Utilizing waste heat from metal industry for drying of organic waste

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| Norwegian University | Department of Energy |
| of Science and Technology | and Process Engineering |

EPT-M-2013-

MASTER THESIS

for

student Saša Dobrić

Fall 2013

Utilizing waste heat from metal industry for drying of organic waste
Utnyttelse av overskuddsvarme fra metallindustri til tørking av organisk avfall

Background and objective

In the modern society the organic waste is not allowed to dump on fillings any more. It has to be taken into processing facilities to be handled. This is done in different ways. One option is to deliver the organic waste to "Bio gas factories/reactors". The efficiency of these processes is related to the fat content and decomposition of proteins in the product. Another option is to deliver the organic waste to a burning facility connected to a district heating systems to utilize the energy in the waste. One major component in the organic waste is water. The water content can be up to 70% of the total mass. This waste will not burn by itself. It needs to be heated to evaporate the water until the water content is down to 20-30% of the total mass. Normally this heat is generated by burning oil. Waste heat from the burning process can be used to evaporate some of the water of the incoming waste products. If we look into the chain of food: we use energy to seed, harvest, process, storage and transport of the food. The food has a variable energy and nutritial content as the end waste product. In the line from seeding, harvesting and into the single homes, approx. 50 to 60% of the food become waste. At the end of the line we need energy to burn the waste. In all aspects were we need energy, it is connected to a CO_2 footprint. Handling of organic waste is also a question of transport. A lot of the organic waste is transported over large distances, even between countries like Norway and Sweden.

This work will focus on the available waste energy in the metal industry, to be utilized to dewater the organic waste, to stabilize it and stored it until it can be burned in the district heating systems. Energy consumption and CO_2 foot print of the system today and system in next generation burning the dried waste.

II

The following tasks are to be considered:

1. Literature review of organic waste handling and processing possibilities
2. Investigation of the transport paths and economy in the handling and processing, and CO_2 foot print of the different steps
3. Investigation of the available low temperature (50-250°C) waste energy sources in Norway and/or in Scandinavia that can be used for drying of the waste
4. Suggest solutions for energy and environmentally friendly solutions for organic waste handling
5. Technical solutions for the handling, milling, drying and storage of the waste – available technologies
6. Write a scientific paper of the results in the thesis.
7. Make proposal for future task not solved in this thesis

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Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

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The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. The final report in Word and PDF format, sientific paper and all other material and documents should be given to the academic supervisor in digital format on a DVD/CD-rom at the time of submission in DAIM.

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☐ Field work

Department of Energy and Process Engineering, September 9th 2013

_____   _____
Prof. Olav Bolland   Prof. Trygve M. Eikevik
Department Head   Academic Supervisor

Research Advisors (co-advisors):
Prof. Aleksandar Jovović, University of Belgrade.

IV

Preface

This work represents my master thesis. It was realized in the autumn 2013 at Norwegian University of Science and Technology, Department of Energy and Process Engineering. Thanks to cooperation between NTNU and my home University of Belgrade, master thesis will be representative at both Universities.

Considering my interests in the field of renewable energy sources and utilization waste energy, this was an outstanding opportunity for me to express myself and to learn something new and interesting in this area. Working on my master thesis increased my desire to improve knowledge and skills in this specific field.

I would like to thank my research advisor Professor Trygve M. Eikevik for fruitful collaboration and all the help during the development of my work, as well as my supervisor at the home University Professor Aleksandar Jovovic for his support and help in creating this thesis. Furthermore, I would like to thank Professor Vojislav Novakovic for giving me the unique opportunity to participate in this great program. Special thank goes to Mr Alf Tore Haug, an employee in ELKEM company, for helping me collect all data necessary for my master thesis and to my friend Kristina Milosevic for lecturing this document.

Without these people, this thesis would not have been possible.

Saša Dobrić
Belgrade, April of 2014

Abstract

Growing generation of organic waste is a real problem all over the world. This is specifically expressed in the developed countries because the amounts of the waste are larger. Therefore, it implies problem connected with organic waste disposal. In the modern society it is prohibited to dump the waste on landfills. It was necessary to find the solution how to deal with this situation.

One of the options is delivering of the organic waste to the burning facilities. In this way it is possible to utilize energy from the waste for district heating systems or making electricity. On the other hand, the problem of waste disposal would be solved. However, this is not so easy. Water amount inside the food waste is very high. This means that energy content of food waste is pretty low which requires a certain amount of plastic and paper with higher energy content to burn it out. Drying of the food waste would increase its energy content and reduce necessary amount of plastic and paper. Instead of it these components can be used for recycling.

The idea is that drying process could be generated with utilizing waste energy from metal industry. The amounts of the waste energy in this industry are very large and possibilities of using them for drying are great. This paper focuses on checking available waste energy sources in silicon and aluminum production plants because Norway has well-developed this particular field of metal industry. Also, the issues of the amounts of the food waste in Norway, technical solutions for drying of the waste, as well as CO_2 foot print calculation are included in this paper.

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1. INTRODUCTION

1.1. Background

In the modern society the organic waste has to be treated in the right way. This means that treatment must achieve minimum health risk and environmental protection. It can be done in different ways. One of the options is delivering organic waste to burning facilities connected with district heating systems and then the energy from organic waste could be used for district heating. However, this process is not so easy. The major component in organic waste is water. The water content can be up to 70% of the total organic waste mass. It needs to be heated to evaporate the water until the water content is down to 20-30% of the total mass. The question is how to achieve it? In general, this process is generated by burning oil, but the idea is that water can evaporate by utilizing waste heat from metal industry. As Norway has a well-developed silicon and aluminum production, this work will be focused on this particular field of metal industry. The work will include overview of silicon and aluminum production plants, as well as the geographical positions of plants all over Norway with an emphasis on available waste energy sources.

The Norwegian industry's potential to reduce energy and improve energy savings was investigated by ENOVA[1] in 2009. The following results were obtained: the aluminum industry was the largest energy consumer with an annual consumption of 22 TWh in 2007 and 17TWh of energy consumption for silicon production. Therefore, the amount of waste energy in this part of metal industry is very high and possibilities of using waste energy are great. On the other hand, Norway is ranked 32nd in the latest list by carbon dioxide emissions per capita. Current goal for Norway is to be carbon neutral by 2050 and, in that sense, concrete measures are being implemented. Therefore, it is important to implement energy recovery systems where it is possible.

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[1] ENOVA is a Norwegian government enterprise responsible for promotion of environmentally friendly production and consumption of energy.

1.2. Scope of work

Considering all specified, the idea is that waste heat from metal industry, with an emphasis on aluminum and silicon production, can be used for drying of organic waste, instead of burning oil for the same process. Dried organic waste could be stabilized and storage before the burning in the district heating systems. In this way using of the organic waste as energy source would be increased, the problem of waste disposal would be solved and using of paper and plastic for burning process would be reduced. Moreover, it would also reduce CO_2 foot print.

This work aims at investigating available waste energy sources, available organic (food) waste amounts in Norway and checking possibilities for drying and using it as energy source. In addition, this work includes investigation of the technical solutions for the handling, milling, drying and storage of the waste.

2. ORGANIC WASTE

2.1. General characteristics

The main characteristic of the organic waste is that it is produced wherever there is a human settlement. Household food waste, human and animal waste, agricultural waste, all make up the total organic waste mass. In industrialized countries the amounts of the organic waste are becoming higher and higher each year. Tremendous increase of the organic waste producing causes serious problem and there is a question how to deal with it. In the modern society the organic waste is not allowed to damp on landfills. In developing countries there is a different approach to dealing with organic waste. Nowadays it is possible to use waste in a useful way- to provide a source of energy.

Figure 1 gives a review of the total solid waste composition in the world.
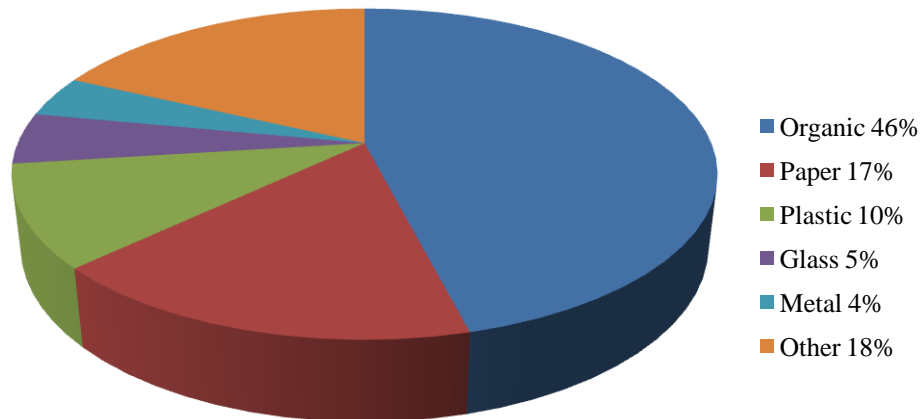
Figure 1: Global solid waste composition

The figure 1 shows that organic waste (food and horticultural waste, but food mostly) made up about half amount of the total global waste in 2012 [1]. Therefore, the potential of utilizing energy from organic waste is great. Composition of the waste depends on many factors such as: climate, level of economic development, location, energy sources, etc. It varies from region to region, from country to country but, in general, low and middle-income countries have a higher percentage of organic waste amounts than high-income countries.

On the other hand, unfortunately, food is becoming more and more expensive. As a result, food waste is becoming more and more expensive. This is the reason why it is of great importance to treat organic waste in the right way.

It should be noted that this work will focus on food waste as a part of organic waste and possibilities of using food waste as energy source.

2.2. Water content in organic waste

As it has previously been mentioned, the biggest problem when it comes to using energy from organic waste is water content inside it. Water is a major component, making up around 70% of the total organic waste mass. As a result, using energy from organic waste for district heating system requires mix of organic waste and large amounts of plastic and paper (with higher energy content) to burn it out. Of course, it is better to use less plastic and paper for this process and more for recycling. Therefore, it is necessary to do one pre-treatment in terms of heating the organic waste to evaporate water until water content is down to 30% of the total organic waste mass. It is in this way that the reduction of the use of plastic and paper is provided.

Figure 2 gives water content in some fruits and vegetables expressed as a percentage.

96% water   95% water   95% water   95% water   95% water

94% water   92% water   90% water   89% water   89% water

© 2012 Beller Nutritional Institute, LLC
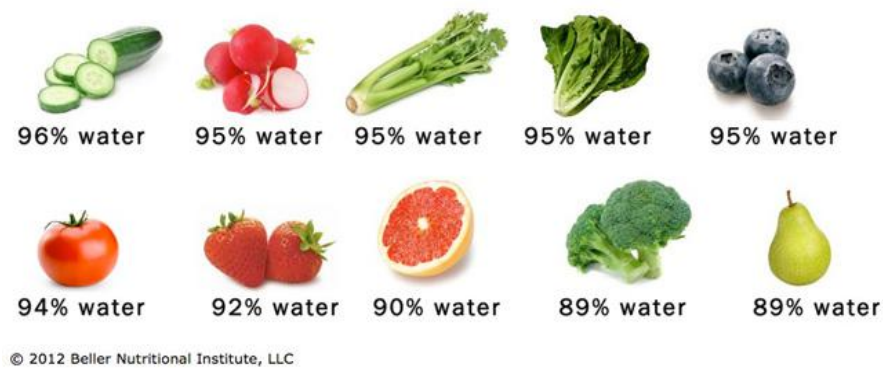
Figure 2: Water content inside some fruits and vegetables

The figure 2 shows very large amounts of the water in this food. Almost everywhere it is over 90%. Therefore, amounts of the water are pretty high and using waste heat from metal industry is just perfect way to reduce it.

So, the first reason for evaporating water from organic waste was to burn it easier in district heating process. There is another very important reason that could increase using of organic waste as a source of energy- storage **of organic waste**.

2.3. Storage of the organic waste

The second problem considering water inside the waste is associated with storage. As a matter of fact, storage of the organic waste is not possible without pre-evaporation treatment. Water inside the waste is perfect field for microorganisms to appear and reproduce. After that waste is not suitable for using. In order to prevent this situation, water amount inside the waste must be reduced. Without pre-evaporation treatment organic waste could be stored just few days before microorganisms start with appearing process. Consequently, it is not possible to have necessary amounts of the organic waste for district heating needs during the winter.

Storage of the organic waste means that it is possible to have larger amounts of organic waste for the winter season (when it is most needed for heating), collected during the summer and autumn.

The conclusion is that the reduction of water amounts inside the organic waste means less plastic and paper for burning process and, on the other hand, possibility for storage of the waste. The result is larger amounts of available waste used as energy source.

Figure 3: Storage of the waste in plastic bags

3. WASTE TO ENERGY

3.1. Waste to energy process

Waste to energy is the process that implies utilizing energy from the waste and producing electricity or heat (or combined). This is a good way for waste handling and securing energy for the future. The most common waste to energy implementation is incineration-the combustion of organic material. Incineration is a process that involves the combustion of organic substances contained in waste materials. Nowadays, new types of incinerations are very effective and reduce the volume of the original waste by 94-95%. Moreover, using of waste in this way means reducing CO_2 emission. CO_2 emitted by combustion has around 30% lower global warming potential than landfills gas emitted to atmosphere through the methane [2]. According to everything that has been mentioned above, "waste to energy'' plants are very popular and very useful.

3.2. Construction of the plant and waste to energy process

Figure 4 shows all parts of the plant and waste to energy process [3]. The first step is transportation of the waste to the plant (waste reception (1)). After that the waste is tipped into a waste bunker (2). Overhead crane (3) loads the waste fuel into the secondary chamber (7) and further into the combustion chamber (orange one). In less than two hours the waste is reduced to 10% of its original volume. All recyclable metals are separated from remaining inert ash. From combustion chamber hot gasses go to the boilers (8) and heat the water in steel tubes (if the system has turbine generator for electricity production, the hot water in steel tubes is heated and turned to steam). Next step in bag-house filter (10) is to capture any remaining particles within the flue exhaust. After that smoke keep moving into economizer (12) where remaining heat is used. If it is not necessary, smoke goes through the by-pass duct (11). The scrubber (13) utilizes reagent additional for removal or acid gases. Part of the smoke goes back to combustion chamber as recycled gas through the flue gas recirculation duct (16). Finally, thoroughly cleaned and continuously monitored gas goes through the chimney (19).
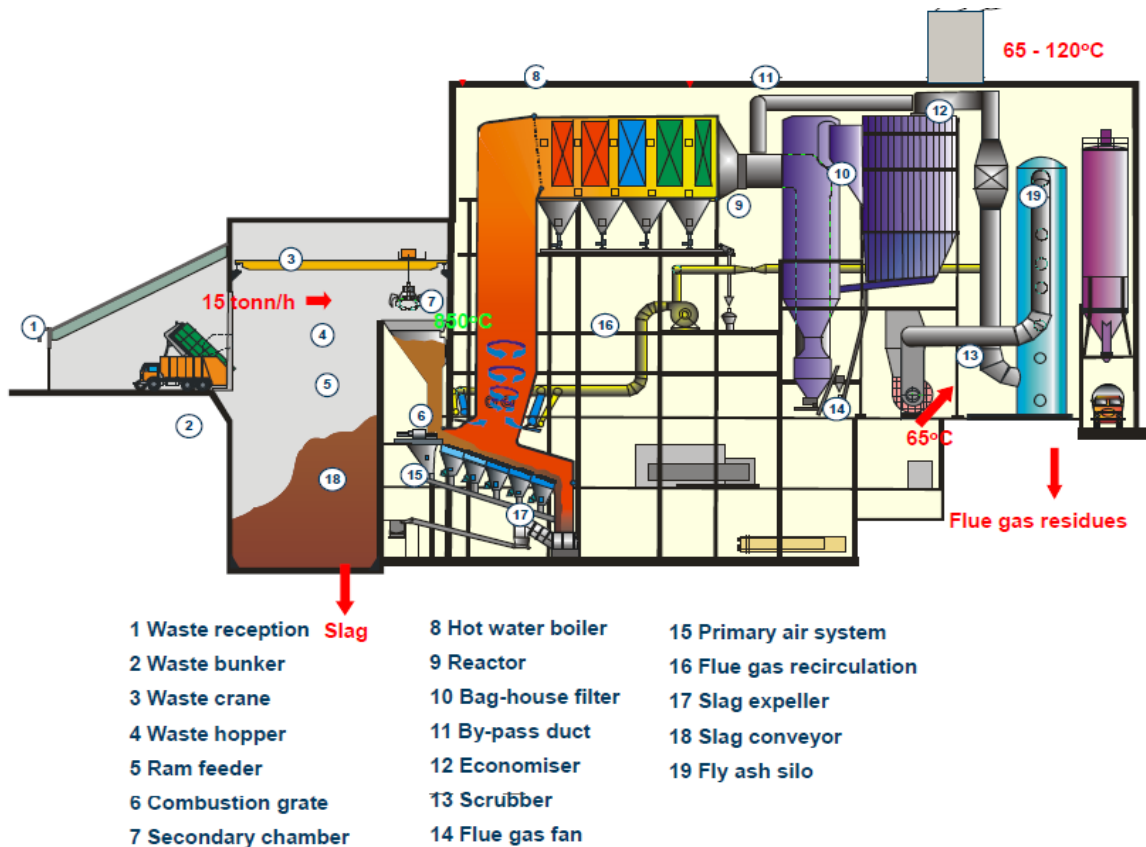
Figure 4: Waste to energy equipment and process

1 Waste reception	8 Hot water boiler	15 Primary air system
2 Waste bunker	9 Reactor	16 Flue gas recirculation
3 Waste crane	10 Bag-house filter	17 Slag expeller
4 Waste hopper	11 By-pass duct	18 Slag conveyor
5 Ram feeder	12 Economiser	19 Fly ash silo
6 Combustion grate	13 Scrubber	
7 Secondary chamber	14 Flue gas fan	

3.3. Current state in Trondheim's waste to energy plants as representative

It is well known that there are two plants for utilizing energy from the waste for district heating in Trondheim; old and new plant. Hopefully, there will be such plants in other cities in the future as well.

3.3.1. Old plant

Old plant started operation in 1985. It was renovated few years ago with the help of investment of 12 million euro [4].

The capacity of old plant: 2 lines, each 5,5 t/h = 11 t/year in total.
Energy production: 2 x 15 MW = 30 MW

In 2007, the old incineration plant had been extended with a new plant.

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3.3.2. New ''HEIMDAL VARMESENTRAL'' plant

New plant started operation in 2007. It is a very modern and expensive plant. Its construction cost approximately 75 million euro [4].

The capacity: 15t/h
Energy production: 40 MW

These three lines produce energy with total of 70 MW of plants capacity (of 298 MW heat production capacities in Trondheim).

Total annual consumption of the organic waste as energy source in Trondheim is approximately 200 000 t/year [4]. This amount of the waste is collected from field with 500 000 inhabitants.

Waste to energy plants in Trondheim are

Figure 5: ''HEIMDAL VARMESENTRAL'' plant

projected so that optimal work is when energy content inside the fuel is between **8000** KJ/kg and **14500** KJ/kg. Currently, food waste makes up just 13% of the total waste utilizing for district heating. The reason is the lower energy content inside the food waste (because of the high water amount). In this ratio total energy content of the waste now is around **12000** KJ/kg thanks to plastic and paper with higher energy content [4].

3.3.3. Share of fuels

Figure 6 shows current state in Trondheim's district heating system regarding fuels consumption [4]. It is obvious that waste is the most important fuel, making up almost 45% of total fuels consumption in Trondheim district heating plants. This diagram also gives us the answer-why energy from organic waste?! Waste is the most important energy source in Trondheim. What should be changed is increasing of food waste consumption if we know that current share of food waste is just 13%. In order to do that, it is necessary to make one pre-evaporation process. In addition, the target for the future is that renewable energy must make 90% of the total consumption.
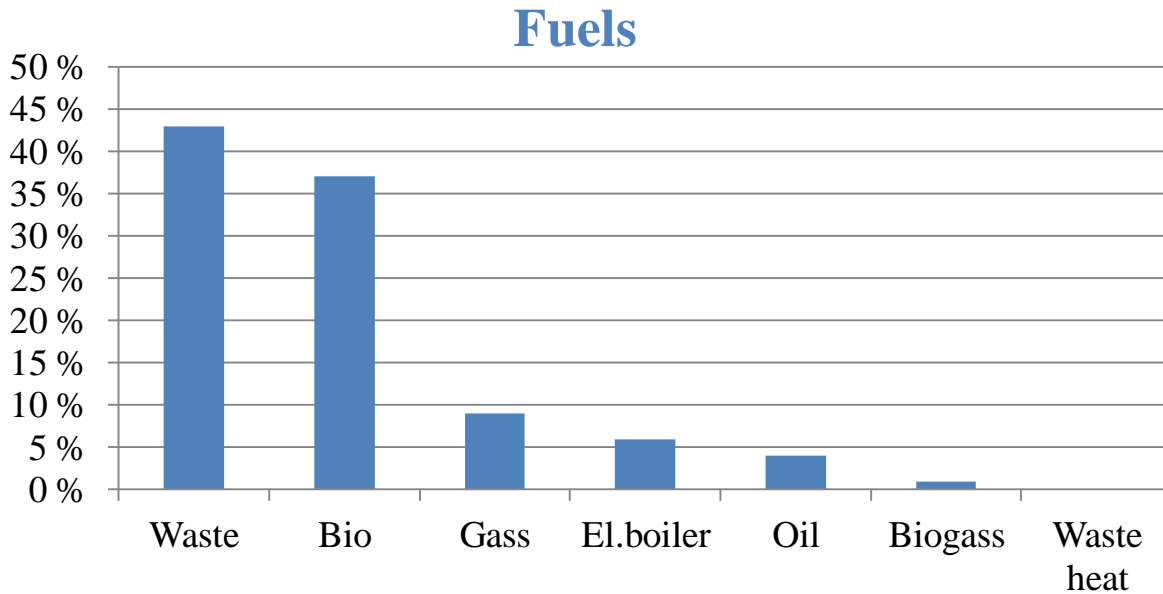
Figure 6: Share of different fuels used in Trondheim's district heating system

3.3.4. Gas emission

3.3.4.1. Gas emission for current state

For the purpose of calculating gas emission, it is necessary to know fuel structure. For Trondheim's plants fuel structure is as follows (approximately):

1. Food waste: 15%
2. Wood chips, brunches, grass: 25%
3. Plastic: 10%
4. Paper: 10%
5. Dust: 10%
6. Textile: 10%
7. Gum: 10%
8. Pelt: 10%

It should be noted that current state means 70% of the water inside the food waste. Calculation for this fuel structure [5] gives the following results:

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Table 1: Fuel structure and shares of combustion products for current state

FUEL:	Currently					
C	**H**	**O**	**N**	**S**	**A**	**W**
32,80	**3,70**	**18,90**	**1,92**	**0,33**	**9,00**	**33,35**
Lhv (kJ/kg)=	**11921**				Σ	100,000
Lhv=339*C+1197*(H-O/8)+105*S-25*W						
a (%) =	21,00					
λ –>		**1,00**	**1,25**	**1,50**	**1,75**	**2,00**
☐						
O_{2min}	m^3/kg	0,6906	0,6906	0,6906	0,6906	0,6906
V_{vmin}	m^3/kg	3,2884	3,2884	3,2884	3,2884	3,2884
V_{vreal}	m^3/kg	3,2884	4,1105	4,9326	5,7548	6,5769
V_{CO2}	m^3/kg	0,6134	0,6134	0,6134	0,6134	0,6134
V_{SO2}	m^3/kg	0,0023	0,0023	0,0023	0,0023	0,0023
V_{H2O}	m^3/kg	0,8291	0,8291	0,8291	0,8291	0,8291
V_{O2}	m^3/kg	0,0000	0,1726	0,3453	0,5179	0,6906
V_{N2}	m^3/kg	2,6132	3,2627	3,9121	4,5616	5,2111
V_{rw}	m^3/kg	4,0580	4,8801	5,7022	6,5243	7,3464
V_{rd}	m^3/kg	3,2289	4,0510	4,8731	5,6952	6,5173
CO_{2w}	%	15,1148	12,5685	10,7565	9,4011	8,3491
SO_{2w}	%	0,0569	0,0473	0,0405	0,0354	0,0314
W_w	%	20,4318	16,9899	14,5404	12,7082	11,2861
O_{2w}	%	0,0000	3,5377	6,0553	7,9384	9,4001
N_{2w}	%	64,3965	66,8566	68,6073	69,9169	70,9333
Σ	%	100,0000	100,0000	100,0000	100,0000	100,0000
CO_{2d}	%	18,9960	15,1410	12,5866	10,7698	9,4112
SO_{2d}	%	0,0715	0,0570	0,0474	0,0406	0,0354
O_{2d}	%	0,0000	4,2617	7,0855	9,0941	10,5959
N_{2d}	%	80,9324	80,5403	80,2804	80,0956	79,9574
Σ	%	100,0000	100,0000	100,0000	100,0000	100,0000

Table primarely gives shares of fuel components (C-carbon, H-hydrogen, O-oxygen, N-nitrogen, S-sulfur, A-ash, W-water). Thanks to these values, the lower heating value L_{hv} is determined.

Knowing all the values that have been mentioned, the value of oxygen content in the air **a [%]** and minimum amount of oxygen for combustion **$O_{2,min}$ [m³/kg],** it is possible to calculate minimum necessary amount of air for combustion **$V_{v,min}$ [m³/kg]** and real necessary amount of air for combustion **$V_{v,real}$ [m³/kg].** With these values and for different values of excess air in combustion **λ[/],** it is possible to have results of the given amounts of all combustion products such as CO_2, SO_2, H_2O, O_2 and N_2 [m³/kg] expressed in cubic meter of product per kilogram of fuel. Sum of combustion products amounts from **V_{CO2}** to **V_{N2}** gives total amount of wet combustion products **$V_{r,w}$ [m³/kg].** If we subtract amount of water obtained with combustion (V_{H2O}), result is total amount of dry combustion products **$V_{r,d}$ [m³/kg].** Finally, it is possible to calculate volume fraction of components in wet (from **CO_{2w}** to **N_{2w} [%]**) and dry combustion products (from **CO_{2d}** to **N_{2d} [%]** without water).

The most important for our calculation is amount of CO_2 produced by burning because of the foot print. As representative will be used amount obtained for the value of excess air in combustion **λ=1** (ideal case of combustion). For Trondheim's annual consumption of 200000 t of total waste amount, this could be done as following:

$$m_{CO2} = V_{CO2} \cdot m \cdot \rho_{CO2} = 0,6134 \cdot 200000000 \cdot 1,97 = 241679600 \frac{kg}{year} \approx \mathbf{242000} \frac{t}{year}$$

In which:

m_{CO2}, kg/year – annual CO_2 emission,

V_{CO2}, m³/kg – CO_2 amount produced by burning of fuel,

m, kg/year – total waste amount used in Trondheim's plants per year,

ρ_{CO2}, kg/m³ – density of CO_2

The conclusion is that currently CO2 emission is around 242000 t/year in Trondheim (for ideal case of combustion as representative). The same calculation will be made for the case when dried food waste will replace plastic and paper and then results will be compared.

3.3.4.2. Potential gas emission for new fuel structure

Next analysis will have two changes compared with the previous one. The first is connected with fuel structure-food waste will replace plastic and paper. The second one refers to the water content inside the food waste. Instead of 70% of the water inside the waste, here will be calculation which implies dry food waste without water.

Structure of the fuel:

1. Food waste: 35%
2. Wood chips, brunches, grass: 25%
3. Plastic: 0%
4. Paper: 0%
5. Dust: 10%
6. Textile: 10%
7. Gum: 10%
8. Pelt: 10%

Calculation for this fuel structure gives following results:

Table 2: Fuel structure and shares of combustion products for new conditions

FUEL:	New condition						
C	H	O	N	S	A	W
38,18	3,80	18,00	2,15	0,37	12,00	25,50

Lhv (kJ/kg) =	14200				Σ		100,000

Lhv=339*C+1197*(H-O/8)+105*S-25*W

a (%) =	21,00				

λ ->		1,00	1,25	1,50	1,75	2,00
□						
O_{2min}	m³/kg	0,8034	0,8034	0,8034	0,8034	0,8034
V_{vmin}	m³/kg	3,8255	3,8255	3,8255	3,8255	3,8255
V_{vstv}	m³/kg	3,8255	4,7819	5,7383	6,6946	7,6510
V_{CO2}	m³/kg	0,7140	0,7140	0,7140	0,7140	0,7140
V_{SO2}	m³/kg	0,0026	0,0026	0,0026	0,0026	0,0026
V_{H2O}	m³/kg	0,7427	0,7427	0,7427	0,7427	0,7427
V_{O2}	m³/kg	0,0000	0,2008	0,4017	0,6025	0,8034
V_{N2}	m³/kg	3,0393	3,7949	4,5504	5,3060	6,0615

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Table 2: Fuel structure and shares of combustion products for new conditions-extension

V_{rw}	m³/kg	4,4986	5,4549	6,4113	7,3677	8,3241
V_{rs}	m³/kg	3,7559	4,7123	5,6687	6,6250	7,5814
CO_{2v}	%	15,8709	13,0884	11,1360	9,6905	8,5771
SO_{2v}	%	0,0576	0,0475	0,0404	0,0352	0,0311
W_v	%	16,5090	13,6146	11,5837	10,0801	8,9219
O_{2v}	%	0,0000	3,6818	6,2651	8,1778	9,6510
N_{2v}	%	67,5625	69,5678	70,9748	72,0165	72,8188
Σ	%	100,0000	100,0000	100,0000	100,0000	100,0000
CO_{2s}	%	19,0092	15,1512	12,5950	10,7768	9,4173
SO_{2s}	%	0,0690	0,0550	0,0457	0,0391	0,0342
O_{2s}	%	0,0000	4,2620	7,0859	9,0946	10,5964
N_{2s}	%	80,9219	80,5318	80,2734	80,0896	79,9521
Σ	%	100,0000	100,0000	100,0000	100,0000	100,0000

Values in the table had already been explained in the previous case. What need to be done is calculation related to CO_2 emission for new conditions. Before that it is necessary to check new amount of the needed waste (with new lower heating value of 14200 kJ/kg) as following:

$$Q = m_1 \cdot L_{hv1} = 200000000 \cdot 11921 = 2384200 \; GJ$$

$$m_2 = Q : L_{hv2} = 23842 \cdot 10^8 : 14200 = 167901408 \; kg \approx 168000 \; t$$

In which:

Q, J –energy obtained from 200000t of waste for H_{d1},

m_1, kg – annual consumption of waste as energy source in Trondheim,

L_{hv1}, kJ/kg – lower heating value of fuel

L_{hv2}, kJ/kg – new lower heating value of fuel (without plastic and paper and with dry food waste),

m_2, kg – new annual necessary amount of fuel.

Emission of CO_2 calculation:

$$m_{CO2} = V_{CO2} \cdot m_2 \cdot \rho_{CO2} = 0{,}7140 \cdot 167000000 \cdot 1{,}97 = 234898860 \frac{kg}{year} \approx \mathbf{235000} \frac{t}{year}$$

In which:

m_{CO2}, kg/year – annual CO_2 emission,

V_{CO2}, m³/kg – CO_2 amount produced by burning of fuel,

m_1, kg/year – new total waste amount that is to be used in Trondheim's plants per year,

ρ_{CO2}, kg/m³ – density of CO_2

Detailed analysis shows that drying of the waste has many benefits. Because of the higher energy content inside the dry food waste, required annual amount of the waste is lower and fuel is more quality. Moreover, amount of the CO_2 emitted to the atmosphere would be 7000 t (around 3%) lower which is very important considering greenhouse effect. Besides, larger amounts of plastic and paper would be used for recycling. These are all advantages of drying of the organic waste. It should be noted that new energy content is still in projected limits (up to 14500 kJ/kg).

4. RESEARCH OF AVAILABLE WASTE ENERGY SOURCES IN NORWAY

As it has already been mentioned, focus will be on aluminum and silicon production because of its great opportunity for utilizing waste energy. Consequently, a research includes this part of metal industry.

The two largest companies in Norway which deal with aluminum and silicon production are **Elkem** (silicon) and **Norsk Hydro** (aluminum). Both have a total of nine plants all over Norway that could be used for drying of the organic waste. These nine plants are located in seven regions all over Norway. Considering that every region does not have representative plant (almost all plants are located in western part of Norway), waste in these regions should be collected and transported to nearest plant in the neighboring region.

Overview of regions that have aluminum or silicon production plant (underlined) is given below (figure 7). Positions of plants are approximately marked with red circles. Some plants in the same region are very close to each other and, in this case, only one of them will be considered as representative.
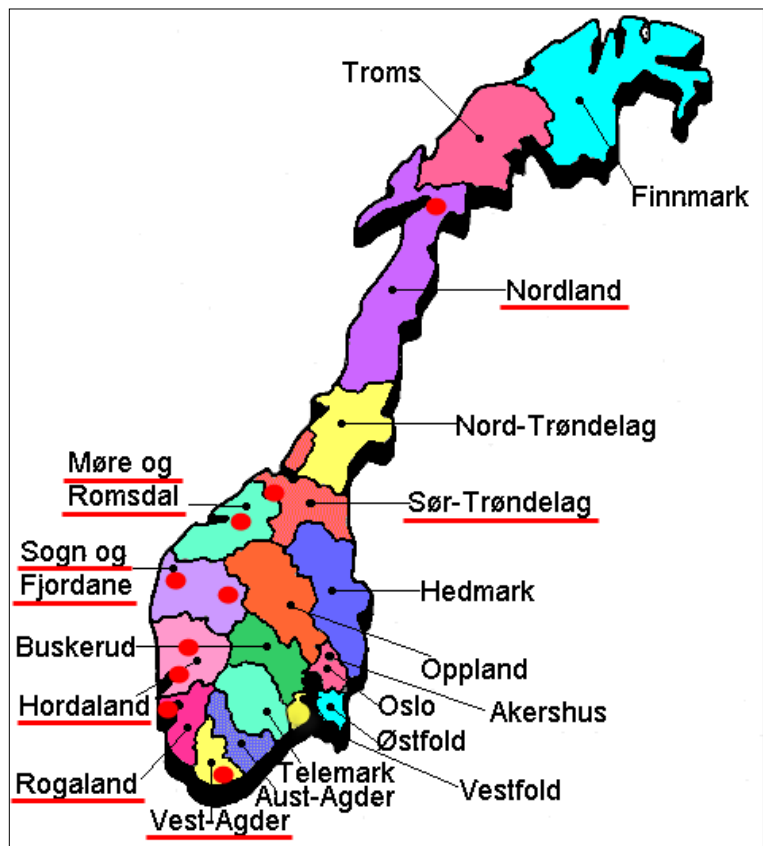
Figure 7: Norway regions and positions of Si and Al production plants

Table 3 gives overview by regions and cities where the companies are located.

Table 3: List of plants all over Norway

ord.	Company name	Plant name	Region	Place
1.	ELKEM	Salten	Nordland	Straumen
2.	ELKEM	Bjølvefossen	Hordaland	Ålvik
3.	ELKEM	Fiskaa	Vest Agder	Kristiansand
4.	NORSK HYDRO	Hydro Aluminium	Sogn of Fjordane	Høyanger
5.	NORSK HYDRO	Hydro Aluminium	Sogn of Fjordane	Årdal
6.	ELKEM	Bremanger	Sogn of Fjordane	Svelgen
7.	NORSK HYDRO	Sunndal Primary Production	Møre og Romsdal	Sunndalsøra
8.	ELKEM	Thamshavn	Sør Trondelag	Orkanger
9.	NORSK HYDRO	Karmøy Primary Production	Rogaland	Karmøy

4.1. Silicon production plants

There are five ELKEM silicon production plants that could be used for drying of organic waste and they are placed in five different regions. The list that follows shows all the plants, with special reference to their geographical position (this is important because of transport conditions) and the available quantity of waste energy [6].

4.1.1. ELKEM Salten plant

Elkem Salten is plant in Nordland region. It is situated in Straumen, in the municipality of Søfold. Elkem Salten is approximately 1150km from Oslo and 1000km from Nord Cape. Fauske is the closest neighbouring town, while Bodø is 80 km from the plant. What is of high importance is that plant is located near highway E6. It is in the mid-1960's that the construction of the plant began, whereas the first electric smelting furnace came into operation in 1967. The second furnace was added three years later and in 1972 the third and largest one. This is one of the most modern and largest plant in Europe. Its main product is silicon with high iron content and specialty silica fume products.

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Figure 8: Elkem Salten plant position on map

Available waste energy amount: 132 MW (1132 GWh)
Available off-gas temperatures: between 350°C and 550°C

Figure 9: Elkem Salten plant

4.1.2. ELKEM Bjølvefossen plant

Elkem Bjølvefossen plant is situated in the Ålvik town, in the western part of Norway, 115km east of Bergen. Hardanger is the closest neighbor. The plant has a good location, just a few kilometers from the roads E16 and E39, but it is also possible to approach it by sea. The plant was founded in 1905. Nowadays the plant is specialized in producing Ferrosilicon and Magnesium-ferrosilicon master alloys. Currently, it is among the largest producers world-wide. It employs 120 employees. Smelter has 4 electric ovens. It is provided with the energy recovery system used for electricity production (6MW) and for district heating (50GWh).

Figure 10: Elkem Bjølvefossen plant

Figure 11: Elkem Bjølvefossen plant position on map

Available waste energy amount: 44 MW (373 GWh)
Available off-gas temperatures: around 150°C

4.1.3. ELKEM Carbon Fiskaa plant

Elkem Fiskaa is a plant developed after the invention of the Soderberg electrode in 1917. Two years later this plant started to produce electrode paste for all over the world. Plant is located in Kristiansand town, to the south of Norway, Vest Agder County. Road and sea connections are both very good in all directions.
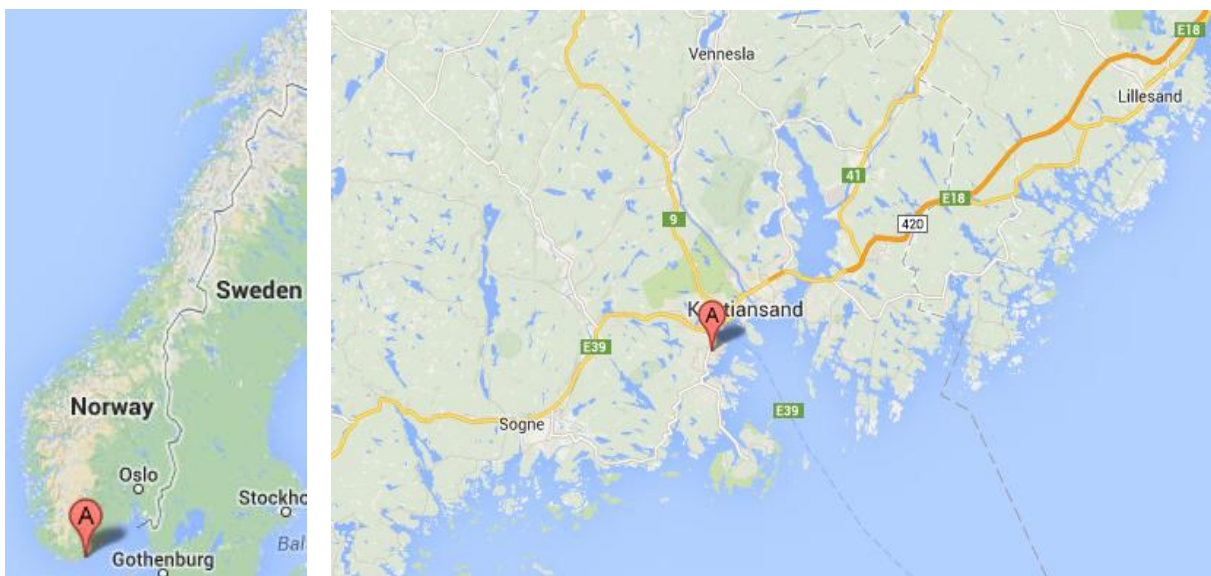
Figure 12: ELKEM Carbon Fiskaa plant position on map

Figure 13: ELKEM Carbon Fiskaa plant

Available waste energy amount: 11 MW (94 GWh)
Available off-gas temperatures: about 400°C

4.1.4. ELKEM Bremanger plant

Elkem Bremanger plant is located in Svelgen. It is a small place on the west coast of Norway, in the Sogn og Fjordane region. Florø airport is on one hour drive from the Bremanger plant. Company has its own port which provides good connections with the main ports of Norway and with the rest of Europe.

Figure 14: Elkem Bremanger plant

Figure 15: ELKEM Bremanger plant position on map

The first pig iron production began in 1928. There are three modern smelting furnaces for production of following products: speciality inoculants, ferrosilicon, silgrain and microsilica. What is interesting and very important is that the products are based on 100% renewable hydropower. It makes Elkem Bremanger's products the greenest of its kind in the world.

Available waste energy amount: 83 MW (701 GWh)
Available off-gas temperatures: between 400 and 450°C

4.1.5. ELKEM Thamshavn plant

Elkem Thamshavn is a plant located 40km southwest of Trondheim, in Orkanger town, Sør Trondelag region. This plant has an excellent position with very good road connections in all directions (on the road E39 and near the highway E6) and is near to Trondheim airport. Also, there is an access to the sea. What is of high importance is that Orkdasfjorden is free of the ice during the winter.

Figure 16: ELKEM Thamshavn plant

Figure 17: ELKEM Thamshavn position on map

In 1964, the first smelting furnace for the production of ferrosilicon started operation. The second furnace was built in 1981, resulting in the increase of the production. The following year the reconstruction of the old furnace as well as the energy recovery system were completed. Nowadays energy recovery system provides 18MW of power production and 30GWh of district heating.

Available waste energy amount: 74 MW
Available off-gas temperatures: around 150°C

Table 4: Values of the available waste energy expressed in MW and GWh from larger to lower

ord.	Plant	Available waste energy (MW)	Available waste energy (GWh)
1.	Elkem Salten	132	1123
2.	Elkem Bremanger	83	701
3.	Elkem Thamshavn	74	628
4.	Elkem Bjølvefossen	44	373
5.	Elkem Fiskaa	11	94
	in total	**344**	**2919**

The values range between 132 MW (Salten plant) and 11 MW (Carbon Fiskaa plant). The total value of available waste energy source from silicon production plants is around 350 MW (2920 GWh).

4.2. Aluminum production plants

There are four NORSK HYDRO aluminum production plants that could be used for drying of organic waste and they are placed in three different regions. The list that follows shows all the plants with a special reference to the geographical position (this is important because of transport conditions) and the available quantity of waste energy. Available waste energy amounts are larger than in ELKEM plants. Unlike the Elkem plant where the data is obtained directly, the values here are obtained according to the flow of waste gases and their temperatures [7].

4.2.1. NORSK HYDRO Høyanger

Norsk Hydro Høyanger plant is located in the village of Høyanger, in the Sogn og Fjordane County. Its road, air and sea connections with Bergen and Oslo are very good. There is an airport in Førde, about 50km away.

Figure 18: NORSK HYDRO Høyanger plant position on map

Norsk Hydro plant is considered as one of the first primary alumina plants in the Norway the production of which started in 1918.

Figure 19: NORSK HYDRO Høyanger plant

Available off-gas temperatures: around 100°C
The gas volume is 610 000 Nm³/h.

4.2.1.1. Available waste energy calculation for NORSK HYDRO Høyanger plant

If we know gas volume and gas temperature, it is easy to calculate available waste energy sources:

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First, we start with available data:

$$V_1 = 610000 \, \frac{Nm^3}{h}$$

$$t = 100°C$$

In which:

$V_1, \frac{Nm^3}{h}$ – off gas volume at normal conditions (T₁=273,15K and p_atm=101325Pa),

$t, °C$ – off gas temperature.

In order to transform normal to real conditions (values market with number 2), we use following relation:

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

It follows:

$$V_1 = \frac{T_1}{T_2} \cdot V_2 = \frac{273}{373} \cdot V_2 = 0,732 V_2$$

$$V_2 = \frac{V_1}{0,732} = \frac{610000}{0,732} = 833333 \, \frac{m^3}{h}$$

$$V_2 = 231 \, \frac{m^3}{s}$$

In which:

$V_2, \frac{Nm^3}{h}$ – off gas volume at real conditions (T₂=373,15K and p_atm=101325Pa),

T_1, K – temperature at normal conditions,

T_2, K – temperature at real conditions (T₁=273,15 + 100K).

When we know off gas volume at real conditions, it is possible to calculate mass flow:

$$m = \rho \cdot V_2 = 0,950 \cdot 231 = 219 \, \frac{kg}{s}$$

In which:

$m, \frac{kg}{s}$ – off gas mass flow at normal conditions,

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$$\rho, \frac{kg}{m^3} - \text{density of off gas at gas temperature t=100°C.}$$

In order to calculate total waste energy amount, we need just more value of specific enthalpy:

$$h = c_p \cdot T_2 = 1,068 \cdot 373 = 398 \frac{kJ}{kg}$$

In which:

$$h, \frac{kJ}{kg} - \text{specific enthalpy at given conditions,}$$

$$c_p, \frac{kJ}{kgK} - \text{specific heat capacity at off gas temperature t=100°C.}$$

Finally, it is possible to have value for available waste energy amount:

$$\boldsymbol{Q} = m \cdot h = 219 \cdot 398 = 87162 \, KW \approx \boldsymbol{87 \, MW}$$

In which:

$$Q, W - \text{available waste energy amount.}$$

4.2.2. NORSK HYDRO Årdal

NORSK HYDRO Årdal plant is located in the village of Øvre Årdal, to the east of Sogn og Fjordane County. This is of high importance because it is well-connected with neighboring regions Oppland and Buskerud. The road 53 connects Øvre Årdal with the highway E16 which leads to Oslo.

Figure 20: NORSK HYDRO Årdal plant position on map

First production in plant started in 1948. In 1986, company became a member of Nors Hydro group. This factory produces semi-finished aluminum that is to be transformed into various products in other factories.

Available off-gas temperatures are between 80 and 100°C.
The gas volume is: 2 149 000 Nm³/h.

4.2.2.1. Available waste energy calculation for NORSK HYDRO Årdal plant

If we know gas volume and gas temperature, it is easy to calculate available waste energy sources:

First, we start with available data:

$$V_1 = 2149000 \ \frac{Nm^3}{h}$$

$$t = 100°C$$

In which:

$V_1, \frac{Nm^3}{h}$ – off gas volume at normal conditions (T_1=273,15K and p_{atm}=101325Pa),

$t, °C$ – off gas temperature.

In order to transform normal to real conditions (values market with number 2), we use following relation:

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

It follows:

$$V_1 = \frac{T_1}{T_2} \cdot V_2 = \frac{273}{373} \cdot V_2 = 0,732 V_2$$

$$V_2 = \frac{V_1}{0,732} = \frac{2149000}{0,732} = 2935792 \frac{m^3}{h}$$

$$V_2 = 815 \frac{m^3}{s}$$

In which:

$V_2, \frac{Nm^3}{h}$ – off gas volume at real conditions (T_2=373,15K and p_{atm}=101325Pa),

T_1, K – temperature at normal conditions,

T_2, K – temperature at real conditions (T_1=273,15 + 100K).

When we know off gas volume at real conditions, it is possible to calculate mass flow:

$$m = \rho \cdot V_2 = 0,950 \cdot 815 = 774 \frac{kg}{s}$$

In which:

$m, \frac{kg}{s}$ – off gas mass flow at normal conditions,

$\rho, \frac{kg}{m^3}$ – density of off gas at gas temperature t=100°C.

In order to calculate total waste energy amount, we need just more value of specific enthalpy:

$$h = c_p \cdot T_2 = 1,068 \cdot 373 = 398 \frac{kJ}{kg}$$

In which:

$h, \frac{kJ}{kg}$ – specific enthalpy at given conditions,

$c_p, \frac{kJ}{kgK}$ – specific heat capacity at off gas temperature t=100°C.

Finally, it is possible to have value for available waste energy amount:

$$\boldsymbol{Q = m \cdot h = 774 \cdot 398 = 308052 \; KW \approx \textbf{308 MW}}$$

In which:

Q, W – available waste energy amount.

4.2.3. NORSK HYDRO Sunndal Primary Production

Norsk Hydro Sunndal plant is located in the village of Sunndalsøra, in Møre og Romsdal County. The village is placed between Kristiansund on west and Oppdal on east. The road 70 runs through the village on its way to Oppdal.

Figure 22: NORSK HYDRO Sunndal plant

Figure 23: NORSK HYDRO Sunndal Primary Production plant position on map

This plant has been operating since 1954. In 2004, plant became the largest and the most modern primary alumina plant in Europe. There are about 900 employees. Annual capacity is over 400 000 metric tons.

Available off-gas temperatures are between 80 and 120°C.
The gas volume is: 2 366 000 Nm^3/h.

4.2.3.1. Available waste energy calculation for NORSK HYDRO Sunndal plant

If we know gas volume and gas temperature, it is easy to calculate available waste energy sources:

First, we start with available data:

$$V_1 = 2366000 \ \frac{Nm^3}{h}$$

$$t = 100°C$$

In which:

$V_1, \frac{Nm^3}{h}$ – off gas volume at normal conditions (T_1=273,15K and p_{atm}=101325Pa),

$t, °C$ – off gas temperature.

In order to transform normal to real conditions (values market with number 2), we use following relation:

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

It follows:

$$V_1 = \frac{T_1}{T_2} \cdot V_2 = \frac{273}{373} \cdot V_2 = 0,732 V_2$$

$$V_2 = \frac{V_1}{0,732} = \frac{2366000}{0,732} = 3232240 \ \frac{m^3}{h}$$

$$V_2 = 898 \frac{m^3}{s}$$

In which:

$V_2, \frac{Nm^3}{h}$ – off gas volume at real conditions (T_2=373,15K and p_{atm}=101325Pa),

$T_1, K-$ temperature at normal conditions,

$T_2, K-$ temperature at real conditions (T_1=273,15 + 100K).

When we know off gas volume at real conditions, it is possible to calculate mass flow:

$$m = \rho \cdot V_2 = 0,950 \cdot 898 = 853 \ \frac{kg}{s}$$

In which:

$$m, \frac{kg}{s} - \text{off gas mass flow at normal conditions,}$$

$$\rho, \frac{kg}{m^3} - \text{density of off gas at gas temperature t=100°C.}$$

In order to calculate total waste energy amount, we need just more value of specific enthalpy:

$$h = c_p \cdot T_2 = 1{,}068 \cdot 373 = 398 \frac{kJ}{kg}$$

In which:

$$h, \frac{kJ}{kg} - \text{specific enthalpy at given conditions,}$$

$$c_p, \frac{kJ}{kgK} - \text{specific heat capacity at off gas temperature t=100°C.}$$

Finally, it is possible to have value for available waste energy amount:

$$\boldsymbol{Q} = m \cdot h = 853 \cdot 398 = 339494 \, KW \approx \boldsymbol{340 \, MW}$$

In which:

$$Q, W - \text{ available waste energy amount.}$$

4.2.4. NORSK HYDRO Karmøy Primary Production

NORSK HYDRO Karmøy Primary Production plant is located in Karmøy municipality, in Rogeland County. This plant is placed near highway E134 which enables connection with others Norway regions.
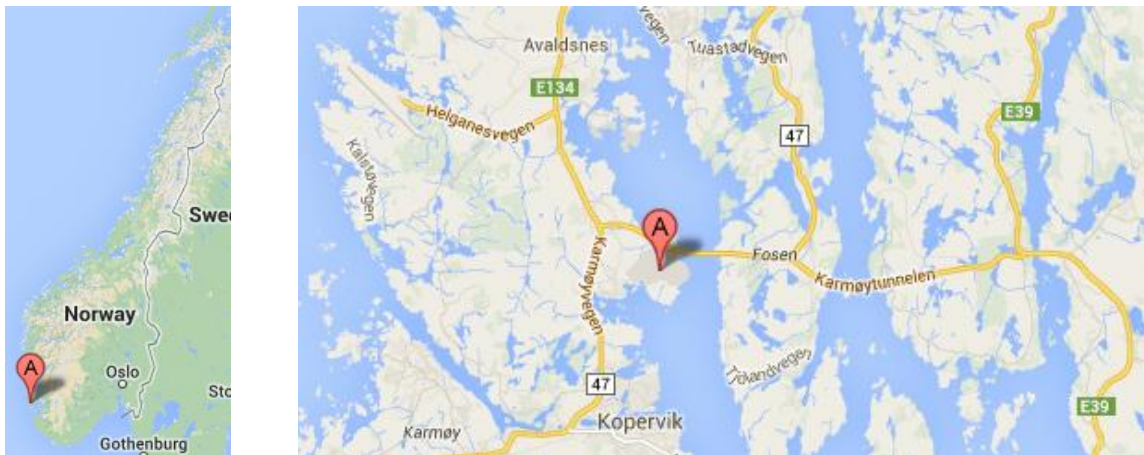
Figure 24: NORSK HYDRO Karmøy Primary Production plant position on map

The primary alumina production plant is the largest Hydro's unit at Karmøy.

Available off-gas temperatures are between 80 and 120°C.
The gas volume is: 1 751 000 Nm³/h.

Figure 25: NORSK HYDRO Karmøy plant

4.2.4.1. Available waste energy calculation for NORSK HYDRO Karmøy plant

If we know gas volume and gas temperature, it is easy to calculate available waste energy sources:

First, we start with available data:

$$V_1 = 1751000 \ \frac{Nm^3}{h}$$

$$t = 100°C$$

In which:

$V_1, \frac{Nm^3}{h}$ – off gas volume at normal conditions (T_1=273,15K and p_{atm}=101325Pa),

$t, °C$ – off gas temperature.

To transform normal to real conditions (values market with number 2), we use following relation:

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

It follows:

$$V_1 = \frac{T_1}{T_2} \cdot V_2 = \frac{273}{373} \cdot V_2 = 0,732 V_2$$

$$V_2 = \frac{V_1}{0,732} = \frac{1751000}{0,732} = 2392076 \ \frac{m^3}{h}$$

$$V_2 = 664 \frac{m^3}{s}$$

In which:

V_2, $\frac{Nm^3}{h}$ — off gas volume at real conditions (T_2=373,15K and p_{atm}=101325Pa),

T_1, K — temperature at normal conditions,

T_2, K — temperature at real conditions (T_1=273,15 + 100K).

When we know off gas volume at real conditions, it is possible to calculate mass flow:

$$m = \rho \cdot V_2 = 0{,}950 \cdot 664 = 631 \frac{kg}{s}$$

In which:

m, $\frac{kg}{s}$ — off gas mass flow at normal conditions,

ρ, $\frac{kg}{m^3}$ — density of off gas at gas temperature t=100°C.

To calculate total waste energy amount, we need just more value of specific enthalpy:

$$h = c_p \cdot T_2 = 1{,}068 \cdot 373 = 398 \frac{kJ}{kg}$$

In which:

h, $\frac{kJ}{kg}$ — specific enthalpy at given conditions,

c_p, $\frac{kJ}{kgK}$ — specific heat capacity at off gas temperature t=100°C.

Finally, it is possible to have value for available waste energy amount:

$$\boldsymbol{Q = m \cdot h = 631 \cdot 398 = 251138 \; KW \approx 250 \; MW}$$

In which:

Q, W — available waste energy amount.

Table 5: Review of the available waste energy in aluminium production plants expressed in MW and GWh from larger to lower

ord.	Plant	Available waste energy [MW]	Available waste energy [GWh]
1.	Norsk Nydro Sundal	340	2970
2.	Norsk Hydro Årdal	308	2700
3.	Norsk Hydro Karmøy	250	2190
4.	Norsk Hydro Høyanger	87	760
	In total	**985**	**8620**

Table 6: Total available waste energy amounts considering silicon and aluminum plants

Ord.	Production plants	Available waste energy	
		[MW]	**[GWh]**
1.	Silicon	344	2919
2.	Aluminium	985	8620
	In total	**1329**	**11539**

Upon the calculation of all available waste energy in each silicon and aluminum production plant, it is possible to have one overview of total waste energy in Norway from this part of metal industry. The overview is shown in Table 6.

5. FOOD WASTE AMOUNTS IN NORWAY

Now that it is known how much waste energy could be used for drying of food waste, the next step was to find out food waste amounts in Norway.

According ForMat[2] report from 2011, each person in Norway produces **51kg** [8] of household food waste per year which represents 25% of all purchased food. Structure of the food waste is such that bread and other bakery products make up around 13kg, fruits and vegetables 12kg, whereas 11kg are rests from prepared dishes. A significant amount of the food waste is in original packaging and has not been opened at all. If we know everything that has been mentioned and, on the other hand, the exact number of inhabitants, it is easy to calculate amount of the food waste that comes from household.

Table 7: Food waste amounts sorted by regions

Ord.	Region	Number of inhabitants	Amount [t/year]
1.	Oslo	630 000	32 130
2.	Akershus	523 300	26 688
3.	Hordaland	499 100	25 454
4.	Rogaland	464 800	23 705
5.	Sør Trondelag	351 800	17 942
6.	Øsfold	267 000	13 617
7.	Møre og Romsdal	264 000	13 464
8.	Buskerund	253 000	12 903
9.	Nordland	238 200	12 148
10.	Vestfold	236 400	12 056
11.	Hedmark	190 000	9 690
12.	Oppland	184 000	9 384
13.	Telemark	170 600	8 701
14.	Vest Agder	167 000	8 517
15.	Troms	158 000	8 058
16.	Nord Trondelag	131 500	6 706
17.	Sogn og Fjordane	111 000	5 661
18.	Aust Agder	107 000	5 457
19.	Finnmark	74 000	3 774
	In total:	**5 020 005**	**256 020**

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[2] Four-year collaboration project consisting of many agents along the value chain, to chart and minimize food waste in Norway

Total amount of household food waste in Norway per year is approximately 256000 t. However, household is not the only source. It makes up around 70% of the total food waste amount. Food is also wasted during the production, wholesale and retail.

According to aforementioned report from 2011, structure of total food waste in Norway is as follows:

-**from production: 52000 tons**
-**from wholesale: 2000 tons**
-**from retail: 68000 tons**
-**from consumers: 256000 tons**

Total food waste amount produced in Norway per year is approximately 378000 tons.

5.1. Required energy amount for drying of the food waste in Norway

As it has already been stated, there is around 70% of water inside the food waste. It has to be reduced if we want to use more of it as energy source for district heating system. It is necessary to calculate how much energy is required to evaporate water from 378000 tons of food waste. This will be done as follows:

$$m_2 = m_1 \cdot 0,7 = 378000000 \cdot 0,7 = 264600000 \ kg$$

In which:

$m_2 -$ mass of the water inside the known food waste mass, kg

$m_1 -$ total food waste amount per year in Norway, kg

If we known value of the heat of vaporization of water, required energy amount can be calculated in a simple way as follows:

$$\boldsymbol{Q} = m_2 \cdot r = 264600000 \cdot 2260 \approx 600000000000 \ KJ = \boldsymbol{600000 \ GJ}$$

In which:

Q − required energy for drying of the food waste, J

r − heat of vaporization of water, KJ/kg

To express it in GWh, we use relation:

$$Q = 600000 : 3600 = 167\ GWh$$

So, in order to dry 378000 tons of food waste, it is necessary approximately 170 GWh of energy.

On the other hand, available waste energy sources from silicon and aluminum production plants are approximately **11500 GWh**. This means that there is almost 70 times more energy than it is needed. Conclusion is that all food wasted during the year could be dried in just one small plant. The question is what is more cost-effective, to have one representative plant and to transport waste from all over Norway in that particular plant, or to make few (for example, one plant in the northern Norway, one in the central and one in the south) in different parts of Norway. Initially, it may cost more, but the transport costs would be lower later.

6. TECHNICAL SOLUTIONS FOR DRYING OF THE FOOD WASTE

As the water makes up 70% of the food waste, it is very difficult to mill or grind it before drying and thus create small pieces that could be easily dried. What might be obtained would look like slurry, and it would not be appropriate for drying. Taking this into consideration, the best solution for drying of the waste without pre-milling or grinding treatment would be a **rotary dryer**.
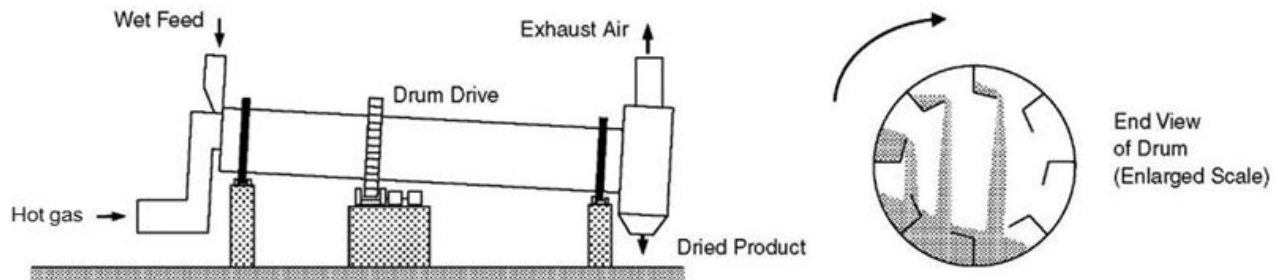

Figure 26: Rotary dryer-scheme

The rotary dryer [9] is an industrial dryer constructed with the aim to reduce moisture content of the material that we want to dry. This is achieved by direct contact between the material and hot gas.

Rotating, cylindrical tube is a main part of the dryer. Wet material enters the dryer on the one end and as the dryer rotates, the material is lifted up by a series of internal fins lining the inner wall of the dryer. When the material reaches an appropriate height so that it can roll back off the fins, it falls back down to the bottom of the dryer, passing through the hot gas stream while falling. Dried material comes out at the other end. Gas stream can move in the same or opposite direction of the movement of materials. Temperatures of the gas depend on the available waste energy sources in metal production plants. The heat (flue gas) can pass directly or indirectly (using a heat exchanger). Exhaust air could be cleaned of dust by filters or cyclones. Also, moisture could be reduced by condensers or scrubbers. In this way, the exhaust gas can be purified and discharged into the atmosphere.
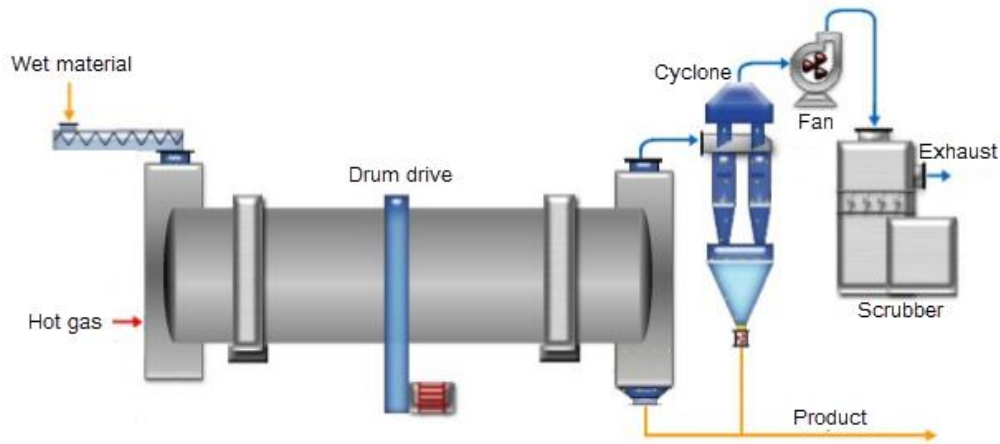
Figure 27: Rotary dryer with cyclone and scrubber

For amount of 387000 t/year calculation leads to necessary rotary dryer capacity of 45 t/h. Currently, total organic waste (including food waste, wood chips) consumption in Trondheim's incineration plant is around 200000 t/year and that amount is mixed with plastic and paper. If we remove water from food waste (around 260000 t/year of available waste) and do not use plastic and paper almost, all of food waste would be utilized for Trondheim's plant needs. Detailed economic analysis would show what is more cost-effective, to have one high capacity rotary dryer installed in Elkem Thamshawn plant, near Trondhem, and transport wet waste from all over Norway to the Thamshawn plant. From this plant dried food waste would be transported to the Trondheim and used for district heating system. Second solution could be few rotary dryers with lower capacity in different parts of Norway. Collected and dried waste would be transported directly to the incineration plant in Trondheim. As density of wet waste is higher of the dried waste, larger amounts of the waste should be transported when the waste is dry. On the other hand, this increases initial costs in terms of buying and installing few rotary dryers with accessories in different parts of Norway. In order to determine what is a better solution, a detailed analysis must be carried out.

7. CONCLUSION

This paper gives review of two main points: available organic waste amounts in Norway and available waste energy sources from metal industry that could be used for drying of the waste. Furthermore, some additional issues were raised: problem of waste storage, CO_2 foot print and technical solutions for drying of the waste.

Results are such that the available waste energy sources are much bigger than what is needed for drying of the food waste. It suggests that the possibilities for drying of the waste thanks to off-gas from metal industry are great. This would lead to increasing share of using food waste as energy source in district heating systems. On the other hand, there are some additional benefits. The first could be solved problem of food waste disposal on landfills. The second benefit could be lower emission of CO_2 to the atmosphere. Of course, there is also using plastic and paper for recycling instead of burning in facilities.

While working on this paper I tried hard to show how important the environmentally friendly solutions for organic waste handling could be. I hope that everything that has previously been mentioned illustrates the importance of it. It would be great if the project of utilization of waste heat for drying the waste once come to life, and that I would notice my modest contributions in all that.

8. FUTURE WORK

This paper does not include points that could be important when deciding on potential investment in this area. This primarily refers to economic analysis.

As it has previously been mentioned, nine plants in metal industry could be used for drying of the food waste. Economic analysis ought to show what is more cost-effective: to transport the waste from all over Norway to one plant or to use a few plants for drying of the waste. On the one hand, there are transportation costs, but, on the other hand, there are costs of installation of driers and additional components for cleaning of exhausted air. Also, potential costs of the waste storage should be taken into account. If the waste is going to be used in some other cities except Trondheim, we should check whether the available amount of waste in Norway is sufficient for that. Otherwise, we should examine the possibilities of imports and cost-effectiveness of this.

Finally, it should be noted that the benefits of the utilization of waste heat from industrial metal to dry the waste would be multiple. The problem of disposal of their waste from the food in Norway would be solved, CO_2 emissions would be reduced, and more components and plastic and paper for recycling would be obtained. We should have all this in mind while conducting the economic analysis and, in this regard, one should not be too exclusive if the costs were slightly higher.

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APPENDIX

Appendix 1 - Typical proximate-analysis and energy-content data for components in municipal, commercial and industrial solid waste

Component	Estimated value of the mass fraction, %				Mass fraction, % (waterless)						Higher heating value, kJ/kg		
	moisture	evaporative components	Cfix	non-combustible components	C	H	O	N	S	non-combustible	calc.	waterless	water and ashless
Paper and paper products													
Mixed paper	10.24	75.94	8.44	5.38	43.41	5.82	44.32	0.25	0.2	6	15817	17612	18736
Newspaper	5.97	81.12	11.48	1.43	49.14	6.1	43.03	0.05	0.16	1.52	18548	19724	20004
Magazine	4.11	66.39	7.03	22.47	32.91	4.95	38.55	0.07	0.09	23.43	12221	12746	16631
Cardboard	5.2	77.47	12.27	5.06	43.73	5.7	44.93	0.09	0.21	5.34	16832	17280	18259
Paper bags	6.11	75.59	11.8	6.5	44.74	6.1	41.92	0.15	0.16	6.93	16883	17980	19190
Food waste													
Kitchen waste I	72	20.26	3.26	4.48	44.99	6.43	28.76	3.3	0.52	16	5513	19734	23493
Kitchen waste II	--	--	--	--	41.72	5.75	27.62	2.97	0.25	21.87	--	16854	21539
Waste meat	38.74	56.34	1.81	3.11	59.59	9.47	24.65	1.02	0.19	5.08	17731	28942	30494
Wood and wooden materials													
Green tree	50	42.25	7.25	0.5	50.12	6.4	42.26	0.14	0.08	1	4889	9781	9886
Wood from the demolition of houses	7.7	77.62	13.93	0.75	51	6.2	41.8	0.1	<0.1	0.8	16980	18413	18596
Evergreen tree	69	25.18	5.01	0.81	48.51	6.54	40.44	1.71	0.19	2.61	6299	20318	20841
Flowers	53.94	35.64	8.08	2.34	46.65	6.61	40.18	1.21	0.26	5.09	8599	18671	19678
Grass	75.24	18.64	4.5	1.62	46.18	5.96	36.43	4.46	0.42	6.55	4787	19334	20701
Leaves I	9.97	66.92	19.29	3.82	52.15	6.11	30.34	6.99	0.16	4.25	18571	20629	21562
Leaves II	50	--	--	4.1	40.5	5.95	45.1	0.2	0.05	8.2	8222	16442	17910
Branches	40	--	--	5	45.52	5.9	41.2	2	0.05	8.33	11037	18375	20004
Household waste													
Clothes	1.02	64.92	27.51	6.55	79.1	6.8	5.9	0.1	1.5	6.6	32099	32345	34657
Pelt	10	68.46	12.49	9.1	60	8	11.5	10	0.4	10.1	18515	20585	22911
Gum	1.2	83.98	4.94	9.88	77.65	10.35	--	--	2	10	26051	26354	29308
Polyethylene	0.2	98.54	0.07	1.19	84.54	14.18	0	0.06	0.03	1.19	43466	45892	46520
Polystyrene	0.2	98.67	0.68	0.45	87.1	8.45	3.96	0.21	0.02	0.45	38191	38263	38402
Polyurethane	0.2	87.12	8.3	4.38	63.27	6.26	17.65	5.99	0.02	4.38	26058	26109	27284
PVC	0.2	86.89	10.85	2.06	45.14	5.61	1.56	0.08	0.14	2.06	22688	22737	23260
Linoleum	2.1	64.5	6.6	26.8	48.06	5.34	18.7	0.1	0.4	27.4	18957	19329	26633
Textile	15.31	--	--	--	46.19	6.41	41.85	2.18	0.2	3.17	--	18692	19306
Dust	3.2	20.54	6.26	70	20.62	2.57	4	0.5	0.01	72.3	8536	8815	31750