental factor for all alternative fuels is 0.55 mg/kg on dry basis. Three out of fifteen values are significantly higher than the rest. The reasons for measuring high concentrations

in these samples may vary. The most possible is the non-removal as a part of source separation system, waste that may contain high concentrations in mercury. Such types of waste are batteries, thermometers, thermostats, lighting and electrical applications, pharmaceuticals and pesticides, high intensity headlights and ABS braking systems etc.

- Comparing to other Refuse Derived Fuels produced in Europe, the values for mercury are at an acceptable level.

4 References

[1] European Committee for Standardization – CEN/TC 343

[2] EN 15414-1:2010: Solid recovered fuels - Determination of moisture content using the oven dry method - Part 1: Determination of total moisture by a reference method

[3] EN 15403:2011: Solid recovered fuels - Determination of ash content

[4] EN 15402:2011: Solid recovered fuels - Determination of the content of volatile matter

[5] EN 15407-8:2011: Solid recovered fuels - Methods for the determination of carbon (C), hydrogen (H) and nitrogen (N) content

[6] EN 15408:2011: Solid recovered fuels - Methods for the determination of sulphur (S), chlorine (Cl), fluorine (F) and bromine (Br) content

[7] EN 15400:2011: Solid recovered fuels - Determination of calorific value

[8] EN 15411:2011: Solid recovered fuels - Methods for the determination of the content of trace elements (As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Mn, Ni, Pb, Sb, Se, Tl, V and Zn)

[9] EN 15415:2011: Solid recovered fuels - Determination of particle size distribution - Part 1: Screen method for small dimension particles

[10] EN 15440:2011: Solid recovered fuels - Methods for the determination of biomass content

[11] EN 15442:2011: Solid recovered fuels - Methods for sampling

[12] EN 15443:2011: Solid recovered fuels - Methods for the preparation of the laboratory sample

[13] EN 15359:2011: Solid recovered fuels - Specifications and classes

[14] European Recovered Fuel Organization – Classification of Solid Recovered Fuels – February 2005