TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

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NEW APPROACH IN ALUMINIUM PRODUCTION FROM ALUMINIUM SLAG – ECONOMICAL, TECHNICAL AND ENVIRONMENTAL ANALYSIS.

Supervisor: Jakob Kübarsepp, Professor
Co-supervisor: Maksim Saat, Professor

Author applies for degree of Master of Science in Engineering (M.Sc.)

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AUTHOR’S DECLARATION

I have written the Master’s thesis independently.
All works and major viewpoints of the other authors, data from other sources of literature and elsewhere used for writing this paper have been referenced.
Master’s thesis is completed under the professor’s Jakob Kübarsepp and Maksim Saat supervision.

“.......” May 2015 Author .... signature

Master’s thesis is in accordance with terms and requirements “.......” May 2015

Supervisor…………...................signature. / Jakob Kübarsepp /

Co-supervisor…………...................signature. / Maksim Saat /

Accepted for defense
.... chairman of defense commission
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.... signature

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MASTER’S THESIS TASK

2014 /2015 academic year, 4 semester.

Student: Jevgeni Baklanov, 132613.

Field of study: Industrial Engineering and Management.

Supervisor: Jakob Kübarsepp, Professor.

Co-supervisor: Maksim Saat, Professor.

Company Consultant: Mihhail Kutuzov.

Master’s thesis topic (English and Estonian languages):

New approach in aluminium production from aluminium slag – economical, technical and environmental analysis.

Uus lähenemine alumiiniumi tootmisele alumiiniumšlakist – majanduslik, tehniline ja keskkonnasõbralikkuse analüüs.

Tasks and timeframe for their completion:

Nr.	Task description	Completion date
1.	Üldmaterjalide kogumine	21.02.2014
2.	Uuritavad materjalid	27.04.2014
3.	Uurimismetoodika	22.05.2014
4.	Katseandmete kogumine	22.02.2015
5.	Vormistamine	10.05.2015

Engineering and economic problems to be solved: Feasibility and profitability of the Alucyc technology. Analyse practical implementation and financial benefit of proposed solution.

Defense application submitted to deanery not later than 18.05.2015. Deadline 18.05.2015

Student: Jevgeni Baklanov /signature/ ……..…………… date …..........………

Supervisor: Jakob Kübarsepp /signature/ ………….……….. date …..........………

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LIST OF ABBREVIATIONS

EAA	European Aluminium Association
IAI	International Aluminium Institute
EFTA	the European Free Trade Association
EU	European Union
USD or ($)	United States dollar or US Dollar
<DL	Below the detection limit
XRD	X-ray diffraction
EPMA	Electron probe micro analysis
SEM	Scanning electron microscope
NOK	Norwegian Kroner
TLV	Threshold limit value
i	Discount rate
ROI	Return on investment
PP	Payback period
CF	Cash flow
NPV	Net Present Value
DPI or PI	Discount profitability index
n	Number of years
t	ton
IRR	Internal rate of return
ARR	Accounting rate of return
ISAL	Icelandic Aluminium Company

GLOSSARY OF DEFINITIONS

Alucyc technology electroslag melting method for reprocessing of aluminium slag is a new process to recover metallic aluminium from aluminium dross and slag.

Aluminium salt slag (also known as aluminium salt cake) is produced by the aluminium industry, is formed during aluminium dross melting or alloys by oxidation of the metal and contains metallic aluminium (Tsakiridis, 2012).

Dross is an oxide alloys formed during aluminium melting process. In the context of this thesis contains recoverable metallic aluminium more than 15%.

Slag is the by-product left after smelted metal from its raw ore. Slag is usually a mixture of metal oxides during the melting process. However, slags can contain metallic aluminium and other elemental metals (Lakishev, 2000).

Rotary furnace is a cylindrical industrial furnace that rotates about its longitudinal axis; it is designed for the heating of loose materials for physicochemical processing (Diomidovskii, 1961).

Hazardous waste are waste that poses substantial or potential threats to public health or the environment (US Environmental Protection Agency, 2015).

Cryolite is an aluminium compound with a lower melting point than aluminium oxide. The use of cryolite reduces some of the energy costs involved in extracting aluminium (BBC, 2011).

INTRODUCTION

Aluminium is the most abundant metal and the third most abundant element in the earth's crust, after oxygen and silicon. It makes up about 8% by weight of the earth's solid surface and it never occurs as a free element in nature (Totten et al., 2003).

Aluminium has several remarkable properties that explain the wide range of its application. It is used in a variety of industries. Aluminum can easily take any form. The aluminum oxide – a thin film that naturally occurs on the surface of products made from primary aluminium – resist corrosion. Lifecycle of created products from aluminum can be very long. Furthermore, to the list of advantages we can add high electrical conductivity, lack of toxicity and ease of mechanical processing.

Few other metal have as much significance by volume in modern high-tech production – aluminium is used in various industries starting from smartphones and ending with aerospace. Today there is continuing trend of increase in the production of aluminum and its penetration into various spheres of human activity. World aluminum production in 2014 was about 51.7 million tons per year starting from 2011 demand grew by 10% in 2012 and 2013 – for another 6% (Review of aluminum global production market, 2014). Thus, we can say there is a continuing trend to increase the production of aluminum.

Modern aluminum industry is on the second place in terms of importance after the steel industry. The aluminium industry as other metallurgy industries produces a lot of waste, some in the form of low-quality molten product and a number of the world's aluminum producers incur huge potentially avoidable losses. The non-metallic residues generated from dross smelting operations is often termed "salt cake" or "salt slag" and contains 5-7% residual metallic aluminium, 15-30% aluminium oxide, 30-55% sodium chloride, and 15-30% potassium chloride and, depending on the scrap type may contain, carbides, nitrides, sulphides and phosphides (Hwang et al., 2006; Jody et al., 1991). At the moment we can estimate the amount of slag and metal in a ton based on practice of the industry. During the production of aluminum alloys slag is formed in an amount of 15-25 kg per one ton of aluminum. Contents of metallic aluminium in that slag varies from 8% to 90%.

Nowadays it is commercially advantageous to process part of this slag to extract the metallic aluminum from it – as it can then be used as a raw material for the production of aluminum alloys. But processing the slag is generally not commercially advantageous with the state of the art technology. It is usually simply disposed of, which has an extremely negative impact on the environment incurring a potentially avoidable loss on the whole enterprise. The author has found an Estonian company, which is interested in creating new ways of recycling secondary aluminium wastes.

METALLURG ENGINEERING OÜ (Estonia) proposed its model and the process of recycling aluminum slag with the support of the European Union. Company believes to have found solutions that can help businesses solve problems reducing waste through processing aluminium slag. A new process was developed to recover metallic aluminium from aluminium dross. The name of this technology is "Electroslag Melting Method for Reprocessing of Aluminium Slag" or Alucyc (used hereinafter). When compared with available state of the art technologies, the total yield of metallic aluminium from slag can be increased from 95% to 99%.

The Alucyc technology is environmentally friendly which is of high importance to the contemporary industry, however, a strong financial efficiency is needed to support its implementation feasibility and further technological development. Based on the above the author will set the following objectives which will be tackled in the bounds of the present work to analyze the financial feasibility of the technology and give recommendations for the further technology development.

To achieve the stated objective, the author will solve the following tasks:

1) give an overview of the traditional aluminium production technology;
2) give an overview on the formation and handling of slag using state of the art technologies;
3) analyze the effect of slag on the environment;
4) give an overview of the Alucyc technology;
5) analyze the technology's economic feasibility;
6) analyze the environmental impact of the technology.

The paper will be based on the available resources from the enterprise, academic research and statistics available on the subject.

The present an overview of used technology in existing plants and the new system developed by METALLURG ENGINEERING OÜ. In the end author will conclude whether it is favorable to implement this new technology or not. The analysis will be made primarily using economic comparisons as well as the assessment of the environmental impact of the processes.

A qualitative method of research was chosen for the primary task which will reference relevant literature as well as common practice of the plants operating in the industry. Stages of this study are as follows:

1) collecting data and information;
2) systematizing information;
3) comparative analysis based on the systematized information.

A literature search was carried out at TUT library, Rahvusraamatukogu and TTK University of Applied Sciences library. To search for scientific papers Author used www.sciensdirect.com database. To find additional electronic sources www.google.com search engine was used. Keywords such as "dross", "slag", "salt cake", "primary aluminium production", "secondary aluminium production", "waste management", "enhanced economic evaluation" and "new product implementation" were used.
In selecting of literature sources, the author was guided by the following criteria:

1) actuality and connection to thesis topic;
2) based on scientific information;
3) the year of publication.

The work consists of an introduction, four chapters and a conclusion followed by a list of references and an annotation in Estonian. Preparation and design of this study was performed with the help of the TUT master's thesis manual. Below is the description of the paper chapters.

In the first chapter the author will highlight the main theoretical aspects of primary aluminium manufacturing and will take a look on the aluminium slag formation, its chemical and mineralogical characteristics. Author also will observe the state of the art technology (rotary furnace) its energy consumption and the environmental impact when humans produce this kind of material this way. The author will give his assessment on the given topics.

In the second chapter the author will describe the methodology used in the preparation of the master thesis. Furthermore, in this chapter the author will give an overview of the company Metallurg Engineering, and the Alucyc technology – how to use the technology in factories, its technical aspects and the environmental impact that the technology will have. As well author will perform the PESTEL analysis and a practical approach where the author will show the steps of the implementation process of the new technology in existing factories.

In the third chapter the author will offer his economic model for Metallurg Engineering technology and propose how to get profit directly and indirectly from the project.

In the fourth chapter, the author will provide the analysis of the company value chain and its strategy assessment.

In conclusion an objective review of the facts and conclusions from the previous chapters will be made. The method for making the final conclusion will be inductive, i.e. bottom-up from the available information on the subject and the benefits that the new technology may or may not have for the producers of aluminium.

1. ALUMINIUM PRODUCTION OVERVIEW

In this chapter the author will give an overview of the traditional primary aluminium production process. The formation of slag during this process will also be looked at along with state of the art treatment and handling processes for the byproduct – which currently implies a heavy negative impact of it on the environment. It will be argued that the current approach can be improved both from the economic and environmental perspectives from the standpoint of the manufacturer.

1.1 Production of primary aluminium

Aluminium – the most common metal in nature its share of the earth's crust is up to 8%. Due to its chemical activity, it practically does not occur in free form, aluminum mines as such do not exist – minerals and rocks containing significant portions of aluminium in their structure (such as bauxite) are mined instead. Primary aluminium is later refined from this mined raw materials.

Aluminum is mainly produced from bauxite. More than 90% of world reserves resources of this mineral are concentrated in the tropical and subtropical zones: Australia, Guinea, Jamaica, Suriname, Brazil, and India.

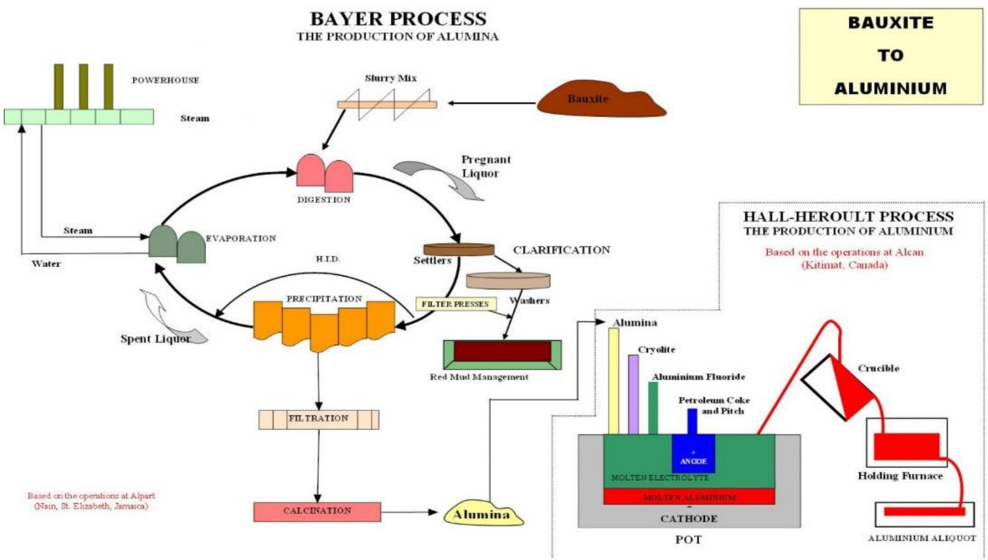

Figure 1. Aluminium full life cycle on factory

Source: The Jamaica Bauxite Institute

The process of extracting alumina from ore is complicated (Figure 1). The first step is to mine the bauxite. The second step is to deliver it to the factory, where it is enriched and the so called alumina – aluminum oxide (Al_2O_3) is obtained. This material is very similar to flour or very fine white sand. Then through electrolysis of alumina it is finally converted to aluminum. To produce the final aluminum product we need to treat two tons of alumina to get just a single ton of aluminum.

Bauxite consist 40-60% of alumina. The rest is mainly silica, iron oxide and titanium dioxide. To separate pure alumina the Bayer process is typically implemented at the enrichment plants. Ore is heated in an autoclave with caustic sodium and then cooled to a solid and separated from the liquid residue. Calcined aluminum hydroxide is used to produce pure alumina.

The mass flow for an output of 1 000 kg primary aluminium is as shown in Figure 1. On average, 5 571 kg of bauxite is required for the production of 1 889 kg of alumina. This high demand of bauxite is due to its significant content of water, approximately 20%, and the large amount of bauxite residue produced, nearly 50% by mass or 2 614 kg on average (Kornelíusdóttir, 2014).

The final stage is the reduction of aluminium through the Hall-Heroult process. It is based on the following principle: when the alumina solution is electrolyzed in molten cryolite (Na_3AlF_6), pure aluminium is produced. The reduction cell bottom serves as a cathode, and coal bars immersed in cryolite serve as anodes. Molten aluminium is deposited under a cryolite solution with 3-5% alumina. During this process, temperatures reach 950°C, considerably higher than the melting point of the metal itself, which is 660°C (UC RUSAL, 2014).

During the electrolytic process, alumina is chemically reduced according to equation (1) and requires a stoichiometric minimum of 1 889 kg alumina and 333 kg carbon from anodes to produce 1 000 kg pure primary aluminium (Kornelíusdóttir, 2014):

$$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2 \quad (1)$$

In the Hall-Heroult reduction process, coal anodes are consumed very quickly and should be replaced with new ones. This problem can be solved with the renewable Soderberg electrode. It is formed in a special restoration chamber of coke and tar paste, which is fitted into a steel sheet cover which lies open at both ends. The paste is filled into the upper opening when necessary. It is heated before it reaches the cell with melt (UC RUSAL, 2014).

The oxygen in alumina is mostly released as carbon dioxide (CO_2) but some of it does, however, form carbon monoxide (CO). Equation (2) occurs in parallel with equation (1) (Kornelíusdóttir, 2014).

$$Al_2O_3 + 3C \rightarrow 2Al + 3CO \quad (2)$$

To lower the energy costs and the impact on the environment is better to use using the pre-baked anode technology in production, which is practiced in many European and American aluminum productions. The anodes are baked in huge gas furnaces and then, having been fixed into holders, are lowered into a furnace. Consumed electrodes are replaced with new ones and remaining ‘butts’ are sent away for recycling (UC RUSAL, 2014).

Therefore the average net anode consumption is larger than the theoretical amount predicted. The actual production process could therefore be described as a four breakdown of alumina via electrolysis, producing 1 000 kg of aluminium, releasing reacted oxygen with the carbon anode as CO_2 (Kornelíusdóttir, 2014).

Due to stricter environmental regulations that are being implemented around the world, companies using the Soderbergh process are faced with a serious problem of reducing harmful emissions. At the moment it is usually solved by implementing colloid anodes made of special colloidal mass with a thermal stability over a wide temperature range. Based on its environmental indicators this method is comparable to pre-baked anode technology. Once a day the metal is removed from the cells and poured into molds.

Aluminium production is very energy intensive. Therefore, aluminum smelters find it most profitable to build in areas with low electricity costs, e.g. near hydroelectric plants.

In 2007 total aluminium production was around 38 million tons (with over 18 million tons recycled from scrap) and in 2013 the total was close to 61,9 million tons (with close to 18,7 million tons recycled from scrap, Figure 2) (US Aluminum Statistics and Information 2013 and 2014). By 2020 metal demand is projected to have increased to around 97 million tons (with around 31 million tons recycled from scrap). In European Union (EU 27 + EFTA 2011) based on latest open data author according on statistics of European Aluminium Association (EAA) and IAI annual reports can conclude that 50% of aluminium produced and distributed in Europe is produced from scrap.

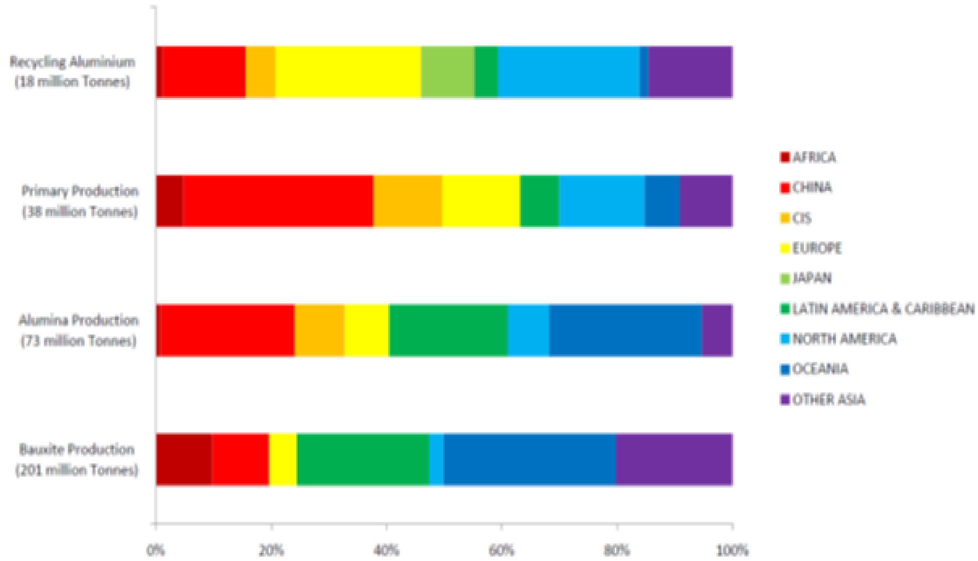

Figure 2. Regional Bauxite, Alumina, Primary and Recycled Aluminium Production, 2007

Source: International Aluminium Institute

Every year the rate of receiving raw material from scrap is increasing. Total amount of primary aluminium production for West Europe starting from January 2014 to December 2014 was 3 514 thousand metric tons of aluminium (Figure 3).

When producing the secondary aluminium they try to make economic savings and reduce the overall environmental footprint of the industry by implementing dross and salt slag from the primary aluminium production process. For this purpose solutions with complex processes and minimum economical advantage are used. These processes are still highly energy-intensive.

Figure 3. Primary aluminium production in West Europe, 2014

Source: The International Aluminium Institute statistics

The slag aluminium production adopts the wide use of reverberatory furnaces and rotary melting furnaces.

1.2 Salt slag formation and characteristics

Residues with more than 45% Al are called "skimming" and materials containing less than 45% Al are called "dross". Dross may also be separated into "white dross" from primary smelters without salt cover and "black dross" from secondary smelter (Figure 4). The white dross may contain from 20% to 45% recoverable metallic aluminium and it comprises a fine powder from skimming the molten aluminium. Typically, black dross contains aluminium metal (10-20%), a salt-flux mixture (40-55%), and aluminium oxide (20-50%). The non-metallic residues generated from dross smelting operations is often termed "salt cake" or "salt slag" and contains 5-7% residual metallic aluminium, 15-30% aluminium oxide, 30-55% sodium chloride, and 15-30% potassium chloride and, depending on the scrap type may contain, carbides, nitrides, sulphides and phosphides (Hwang et al., 2006; Jody et al., 1991).

To provide a clearer understanding of the topic and the problem, which the author faces we must look at the mineralogical characteristics of raw materials, semi-products and by-products of the primary aluminium production process to gain a more detailed understanding of the problem. For this we shall look at research based on salt cakes obtained from Australian aluminium smelters.

Figure 4. The aluminium mixture of dross and slag

Source: Made by the author

Slag itself contains metallic aluminium as well as many other substances, some of which have an intrinsic value, some of which are toxic, and some of which react with water to give off toxic gases. Slag contain many different components, and most of the elements present are listed in Table 1 for two separate Australian samples. Although the two samples are broadly similar in composition there are many subtle differences in detail (Bruckard, et. al, 2009).

These differences presumably result from differences in feedstock and operating practices. Table 2 lists the various phases identified in the two Australian salt cakes studied in this work using qualitative X-ray diffraction (XRD), scanning electron microscope (SEM) examination, electron probe micro analysis (EPMA), various chemical techniques, and hand sorting of the coarser size fractions of crushed salt cake to remove relatively coarse pieces of metallic aluminium. Of particular note is the method of determination of the fine-sized metallic aluminium by cold bromine methanol extraction followed by analysis of the extract solution *(Ibid.).*

Table 1. Chemical analyses of Australian salt cakes (wt%)
Source: Bruckard et al., (2009)

Element	Smple A	Smple B	Intermediate elements (0,1-1,0%)	Samble A	Sample B
Major elements (>1%)	-	-	Ca	0,72	0,50
			Ca	0,55	0,42
Al (total)	37,2	36,8	Ti	0,13	0,50
Al (metallic)	1,22	2,79			
Cl	9,39	6,79	Minor elements < (0,1%)		
Na	8,52	5,20	Zn	0,089	0,012
N	7,53	1,96	P	0,065	0,020
F	5,50	5,50	Mn	0,057	0,047
K	3,18	3,74	Ba	0,017	0,018
Mg	2,59	0,70	S	0,020	0,020
Si	2,07	1,03	Pb	0,019	0,024
Fe	0,82	5,85	V	0,013	< DL

The Table 2, is the alphabetical list of phases identified in typical Australian salt cake by qualitative XRD and other methods including SEM examination, EPMA, and chemical analysis by various methods and hand sorting. The decreasing order of relative abundance is as follows: major, medium, minor, trace and <DL, where <DL was below the detection limit by XRD conditions used say (3-5%). This phase was detected by one or more of the other analytical methods. And some phases have got the same composition, but different crystal forms *(Ibid.)*.

Table 2. Salt cake consist of minerals (wt%)
Source: Bruckard et al., (2009)

Phase	Formula	Relative abudance
Aluminium calcium	AlCa	< DL
Aluminium metal	Al	Trace
Aluminium nitride	AlN	Medium
Aluminium oxide	Al_2O_3	< DL-trace
aluminium oxide nitride	Al_5O_6N	< DL-trace
Bayerite	$Al(OH)_3$	< DL-minor
Corundum	Al_2O_3	Major
Cryolite	Na_3AlF_6	Trace-minor
Diaoyudaoite	$NaAl_{11}O_{17}$	Minor
Elpasolite	K_2NaAlF_6	Trace-medium
Fluorite	CaF_2	< DL
Gibbsite	$AL(OH)_3$	< DL
Halite	NaCl	Major
Iron metal	Fe	< DL
Silicon metal	Si	< DL
Sodalite	$Na_6(Al_6Si_6O_{24})2NaCl$	< DL
Sylvite	KCl	Minor-medium
Villiaumite	NaF	< DL

Determined by direct analysis of the screen size fraction. Sum of aluminium in the three coarsest size fractions. Calculated by assuming that all of the carbon present is there as aluminium carbide (Al_4C_3). Calculated by assuming that all the nitrogen present is there as aluminium nitride (AlN), but some aluminium oxide nitride (Al_5O_6N) is also present. Present in an unknown form, but calculated as the Al_2O_3 equivalent. Calculated by the difference between the aluminium accounted for here and total aluminium content of the feed *(Ibid.)*.

Table 3 also shows that reasonably high levels of aluminium carbide (Al_4C_3), aluminium nitride (AlN), and aluminium oxide nitride (Al_5O_6N) are present. These and other compounds present can react with water to give off noxious gases such as hydrogen, ammonia, methane, and gaseous sulphides and phosphides, and this must be taken into account in any proposed wet treatment process as discussed later *(Ibid.)*.

Table 3. Salt cake contribution of bearings (wt%)
Source: Bruckard et al., (2009)

Aluminium-bearing phase	Sample A (%Al in feed)	Sample B (%Al in feed)
+20 mm metallic Al	0,50	0,88
-20+0,85 mm metallic Al	0,36	0,09
-0,85 mm metallic Al	0,36	1,82
Total metallic Al	1,22	2,79
Carbide aluminium	1,59	1,21
Nitride aluminium	4,80	1,26
Water-soluble aluminium	0,28	0,30
Other aluminium	29,3	31,24
Total aluminium in feed	37,20	36,80

The characteristic data showed that the salt cakes contained at least 12 major elements present in at least 19 identifiable phases. The major elements (greater than 1%) differed for each sample, but also presented some similarities. The aluminium content is similar at about 37% Al, the fluorine content at 5% F, and the potassium content at 3-4% K. However, the nitrogen content, which is present as aluminium nitrides, range from 2% to 7% N. The intermediate elements calcium and carbon are present in similar amounts, but the others (iron, magnesium, and titanium) were variable. The minor elements are very variable. These variations are difficult to interpret, but presumably result from different feed-stocks and differences in operating practices. The phases identified in the two salt cakes by qualitative

XRD were: aluminium (Al), aluminium calcium (AlCa), aluminium nitride (AlN), aluminium oxide (Al_2O_3), aluminium oxide nitride (Al_5O_6N), bayerite $Al(OH)_3$, corundum (Al_2O_3), cryolite (Na_3AlF_6), diaoyudaoite ($NaAl_{11}O_{17}$), elpasolite (K_2NaAlF_6), halite (NaCl) and sylvite (KCl) (Tsakiridis, 2012).

To calculate the world slag volume we need input data in regards to world aluminium production. We know that in 2014 production of primary aluminium in the world was $51{,}746 \cdot 10^6$ metric tons (hereinafter t). Peoples Republic of China (hereinafter China) was producing half of the world capacity $23{,}94 \cdot 10^6$ t, Russian Federation (hereinafter Russia) $3{,}92 \cdot 10^6$ t, Persian Gulf Arab States $4{,}833 \cdot 10^6$ t, North America (USA and Canada) produced $4{,}576 \cdot 10^6$ t, Central Europe $3{,}765 \cdot 10^6$ t, Western Europe $3{,}513 \cdot 10^6$ t, Asia countries (ex - China) $2{,}42 \cdot 10^6$ t, Oceania produced $2{,}043 \cdot 10^6$ t, Africa $1{,}745 \cdot 10^6$ t, South America declared $1{,}745 \cdot 10^6$ t and others $0{,}985 \cdot 10^6$ t (Figure 5).

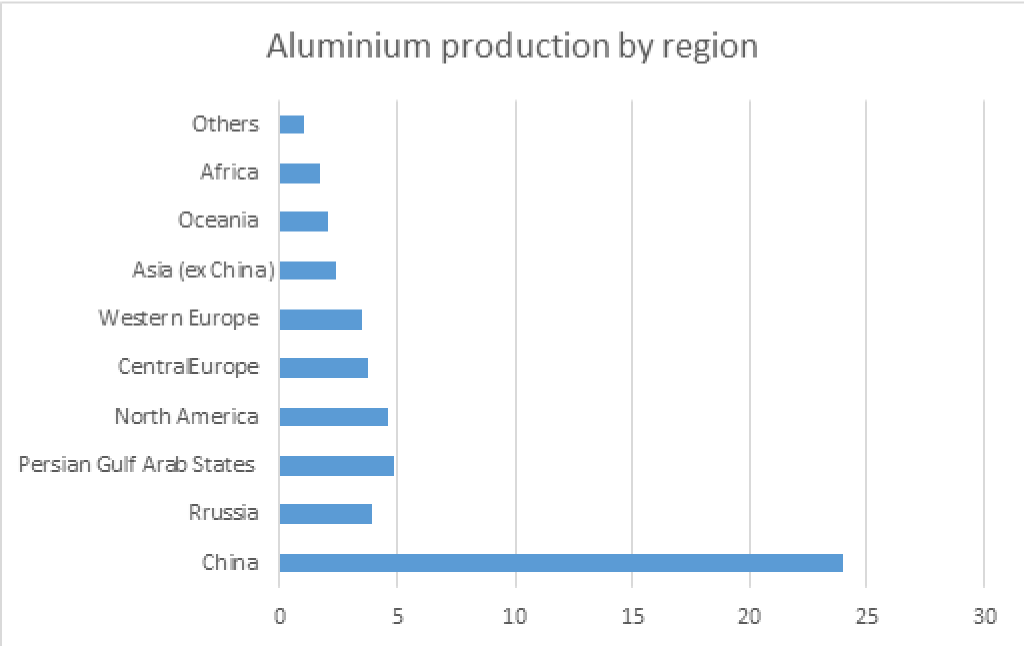

Figure 5. Aluminium production by region (thousand tons)

Source: Composed by the author

We can now construct a simple equation to calculate how much slag was created as a byproduct of production of primary aluminium. Aluminium is produced from bauxite. On average it takes two tons of bauxite to produce one ton of primary aluminium. At the same time 25 kg of slag is produced as a by-product. The formula can be written as:

$$\frac{a}{b} = x, \qquad (3)$$

where, a - denotes the amount of slag in weight formed per ton of primary aluminium production

b - one ton of aluminium

$$\frac{25\ kg}{1\ 000\ t} = 2{,}5\%$$

Thus, when a factory produces one ton of primary aluminium it is also creates an extra 2,5% of slag which is harmful and dangerous.

To calculate world slag production:

$$T \cdot x = y, \qquad (4)$$

where, T - world primary aluminium production in tonnes per year

x - amount of slag per ton

$$51{,}746 \cdot 10^6 \cdot 2{,}5\% = \frac{51{,}746 \cdot 10^6 \cdot 2{,}5}{100^2} = 129{,}4 \cdot 10^4 = 1\ 294\ 000\ t/year$$

So worldwide we will have more than 1 million tons of slag. Which is going to landfills and causing a negative impact on the environment.

We can calculate the slag production for every region in the world, but this paper will focus on China and Western Europe (Norway and Iceland). China is the main world aluminium producer, the industry here having a noticeable positive impact on the environment, Norway and Iceland are the biggest producers in Europe excluding Russia.

1.3 Recycling slag in rotary furnace

Many scientists and researchers dealing with recycling dross and slag suggest that recovering aluminium is not economically viable and it must be disposed on landfills. Others see benefits and try to remove unwanted components using different complicated processes which are suitable for dross with high concentrations of aluminium.

Enterprises should be interested in the new approaches of slag treatment as these can increase the overall efficiency the aluminium production process. The development of these processes started in late seventies by the United States in Bureau of mines. Using this method we can recover up to 80% of the metallic aluminium. Disadvantages are the produced slurry, the time and the complicated process that uses vacuum filtration and gas elimination.

Also in the late 70s a method was developed using wet milling technology. The main idea is to wash up all aluminium from slurry. It is technologically very complicated, takes more time, but the byproducts can be used in cement production as a supplement.

The most popular recycling process is the tilting rotary furnace (Figures 6, 7) as it produces the largest amount of recoverable metal. Today we can say that it is a state of the art technology – the author will describe it in detail. First we need to point out that it is a complicated process compared with the melting of solid materials. This technology uses a salt bath for maximum recovery of aluminum from dross. The recovery rate is 94% aluminum metal the process of economic benefits in the case of the aluminum content in the slag more than 35%. During the processing of saline slag obtained Al_2O_3, salts, impurities and about 6% aluminum. Waste from this process is toxic, uneconomical to recycle and disposed of in the bulk, which is extremely negative impact on the environment and makes the disposal of these wastes both an expensive and a complicated process. Because the process is carried out in gas rotary furnaces, the process is accompanied by the processing of gases (CO_2, NO, NaCl, KCl etc.). In a volume of tens of thousands of cubic meters per ton of slag, which requires special expensive scrubbing systems. There are also other processing technologies, but they do not allow the use of alumina remaining after refining slag for the production of primary aluminum, or are accompanied by generation of waste or are on the whole economically disadvantageous.

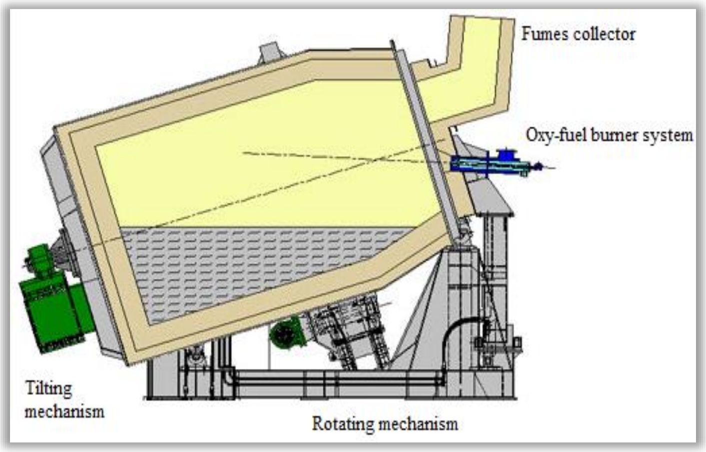

Figure 6. Rotary furnace

Source: Metallurg Engineering OÜ

In the rotary salt furnace process, an oil or gas fired furnace is charged with the dross and a salt flux (up to 50% of the feed) is added. The metal when comes in contact with air forms aluminium oxide at the outer surface of the melt. The salt protects the metal from the reactive atmosphere and facilitates agglomeration and separation of the metal, thereby increasing metal recovery (Unlu et al., 2002). It also enhances the heat transfer to the metal, it prevents the oxidation of the metal and takes up contaminants, such as oxides, nitrides, carbides and others contained in the scrap or produced by reactions during the melting process. After melting, aluminium metal and salt slag are tapped from the furnace. The non-metallic components from raw mix are completely absorbed by the liquid flux and forms after tapping and cooling the so-called salt slag or salt (Tsakiridis, 2012). The oxide in the dross (in the raw mix) exhibits the form of a continuous net where aluminium stays entrapped. The molten flux breaks this framework and facilitates the coalescence of aluminium drops that sinks to the aluminium bath (Das et al., 2006). Organic contaminants after decomposition normally leave carbon in the salt slag. If there is insufficient salt, high concentration of oxides and other contaminants may lead to high viscosity levels in the molten salt. More viscous slag keeps the metal droplets entrapped and leads to significant metal loss in practice. Aluminium carbide Al_4C_3 is formed when liquid aluminium is in contact with finely dispersed carbon, originated from organic contaminations of scrap like paints, plastic coatings, and hybrid-sandwich components. The dross containing AlN is fed into rotary furnaces, where the AlN is picked up by salt slag. Aluminium phosphide and sulphide are generated by the reaction of liquid aluminium with phosphates and sulphates in the feed (Zhou et al., 2004). The recovery efficiency of aluminium is range from 65% to 75% (Lazzaro et al., 1994).

Figure 7. Rotary furnace at Herwick AB in work

Source: SMS Concast AG

The wastes in this process contains large amounts of non-environmentally friendly salts that must be buried or disposed of in landfills. Another way to recover Aluminium from Aluminium dross is in the use of a plasma arc torch as a heating source.

The plasma treatment of Aluminium dross is a promising technique among the proposed salt-free Al dross treatment processes. Nowadays there are two plasma processing plants of Aluminium dross: the Alcan plant in Canada and the Plasma Processing Corp. plant in USA (Yoshimura et al., 2008).

Author will provide some technical facts:

1) Melting capacity is from 0,5 to 0,7 tons per hour.
2) The process is catalyzed with salts.
3) Melting temperatures are 700-750°C.
4) Greenhouse gases emission have reach up to 1 000°C in a normal working cycle.
5) High energy demand.
6) 500 kg of salt slag can be generated in the production of one ton of aluminium metal.

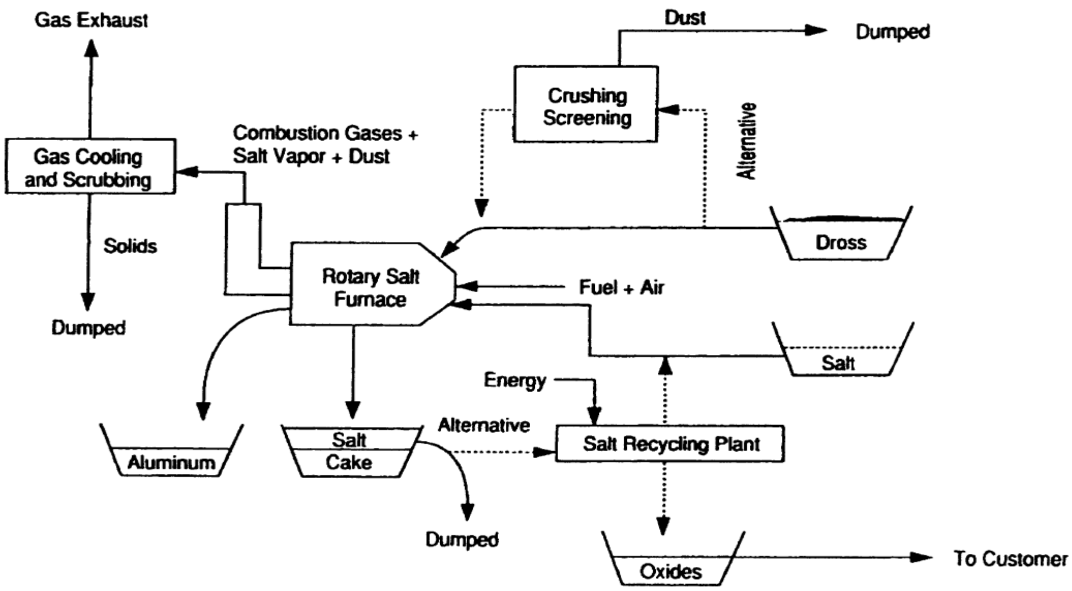

Figure 8. The rotary salt furnace process

Source: Unlu et al., 2002

Using this method brings some disadvantages such as its cost, environmental and safety hazards (Unlu et al., 2002). The non-metallic by-product is referred to as salt cake, to a mixture of aluminum oxides and other metals with salts. The by-product itself is an environmental problem *(Ibid.)*

The process is started when the salt slag collected after Hall-Heroult process transported to the recycling area on the aluminium factory. The process will start from crushing and milling the material after that it will be loaded in furnace. Furnace will be heated till 750°C. The mechanical drum in furnace will rotate till the fulfilled slurry became a homogenous material. Once molten, the furnace is stopped and the molten aluminium is then discharged from the furnace *(Ibid.)*. A schematic view of a usual layout is shown in Figure 8.

The author will provide energy consumption examples which is widely utilized in Alcan. Alcan is a Canadian Aluminium Company that was purchased by Australian-European multinational Rio Tinto in 2007, becoming Rio Tinto Alcan Inc.

The Alcan model is to treat with plasma torch dross process to recover them aluminium losses among getting the primary aluminium. The process was described in detail in the last section (see Figure 8).

Alcan uses air plasma, because the air is much cheaper than nitrogen, thus an efficiency of air is much higher than any gas. The energy efficiency is reported to be as high as 80-95% *(Ibid.)*. In Figure 9 the typical energy origin and utilization is given. The energy input may also come from the nitridation and oxidation of the metal in addition to that coming from the burner or the electrical torch or an arc. Losses are through the walls, the door when open, the stack, and also in the torch cooling water. The oxidation and nitridation of the aluminum by the air plasma is an important source of heat (28% as indicated). This reduces recovery of aluminum by 5% and increases the amount of residues by 8% (Lazzaro et al., 1994).

However, using recoverable aluminum metal as a fuel to heat the furnace is not economical and should be avoided if possible. Furthermore, in the plasma torch process, the necessity to periodically remove the torch from the furnace for electrode maintenance requires highly specialized torch maintenance personnel *(Ibid.)*.

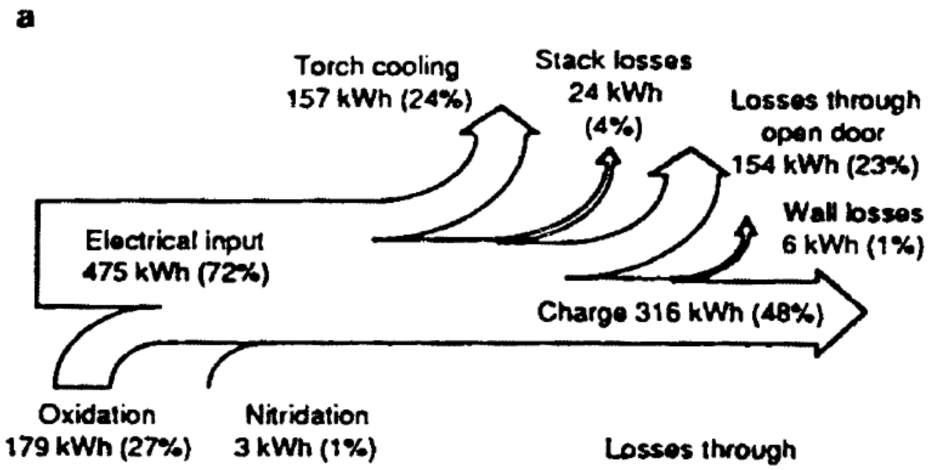

Figure 9. Rotary furnace energy consumption

Source: Unlu et al., 2002

Energy sources and utilization per ton of dross input containing 50wt% free aluminum (Unlu et al., 2002).

Overall energy consumption, including these elements as well as the energy required for anode production, is in the range of 14 700 kW h/ton for new plants. Design and process improvements have progressively reduced this figure from about 21 000 kW h/ton in the 1950s, a decrease of about 30%. Energy consumption in Soderberg plants is higher, ranging from 15 500 to 16 500 kW h/ton aluminium produced (Lazzaro et al., 1994).

The production of one metric ton of aluminium from ore (bauxite) requires about 16 500 kWh of electricity while the same amount of recycled aluminium consumes approximately 850 kWh.

1.4 Environmental impact

In order to decrease the environmental burden (or increase in environmental efficiency) drastic changes must be made to both consumption and production systems. This can include technological innovation, closing industrial production and consumption loops, altering consumption patterns, and transition management. In terms of industrial production, both incremental and radical technological changes play a significant role. With incremental innovations, a 10-30% reduction of the environmental burden could be generally achieved in industry over a 50 year time-horizon but radical changes are also necessary in order to achieve higher environmental efficiencies (80-95% reduction levels) in emissions, waste and energy use (Moors, 2006).

In other words we must invest capital in new technologies, the innovations will pay themselves off in the future years both economically and by brining less harm to the environment as was written in Technology strategies for sustainable metals production systems article.

In all articles that have been used by the author, author can conclude that aluminium production is very energy intensive there will be a big amount of greenhouse gas emission and the worldwide gas emission will be approximately 1% annually. Due to the salt slag properties, it is classified as toxic and hazardous waste (10 03), according to the European Catalogue for Hazardous Wastes. It is considered as “highly flammable” (H3-A: substances and preparations which, in contact with water or damp air, evolve highly flammable gases in dangerous quantities), “irritant” (H4: non-corrosive substances or preparations which through immediate prolonged or repeated contact with the skin or mucus membrane can cause inflammation), “harmful” (H5: substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, involve limited health risk) and “leachable” (H13: substances and preparations capable by any means, after disposal, of yielding another substance) (European Waste Catalogue and Hazardous Waste List, 2002; Moors, 2006).

A disposal of salts cakes as by-product after rotary furnace is a headache for aluminium enterprise and become a worldwide problem. The entering in to soil, water of any toxic metal compounds will seriously harm environment or even pollute an air. (Tsakiridis, 2012)

The main problem is its leachability (H13) and its high reactivity with water or even humidity in air (H3-A), leading to the formation of toxic, harmful, explosive, poisonous and unpleasant odorous gases, such as NH_3, CH_4, PH_3, H_2, and H_2S. The gaseous emissions from the salt slag that result from contact with water are of great environmental concern (Das et al., 2006).

As a result, when aluminium salt slag is disposed on hazardous waste landfills, pollution of ground water (e.g.: F-, Cl-, NH_4+, CN-, high pH) and ambient air (e.g.: CH_4, H_2, NH_3) can be observed. However, because of increasing local environmental and institutional barriers to the development of new landfills, the disposal of salt cake residue is expected to be forbidden or become scarce and costly *(Ibid.)*.

All this confirms the author's beliefs that a better waste handling technology is a viable and needed solution for the future of the industry; and demand to install such technology in industrialized or in developing countries such as India, China, Russia, Australia, Guinea, Jamaica or in Europe such as Norway is high.

Depending on that companies must utilize the slag. In the past, the salt slag was buried without any treatment methods. Today, the minimization of landfilling any slag is generally done in Europe, US and Canada. The aluminium and the salt within the salt slag are recovered. Graczyk et al., Bruckard and Woodcock, Davies et al., Lopez et al., Pereira et al. reported that salt cakes are very expensive to dispose of in waste dumps because they contain many toxic compounds and many water-soluble compounds. Environment problems are huge due they hazardous impact.

Salt slags are the by-products of the secondary aluminium industry, which should be recycled and processed in a proper way by taking environmental impact into consideration (Yanping Xiao et al., 2005).

The gaseous emissions from the salt slag (slurry) that result from contact with water are of great environmental concern. In the leaching process, the components in the slags react with water and generate explosive, poisonous, and/or unpleasant odorous gases. Because of the soluble residues and the hazardous gas evolution, the salt slag cannot be simply dumped. So far, the best way is to recycle the salt, to utilize the residues, and to recover the generated gases *(Ibid.)*.

The responsibilities of the metallurgists are not only to produce high quality metal products, but also to protect the environment and further to protect human health. Through improving the quality of the industry byproducts and increasing the utilization rate of salt slag residues, the living environment can be protected and an economic use of the natural resources can be guaranteed *(Ibid.)*.

1.5 Conclusions

The author has presented an overview of primary aluminium production lifecycle from bauxite. The master's thesis describes salt slag formation and characterization, including the precious aluminium used in the aluminium alloy industry, which is lost when disposed of to the landfills.

Also, classification of the slag as a toxic and hazardous waste (highly flammable, irritant, harmful and leachable) is discussed. As a result, its landfill disposal is forbidden in most of the countries of the world and it should be recycled as much as possible to minimize its impact on the environment. High energy consumption of the existing processes has been underlined. The technology to be used by most of the enterprises is to treat slag using rotary furnaces.

The following problems identified and the objectives outlined must be solved in the thesis are as follows (Terehhov, 2010):

1) Incomplete extraction of aluminium from the aluminium slag. The method allows one to extract no more, than 95% of metallic aluminium or aluminium alloys. Thus, an average of 5-10% of metal aluminium remains in the secondary waste in the form of salt slag.
2) The necessity of expensive environmental protection measures. This is due to the large quantity of waste gases forming at the reprocessing of aluminium slag using the known methods, which demands a high-powered gas-cleaning plant. Besides, for the environmentally harmful waste disposal, it is needed to assign the large territories with the specific measures of protection against the ingress of salts into subterranean waters. The existing methods for complete reprocessing of the environmentally harmful salt slag are very expensive and therefore rarely used.
3) The economic inefficiency of the known method for reprocessing of aluminium slag with metallic fraction content below 25%. Accordingly, such aluminium slag is practically not being reprocessed at present.

The objective of the new technology is to eliminate the above-mentioned deficiencies and to create a new high-performance, an environmentally acceptable method of reprocessing of aluminium slag, in particular the method that would guarantee high level extraction of the metallic component. At the same time, it is preferable for the new method to provide a possibility of reuse of the obtained slag, e.g. alumina (Al_2O_3) or its mixture with the cryolite in the production of the primary aluminium *(Ibid.)*.

The objective of this thesis is to analyze the financial, environmental and technological feasibility of the technology and give recommendations for further technology development.

To achieve the stated objective, the author will solve the following tasks:

1) give an overview of the traditional aluminium production technology;

2) give an overview on the formation and handling of slag using state of the art technologies;
3) analyze the effect of slag on the environment;
4) give an overview of the Alucyc technology;
5) analyze the technology’s economic feasibility;
6) analyze the environmental impact of the technology.

2. ALUCYC TECHNOLOGY ANALYSIS

For the analysis of the Alucyc the author will use a qualitative research method. The method refer to how the researcher chooses to analyze and work with the information that has been gathered from the research subject (Patel et al., 2003). Qualitative research is characterized by a lower grade of control and formalization and is mostly used when trying to understand and create a deeper understanding about complex real life phenomena. Qualitative research aims at understanding rather than explaining (Gummesson, 2000).

A qualitative method of research was chosen for the primary task which will reference relevant literature as well as common practice of the plants operating in the industry. Stages of this study are as follows:

1) collecting data and information;
2) systematizing information;
3) comparative analysis based on the systematized information.

These were limited in terms of linguistics: where only papers published in Russian, Estonian and English were used. The structure of this paper is divided into four parts.

Information collection started with a particular article "Aluminium salt slag characterization and utilization – A review" and was continued while the master thesis was written.

2.1 Technology review

The main initiator of the Alucyc technology is Metallurg Engineering Company. Metallurg Engineering (Figure 10) is an Estonian enterprise based on Estonian capital. Business Activities which occur in the metallurgy industry we must to mention that company is an engineering company that use 10 years of experience on development of unique alloys and their manufacturing technology for aluminum industry. They have experience on initialization and management of development projects with large scale enterprises. They have, also, experience on development of silica metal refineries and utilization equipment for low-radioactive waste (Alucyc Project Site, 2014).

Figure 10. Metallurg Engineering logo

Source: Metallurg Engineering web page

The Alucyc technology is a new process to recover metallic aluminium from aluminium dross and slag. The goal of the new technology is to enable the almost complete recovery of aluminium from dross. Compared with available state-of-the art technologies, the yield of metallic aluminium will be increased from 95% to 99% using the new technology developed in Alucyc.

Alucyc technology is waste-free, cryolite and the remaining aluminium oxide could be used in melting of primary aluminium as additives. To develop the Alucyc technology, a phase model, novel electroslag furnace with non-consumable electrodes and process and power control systems will be designed and integrated. With support from primary aluminium smelters, Alucyc technology will target potential end users in the industry and will be therefore easily implementable.

The research leading to these results has received funding from the European Community's Seventh Framework Programme managed by REA (Research Executive Agency) under grant agreement no. 286676 (Alucyc Project Site, 2014).

Aluminium is a very useful material, it is worth a special mention that primary aluminium is as good as the product received from recycling. The obvious benefit from that is that you can get nearly the same amount of aluminium from recycling an aluminium can as was used to produce it in the beginning from primary aluminium. From that we can conclude that there is no difference what kind aluminium to use – the only difference is the energy consumption: when factories remelt secondary aluminium the process is much less energy intensive than that of primary aluminium production.

We will now look in detail at the invention of Metallurg Engineering: what equipment is needed, what are the requirements for the process and give quantitative examples of introducing the new technology. The text is compiled based on patent WO 2010/022742 A1 “Electroslag melting method for reprocessing of aluminium slag” which can be found in World Intellectual Property Organization, the patent can be found on Espacenet web page:

http://worldwide.espacenet.com/publicationDetails/biblio?DB=worldwide.espacenet.com&II=1&ND=3&adjacent=true&locale=en_EP&FT=D&date=20121010&CC=RU&NR=2011111585A&KC=A

The technology is interesting, firstly, in its simplicity and uniqueness which allows for efficiently processing slags without generation of any toxic wastes into the environment (Alucyc Project Site, 2014). The income gained from selling the by-product which is of no use to the aluminium industry will further cover some costs incurred during installation of equipment and will bring extra income after the project has reached its break-even point.

The author above will overview the following points:

1) aluminium and alloys that will be used as a raw material for production primary aluminium;
2) how cryolite from boiling aluminium dross can be used in primary aluminium melting process which is of great benefit to the industry as it reduces waste from production and in future minimizes utilization penalties;
3) patent author claims that in combination with high economic indexes, the method permits to reduce the environmental pollution.

2.2 Characterization of Alucyc process

Schematic view of the equipment is on Figure 13.

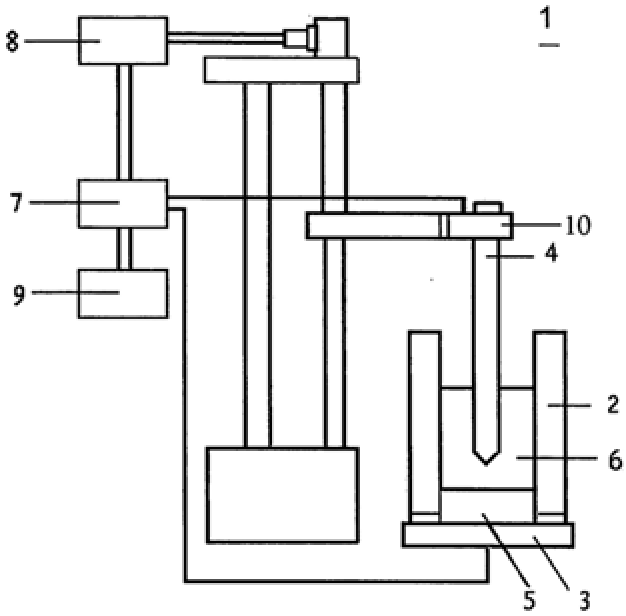

Figure 11. A schematic representation of the Alucyc furnace

Source: patent WO 2010/022742 A1

The Alucyc furnace (Figures 11, 12) will be produced from steel with electronic and electric units – the diagram above shows the schematic overview of the product. The pot (marked number 2) will be made from special materials which will resist the calcic liquid, in our case cryolite (Na_3AlF_6) with temperatures reaching 800-2000^{0}C. Inside the pot one can see the bottom electrode attached to the lower cap (cathode number 3), this will accumulate the negative electric charge (-) – this is where liquid aluminium will settle. Number (4) on the diagram shows the location of the removable anode on which will be supplied with the positive electrical charge (+). Aluminium is schematically shown by number (5) – it is extracted from the slag during the extraction process which is started by the cathode (3). Number (6) is liquid secondary slag which is gathering near the anode (4) in the top part of the pot (2). When we look to the left of the figure we will see number (7), showing where the supply power box that is connected directly to the bottom electrode (3 cathode). On the hull of the device the smart computerized control panel (8) is installed, above it there is a processing and registration system (9). And the last but not least – the atomized anode drive (10).

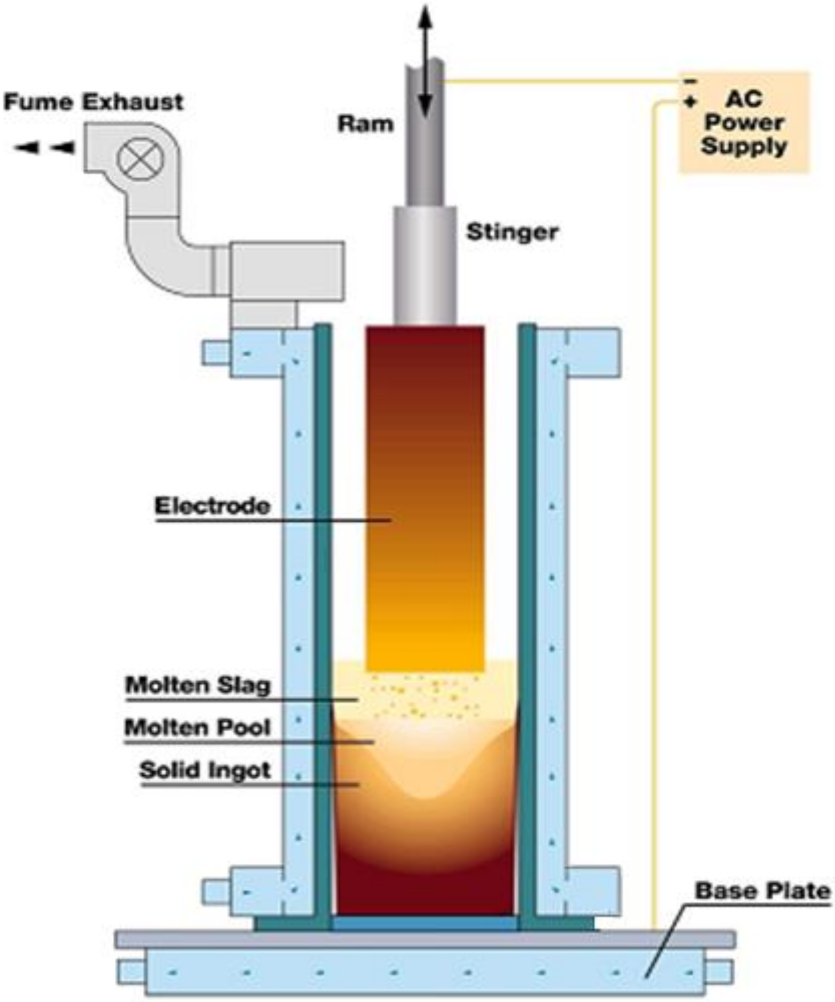

Figure 12. Graphic representation of the Alucyc furnace
Source: Created by Metallurg Engineering

The invention must reduce and eliminate the inefficiencies of rotary furnaces and Metallurg Engineering claims to have created a new high performance method to extract and produce new aluminium from slag. The mentioned method is environmentally friendly, also the new processes will provide the possibility to use aluminium dioxide (Al_2O_3) along with reused cryolite not only in secondary production, but also in primary aluminium production, which will save costs of buying chemical mixtures for primary production, in our case – cryolite.

The process will be easy to control and maintain. The process is similar to primary aluminium production of which the workers at the plants should have a good understanding. The first production step is to load the mineral cryolite (Na_3AlF_6) or a mixture of aluminium dioxide (Al_2O_3) and cryolite, optionally extra components can be added to create the needed composition of the aluminium product (Figure 13). After that aluminium dross or slag is added to the pot, the machine warms up heating and melting the raw-materials in the pot. The bottom and top electrodes begin working powered by the electrical current: bottom cathode will attract the aluminium, the top cathode will collect slag. After some time that the process is active and the liquid aluminium with alloys is being refined we can easily add additional batches of material that are to be processed in the pot. There is, also, a possibility to add extra cryolite mixture as needed. The process supposes that a conveyor line at the bottom of the pot will automatically carry off the refined aluminium when a certain level is reached: sensors mounted in the pot and the conveyor platform will communicate each with each other and the furnace will pour its contents – the refined aluminium, which may be now used for production purposes.

Figure 13. Alucyc process
Source: Made by the author

In the process of reprocessing of aluminium slag in the above-described electro-slag furnace, the anode is being inserted into the cryolite or mixture thereof with alumina and other components until the anode completely contacts with the cathode, then the melting of the mixture occurs and the electrolyte is being formed. After that the aluminium slag and cryolite are being charged portion-wise into the electrolyte, with following melting and dissolution. The segregation of the obtained melt into metallic fraction and non-metallic fraction occurs due to the gravitation force and also due to the electromagnetic force, arising at the passage of current through the electrolyte. This determines the efficiency of the described process (Patent No. WO 2010/022742 A1, 2010).

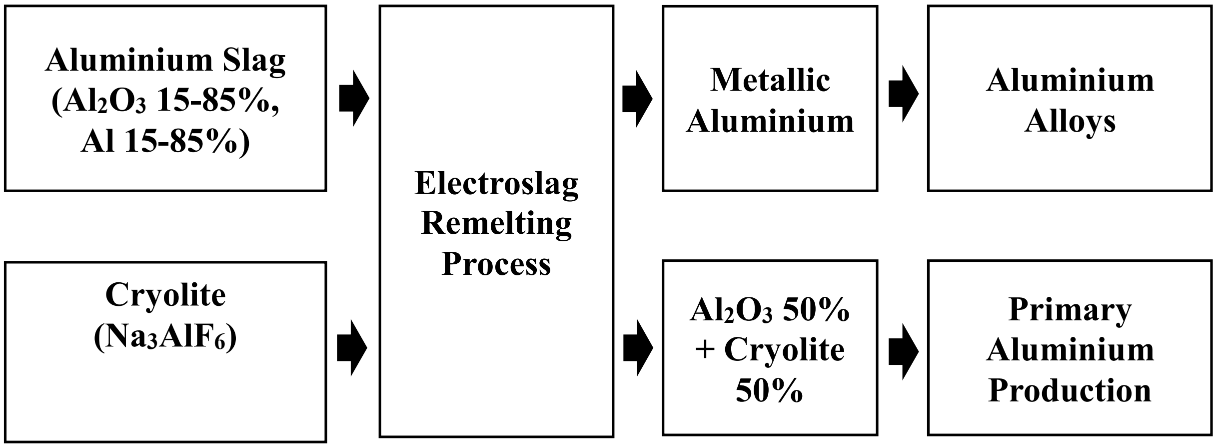

Figure 14. Alucyc chemical process

Source: Composed by the author

To correctly fulfill the working requirements and not to spoil the recycling process (Figure 14), the producer must count the necessary quantity 10-20% of the full charge the mixture of cryolite and alumina. Normally the components of this mixture are taken in ratio of 18% Al_2O_3 and 82% Na_3AlF_6 (also other concentrations and the use of other components and additions are possible). After the complete melting and dissolution of the initial portion of mixture, the consecutive charging by portions of crushed aluminium slag (i.e. mechanical mixture of metal aluminium and (Al_2O_3) and of cryolite and optionally other components is being realized *(Ibid.)*.

Therefore the electric arc occurs causing the melting of mixture, and the liquid electrolyte is being formed; further the process of melting is being conducted in the regular mode without the electric arc. The furnace is being set into the automatic mode of operation, in which the power level necessary for the melting is maintained. During the reprocessing of aluminium slag the melting temperature in the crucible is being maintained in the range from 800 to 2 000^{0}C. At the higher temperatures the cryolite consumption is lower, but the electric power consumption is higher due to the heat loss. The melting temperature and the capacity of the furnace are chosen depending on the type of aluminium slag and the specific conditions. The charging of the components is being made until the filling of the whole crucible with the melt. After the complete segregation of metal and secondary slag, the electro-slag furnace is being switched off.

The received melt of metal and secondary slag is either being cooled in the natural way up to crystallization and is being discharged cooled, or the electrolyte (secondary slag) is being pumped out from the top part of the crucible using the vacuum ladle for slag, and the liquid metal is being pumped out from the bottom part of the crucible using the vacuum ladle for aluminium. Herewith there is no need to pump out the electrolyte completely. It is possible to leave 10-15% of the full charge in the crucible, turn the furnace on and continue the melting process with the consecutive portion-wise charging of the aluminium slag and cryolite, as it was described above. In this case the process is practically continuous and more efficient.

Based on the patent (WO 2010/022742 A1) and the current state of the art in METALLURG ENGINEERING the following electro-slag furnace with the following parameters is chosen as the basis for studying implementation benefits:

1) Capacity – 600 kWt.
2) Volume of the crucible – 0,5 m^3.
3) Productivity processing of slag – 8 000 tons per year.
4) Volume of release liquid aluminum – 4 000 tons per year.

Furthermore in patent we can find important experimental data which can be used to confirm the success of the instrument specific mass of the substance:

1) iron – 0,45%;
2) silicon – 0,3%;
3) oxygen – less than 0,05%;
4) other components – in total not more than 0,15%, each not more than 0,03%

And the test results regarding the required material as specific mass of the substance:

1) alumina (Al_2O_3) – 80,0%;
2) cryolite (Na_3AlF_6) – 19,0%;
3) SiO_2 – 0,2%;
4) other components – up to 0,3%;

The slag that remains is no more than 0,5% by mass. Initially the aluminium slag to be reprocessed contained 40-45% of metallic aluminium.

Figure 15. Metallic aluminium from Alucyc
Source: Made by the author

Preferably, in the method, according to the present invention, the melting and dissolution of aluminium slag in the electrolyte melt is happening at the temperature in the range from 800 to 2 000^{0}C *(Ibid.)*.

The obtained result confirm the efficiency and workability in comparison with traditional methods i.e. when using the rotary furnace. Also, the invention will achieve the yield of valuable material that is no less than 99% (Figure 15), the process all the while being more environmentally friendly.

This method permits to reuse the received slag (mixture of cryolite and alumina) in the electrolyze for production of primary aluminium from alumina using electrolysis. This permits to reduce the environmental pollution and increase the cost-efficiency of reprocessing of aluminium slag, due to nearly waste-free production (since the waste disposal stage is thereat excluded) *(Ibid.)*.

The results of the experiments showed that the combination of the features of the method according to present invention, described in the claim 1, ensures the creation of a new high-performance and waste-free technology, namely the method for reprocessing of aluminium slag, allowing to increase significantly the extraction of metal aluminium, to not less than 99% and to reduce the environmental pollution. Hereby, the present invention provides the achievement of the object of the invention *(Ibid.)*.

The author has brought out some chemical equations to study the proposed process in more detail form.

The processing of secondary aluminum dross is partly identical to the process of electrolysis used in processing of primary aluminum slag and differs only in the content of aluminum in bauxite. After contact with the molten cryolite bauxite is dissociated (decomposed into ions):

$$Al_2O_3 \rightarrow Al^{3+} + Al_3^{3-} \quad (5)$$

Electric dissociation – is a sign that the material conducts electricity. During the electrolysis Al^{3+} ions are recovered at the cathode and oxidizing AlO_3^{3-} ions settle at the anode:

$$Al^{3+} \xrightarrow{+3e} Al^0 \quad (6)$$

$$4AlO_3^{3-} \xrightarrow{-12e} 2Al_2O_3 + 3O_2 \quad (7)$$

The overall equation of electrolysis is as follows:

$$2Al_2O_3 \xrightarrow{\text{electrolysis}} 4Al + 3O_2 \quad (8)$$

The released oxygen reacts with carbon (which is composed of the anode) and the resulting mixture of carbon dioxide and carbon monoxide CO and CO_2. Al is deposited on the cathode bottom of the crucible.

Using a conservative estimation of the method of producing a mixture of alumina Al_2O_3 and Na_3AlF_6 is electrolyzed only once after which the aluminum slag, which still contains an amount of aluminum, is counted as a by-product. Using electroslag furnace allows to newly electrolyze the received aluminum slag, thereby the output of aluminium can be further increased reducing waste accordingly. It makes practical sense to place the electroslag furnaces either in parallel or consecutively. In a consecutive scheme the pots will serve as a separator and sump as well as increasing aluminum yield using the slag from the previous process for the production of primary aluminum.

2.3 PESTEL analysis

A PESTEL analysis is a macro-environmental factors that will show an impact on an organization.

PESTEL stands for the following set of factors:

P – Political

E – Economic

S – Social

T – Technological

E – Environmental

L – Legal

This thesis will limit itself to investigating the PESTEL climate. The geographic proximity is also a factor. This focused approach is used as there is a lot of data on company and region. Based on the above the author has decided that it is not worth to make a poor quality large scale PESTEL analysis but to concentrate on a single company and region on which there is sample data to make better quality assumptions and future plans on technology. The author decided to take Norway and a large corporation Norsk Hydro as its prime example.

Political factors:

The government is always interested in the welfare of the industries in its country. The higher the turnover – the more taxes the industry is likely to pay. For example the income tax of Hydro a large Norwegian company dealing, also, with aluminum in 2013 was 93 036 270 NOK (Norsk Hydro annual report, 2014). Political factors for such an industry are in a way an extension of its economic and environmental factors – for these are the factors which the governments use to make judgments and asses the feasibility of stricter regulations on the industry. If the government are not satisfied with the business of the company for environmental or other reasons it can pass regulations which can turn a once profitable project to an unprofitable one even after significant investments has been made. Within the aluminum industry made investments are made almost exclusively on the long-term basis, which requires stable framework conditions. Within the EU, it was resolved in 2005 a quota system for CO_2 emissions. The problem with this resolution is that it covers all energy-intensive industries, even those who make use of green energy. To help Norwegian industry the government adopted a CO_2 compensation scheme, through which Hydro partly entailed a state subsidy of over 200 million NOK (Norsk Hydro annual report, 2014).

Therefore, aluminium industry stakeholders constantly collaborate with governments because aluminium production is a capital-intensive industry tied closely with the mining industry as such many economic sectors are involved. These are large tax payers. And governments are usually willing to cooperate with aluminium producers to obtain a mutually-beneficial set of rules.

Economic factors:

The overall macroeconomic climate impacts aluminium producers greatly. A slowdown in the economy will lead to less investments and greater uncertainty among investors. Developments in the aluminum industry have followed cyclical fluctuations closely and the companies involved try to ride economic waves to earn money during the periods of macroeconomic growth. Hydro, for example, sells its products in a global market and will therefore be affected by changes in the world economy, where developments in the EU are particularly important. The financial crisis has shown us how vulnerable the industry is during the recession, when very few companies managed to operate with profit.

The overall demand for aluminum in the world is expected to grow by 5,9% annually by 2018 (Global Aluminum Market, 2014-2018). Although demand is expected to increase, prices will not increase accordingly, as many manufacturers have much aluminum in stock that they choose not to sell to avoid pushing the price down even further (Reuters, 2014). A likely sequence of events is that any potential increase in price due to higher demand will be prevented by increased supply and as such lead prices back to the current level or in the worst case even lower. Meanwhile several of the players are building up their capacity, Hydro included, with a hope to get a greater share of future demand.

Hydro itself estimates that the demand for primary aluminum excluding China will rise by 2-4% in 2014. The offer will not increase as much (Norsk Hydro annual report, 2014). Two thirds of the costs are directly linked to production in terms of energy and raw materials. The price of electricity is a significant cost driver for both alumina and aluminum production. EU climate targets to be achieved by 2020 (Renewable energy report, 2013) indicate that electricity prices will rise in line with new taxes on CO_2 emissions. Especially in Germany, where much of the power comes from coal plants. While Hydro is working actively to reduce their costs, production costs rise fairly equally with the revenue that the company targeted.

In China more new primary aluminum plants are being established; an estimate predicts that China will reach a capacity of 33 million tons by 2015 (South China Morning Post, 2013). If demand in the country would fall and the authorities remove export duties, it would be likely that Chinese companies will look for potential customers abroad. Such a development may eventually lead to an even tougher market.

Social factors:

Social factors include responsibility for ensuring economic growth, work process efficiency, insurance, safety issues and following the regulations for workers and work environment ethics in factories. Also, we must not forget about education. One of the primary supporting industries for the aluminium industry is the mining industry which is a very technologically-intensive sector where huge pieces of machinery and large quantities of people are involved. These people must have a solid educational basis to produce stable long-term results and manage large strategic projects.

Technological factors:

Technological advances may make current technology second-rate within a relatively short time. Companies that do not follow with the technological developments are the ones that are often eradicated. Research and Development is an important part of all major groups, with a focus on finding new applications for existing products, developing new products and developing better and more cost-effective manufacturing processes. For Hydro importance of Research and Development is invaluable in order to be cost leaders in the industry and to develop new uses for aluminum. Hydro has an ambitious target to cut power usage of their primary processes from 14 kWh to 10 kWh per kilogram of aluminum produced. That is why they started up a test plant in Årdal that produces 12,5 kWh per one kilogram of aluminum (Norsk Hydro annual report, 2014). The industry must follow world trends using renewable energy what is produced from natural resources which will reduce CO_2 emission and implement waste free technologies like the Alucyc technology.

Environmental factors:

Environment is coming increasingly into focus and it is important for companies to show that they take this matter seriously. The biggest challenge for aluminum industry is related to the power demand, where it is often necessary to use energy from fossil fuels and especially coal. In Norway, Hydro self-sufficient power from its own hydropower plants with zero emissions. Production in Brazil and Canada are also based on hydropower. At power plants in the other countries where Hydro operates used power from non-renewable sources, mainly coal, gas and nuclear power. Hydro emits 1,58 grams of CO_2 per kilogram of aluminum produced. The EU has set a target that 20% of all electricity generation to come from renewable sources by 2020, at the end of 2013 this figure was 12,7%, which is in accordance with the expected progression (Renewable energy report, 2013).

Alunorte alumina plant are from February 2014 charged with a new tax on the use of fuel oil (Norsk Hydro Site, 2014). This results in additional costs for Hydro and comes as a result of greater focus on the reduction of emissions in Brazil. In virtually all countries that Hydro has operations there are strict rules for the disposal of waste to avoid contamination locally. Hydro has a goal to produce as little waste as possible, recycle what can be recycled and depositing it to be deposited in a proper manner. Bauxite contains ca 40-60% alumina which is produced through a chemical process in which water is added along with caustic soda. The sludge remaining after recovery must be disposed in a proper manner, which is done through filtering out as much caustic soda as possible before settling in artificial ponds.

Legal factors:

From a legal point of view the project is compliant – there are several directives. That regulate working requirements and conditions, environmental protection that the current technology of Alucyc is in compliance with.

To conclude the PESTEL analysis with an outlook towards 2020 paints a positive picture. With expected growth in demand of aluminium estimated at approximately 20%. Stricter environmental regulations are a further bonus from the standpoint of the growth of attractiveness of Alucyc technology to potential investors. The largest uncertainty resides with the global macroeconomic climate.

2.4 Alucyc technology environmental impact

The natural environment of Europe is one of its most valuable resources and a natural competitive advantage for many industries and sources of livelihood for the people living there. This fact is further highlighted by the various state and international regulations that are implemented to protect the natural environment of Europe. The economy must try to be ecological and cause as little harm to the environment as possible – this, in some sectors, is very difficult to achieve. It is important not to close our eyes on the various ecological threats that are today seen as the normal state of affairs, but companies, individuals and governments must to their best to improve the status quo as far as possible. The harm caused to the environment must be minimized where it is technically possible and economically rational to do so. Often this is done by shifting harmful production to certain areas of the land and limiting its harmful emissions, which may indirectly, also, limit the production capacities of the producers. This also, causes some technologies to stop being used, with improved processes taking their place. Alucyc, the author believes, can be one such technology.

The problem of ecology is of interest to a great number of the EU citizens. As such the Union makes much effort to limit harmful emissions and the amount of landfills as well as the ecological footprint that these landfills bring with them. The Alucyc technology that was noted by the author solves many of the environmental problems faced by an important industry of the EU, decreasing the landfilling problems for the sector to nearly zero. Metallurg Engineering wish to install their new technology on to existing aluminium factories, for whom it will not only be a source of additional revenue but also decrease technologic waste.

Metallurgy as a whole requires much care as some of its processes can be explosively hazardous, such as gas purification. Alucyc can boast that the gas cleaning required for its operation is minimal – which is an additional benefit to the process reducing the risks for the people and the toll on the environment in case of failure of the process.

Human health and the health of the environment are priceless, though economically they can be deemed to have a price, which at the moment, the author believes, is undervalued. Yet even this relatively low economic cost that is associated with health and the environment pushes companies to innovate, producing favorable results on the bottom line of the company's future fiscal years if they wish to adopt innovative environmentally-friendly technologies. The goal of the assessment of the Alucyc technology is to gather as much information as is possible from different sides of the debate to answer the question of whether the technology is needed by the industry and, perhaps, by humanity as a whole.

For many biologically hazardous substances there is threshold limit value (TLV) is a chemical substance maximum average airborne concentration of a hazardous material to which healthy adult workers can be exposed during after 40-hour workweek – over a working lifetime – without experiencing significant adverse health effects (US Department of Commerce: NOAA's, 2015) .

These values, however, are the bare minimum to which responsible companies must adhere to. The actual level of the hazardous substances to which the workers and the environment is subject to must be kept as low as reasonably possible.

According to the research made by the company a single Alucyc furnace can reduce the CO_2 emissions by seven tonnes of CO_2 gas per each ton of aluminium produced. As can be seen none of these values exceed the TLV level for the substances. Special plans of action have also been developed by the engineers of the company in the unlikely case of any foreseeable emergencies, which would help minimize the ecological cost in case something goes wrong.

Apart from the TLV level, which the minimum standard in regards to the wellbeing of the workers of the company – long exposure to varying levels of harmful substance on the surrounding environment is difficult to estimate. The environment is a sum of many natural process bound together by ties and loops, where disturbing the slight balance in one part of the system may lead to a significant failure in some other part if given enough time to propagate. Imagine, for example, the artificial changing of the compositions of air and water in a certain area – this is what is usually referred to as pollution whether it exceeds some arbitrarily set TLV or not. One of the numerous components of the environment be it a tree, an animal or a species of moss may fail, causing a chain reaction and the more significant failure of the existing biosphere in the area. Considering this, a physicochemical survey and 3D modelling of the effects on the environment has been carried out while developing the Alucyc technology.

Thanks to a high rate of refinement and yield of aluminium – the new technology helps to significantly lower the environmental impact of the primary aluminium production process. The author believes the new technology to have great potential to become the new state of the art in primary aluminium production and processing aluminium slag, helping companies who adopt it take a leading place on the market thanks to its economic advantages and in the ranks of social and environmental responsibility thanks to its ecological benefits.

2.5 Implementation process

To implement the technology in a primary aluminium factory the management of Metallurg Engineering and the project management team from that factory must agree on the terms and sign the documents describing the implementation process with approved technical requirements for installation which are:

1) foundations,
2) electrical networks,
3) gas supply (e.g. argon),
4) water supply,
5) cooling system,
6) gas cleaning system,
7) ventilation,
8) civil works,
9) communication network.

Metallurg Engineering provides manufacturing equipment according to customer specifications and the preliminary layout for the project – this step takes 6 to 9 months, depending on the conditions of the contract and the enterprise load. When the preparatory installation works are completed by the client company the installation phase can begin. Work will be executes by experienced teams of specialists with supervisors provided by Metallurg Engineering.

Equipment installation and commissioning work will take about two months. Putting technology into operation and training of personnel will take one and a half to two months. After the mentioned activities of construction and installation Metallurg Engineering will work closely with the client and specialists of Metallurg Engineering will be responsible for timely maintenance works and provide the specialists of the plant with technical support and instructions, including warranty servicing and supply of expendable materials and spare parts (e.g. electrodes).

2.6 Alucyc technology conclusions

In the case of implementation of the Alucyc technology, aluminium yield will grow, thus, achieving goals in environmental sustainability and eliminating extra production costs (acc. landfilling, transportation etc.) as well as giving extra conditional electricity savings for the process of production of raw-material.

The claimed benefits of implementing the Alucyc technology are (Alucyc Report Summary, 2014):

1) Reduction of energy consumption – energy consumption phase of the process is significantly lower than that of the process currently used in the aluminium production industry. The Alucyc process uses 600 KWh/ton of energy. Thus, each Alucyc technology unit installed will save 4 875 (TWh) of electricity each year. Furthermore, based on the market figures for a 10 year post-project period, the author can estimate a total cumulative energy saving of 131 625 TWh. This is the equivalent of a continual three GW generator, the same as a medium power station.
2) Reduced CO_2 footprint – as compared to the production of aluminium from the primary source, seven tons of CO_2 emission and 16 250 KWh/t of electric energy will be saved per 1 ton of aluminium produced from aluminium dross.
3) Reduced primary resource usage – additional yield of 22,5 thousand tons of metallic aluminium enables one to reduce imports or allows for additional production.

As not every new technology will meet the needs and objectives of the assigned tasks of the enterprise. To estimate the necessity of the new technology, the author must estimate disadvantages and the risks that will occur during technology initiation. The main disadvantages can be listed as follows:

1) automation of the business processes;
2) need for a partial reorganization of the company structure;
3) temporary increase of the load on the staff during the implementation of the technology;
4) need to develop a skilled implementation team, including the choice of the influential head of the group;
5) financial risk that may not be paid back.

For the investor who will estimate the risk opportunities on the capital invested in the new technology, the payback period and the efficiency of future operations is essential. Therefore, some factors that can destroy a successful project are:

1) bad overall results from the implementation of the project;
2) failure to properly implement the new technology in the existing production system;
3) failure to provide the technology with the needed volume of raw materials to produce required results.

The financial risks mainly comprise macroeconomic risks that are a daily routine part of the business as it is. In the next chapter the author will calculate the interest rate, payback period and other important indicators that will estimate the project financial risks in the long term period with constant raw material flow equal to “zero”. The risk of price fluctuations on the metal exchange is very difficult to predict and impossible to control, because the worldwide tendency shows that use of aluminium in many aspects of production is popular. The metal is easily recyclable and the price on the stock market should not fall below the current average level of 1 800 USD per ton and should probably grow. Therefore, the only uncertainty remains that the prices will fluctuate due to an economic crisis, but as it is scientifically called acts-of-god-risks that are beyond control of the project team.

Apart from macroeconomic risks a set of uncertainty related risks exist that are related to tying up the company’s capital in a large investment endeavor. These risks are further underlined by the newness of the technology not only to the company but the industry as a whole. However, this is a risk that comes along with the introduction of a potential competitive advantage. Thus, it is a risk that the company should take based on the cold-headed analysis of the straightforward advantages that the technology will bring. The introduction of Alucyc technology into the production cycle should be viewed as an R&D expenditure, for which the research and development has been prepared for the aluminium producer by Metallurg Engineering. The company is thus spending in-to the new technology hoping to gain a competitive edge by optimizing its production process before its competitors catch up. The risk of adopting the technology is limited by the cost of the new installation and the resources expended by the company on its implementation. The advantages on the other hand are roughly limited by the additional savings and income that the technology can bring to the company. Furthermore, however, that additional edge can turn in-to a competitive advantage through a positive feedback mechanism allowing the company to expand its business at the cost of its competitors. Thus if we summarize the best and worst case scenarios – the risk matrix will look as follows (in Table 4).

Table 4. Qualitative Risk Management Assessment Matrix for the Alucyc technology
Source: Composed by the author

		Consequences	
		Low	High
Likelihood	High	The productivity of the Alucyc is not as good as the calculations show, but the technology has a positive impact on the environmental footprint of the process	-
	Low	The Alucyc technology is difficult to integrate smoothly into the structure of the company, bringing with it unforeseen overhead costs which drain most of the benefits from the implementation.	The Alucyc installation cannot pay itself back – it becomes obvious that there are significant barriers to adopting the technology in practice

Thus, the author can conclude that the implementation of the Alucyc process as an addition to the traditional slag treatment method can provide significant economic advantages for the smelters, as it can refine dross containing just 37% of aluminium (whereas the classical process needs a fraction that is higher than 50%). The slag with fractions of lower than 50% of aluminium can be further refined using the Alucyc technology process, thus cutting down on waste that must be transported and deposited to the landfill and is harmful to the environment. Related costs can be reduced for the company accordingly.

3. FINANCIAL ANALYSIS OF THE ALUCYC TECHNOLOGY

In the following chapter we will look at the financial side of the practical implementation of the Alucyc technology. For this analysis the following companies were chosen: Norsk hydra and Rio Tinto Alcan Iceland. The formation of slag in China and Europe will also be studied. Based on the analysis made in this chapter the author will then propose a market penetration strategy for Metallurg Engineering with its Alucyc technology. This market will not be the first one for the company as proposed by the strategy in this paper due to the difficulty of handling customers in faraway locations with a different cultural background. Entering the Chinese market is a long-term strategic goal which can be achieved after the technology is tried and tested.

3.1 Analysis for China

23,941 million tons was declared by China in 2014 as the volume of primary aluminium production. To estimate the slag formed during this process we need to multiply this number by 2,5% (based on 25 kg of slag formed per ton of primary aluminium produced as practice shows). The formula can be written as:

$$T \cdot x = y, \qquad (9)$$

where, T - China yearly primary aluminium production output

x - amount of slag generated per ton

$$23{,}941 \cdot 10^6 \cdot 2{,}5\% = \frac{23{,}941 \cdot 10^6 \cdot 2{,}5}{100^2} = 59{,}85 \cdot 10^4 = 598\ 500 \text{ t/year}$$

Thus China produces almost 600 thousand tons of slag annually. A single Alucyc furnace can recycle 8 000 tons of slag annually and refine 4 000 tons of liquid aluminium. The average aluminium price in 2014 on the London Metal Exchange stayed at the level of approximately $ 1 800 at the end of that year.

Cost of liquid mixture (cryolite) and electricity is estimated at $ 505 per ton of slag and the overhead expenses are estimated at $ 78,5 per ton of slag. Total expenses are, thus, $ 583,5 per ton of slag. From this we can calculate profits when project will be implemented.

To calculate the annual direct plant revenue we now must multiply the production capacity of liquid aluminium by the average price per metric ton of the product:

$u \cdot p = O,$ (10)

where, u - production capacity of liquid aluminium in tonnes per year

p - average price of primary aluminium per metric ton

O - one year direct plant revenue

4 000 t · $ 1 800 t = $ 7 200 000

We now calculate the expenses of the plant by multiplying the total costs for processing one ton of slag by the plant's annual capacity:

$f \cdot h = L,$ (11)

where, f - total Alucyc technology production capacity per year

h - total expenses cost per one metric ton processing

L - one year plant expenses

8 000 t · $ 583,5 t = $ 4 668 000

To calculate gross profit we subtract the received findings:

$\Delta = O – L,$ (12)

where, Δ - gross profit per year

O - one year direct plant revenue

L - one year plant expenses

$ 7 200 000 - $ 4 668 000

Δ = $ 2 532 000

Continuing with the estimation of the China scenario with its slag production of 598 500 t/year. The price of a single 8 000 t/year plant is $ 9 660 000. The equation will thus look as follows:

1plant – $ 9 660 000 (13)

X plants – $ 1 326 150

$X = \frac{1 \cdot 326\ 150}{8\ 000} = 165,\ 7 \approx 165$

Total revenue will be:

$$\$ 2\,532\,000 \cdot 165 \cdot 10^6 = \$ 417,78 \cdot 10^6 \quad (14)$$

And payback period for 1 plant is estimated by dividing cost of the plant by the revenue received per year:

$$\frac{9\,660\,000}{2\,532\,000} = 3{,}815 \text{ years} \approx 3 \text{ years and } 10 \text{ months} \quad (15)$$

The number of course stays the same in the case of 165 plants 1 593 900 000/ 417 780 000 = 3,815 ≈ 3 years and 10 months. To reduce the total impact on the environment of China and secure future revenues China must invest about 1,6 billion dollars to purchase Alucyc installations for its aluminium factories. In the future chapters we will look at the money flow by each period using all the instruments to calculate more detailed numbers about the technology.

Approximate calculations in the case of China showed that the project will provide some extra capacity by improving the productivity of the process and reducing landfill costs. Cryolite mixture can be reused which will further be very useful in bringing down costs and in improve long-term profits. This profit can be reinvested into further improving the quality and decreasing the environmental footprint of the production process.

Below are the tables illustrating a more detailed financial investment analysis on the example of adopting the Alucyc technology in China:

Table 5. Initial financial project data (US Dollars)
Source: Composed by the author

i (discount rate)	0,666%
Investing project costs	$ -9 660 000
cash outflows in each period	$ -4 668 000
cash inflows in each period	$ 7 200 000

Where: i, is the discount rate – taken as nominal 8%.
Annual interest rate is calculated as:

8% per year / 12 months = 0,666% per period (16)

In Table 5 we will present accurate numbers on the discount rate, project costs for one plant and cash flow in each period. The author will make calculations for 10 periods. One period length will be one year.

The Alucyc technology cost is \$ 9 660 000. The invested cost is with “-” shows the invested capital for one plant. Cash outflows will mark that in each period the company will pay for direct and indirect costs which will be used to maintain the work shop. Thus, cash inflow are the profits from the sold raw material: in case of the primary aluminium production – it is 4 000 metric tons of liquid aluminium at a total value of \$ 7 200 000. The numbers are taken from equation (10) and (11).

Table 6 illustrates the cash flow in each period. The numbers in each period are taken from the average price on London Metal Exchange stock market and the author’s decision and reports that in coming five years period the aluminium price will be at a level of approximately \$ 1 800 +/- 50-70 per one metric ton annually. The input parameters are needed to create detailed calculations for the price in the coming 10 years and calibrate them annually to control profits from the investments.

The calculations are created in excel spread sheet also expected the gross profit of the project in flowing 10 periods are \$ 15 660 000. Therefore, if the price on stock market will grow then the invested capital and gross profit from sold raw material will also grow. If on the stock market price will be \$ 2 050 for one metric ton as in year 2010 then the net cash flow will be \$ 25 660 000 in the same time period and the annually average gross profit price will reach \$ 3 532 000.

Return on investment (ROI) represents the actual value developed by comparing costs and benefits of the technology. The two most common measures are the benefits of costs ratio (Phillips, 2003). Other words it is the ratio between invested capital and the annual gross profit in percent. Every investor is interested in how fast his money will return and start to bring dividends. The author has calculated a payback period (PP) and ROI. Therefore to complete the correct and objective decision making process for the investors we must calculate the efficiency of the project. The indicators of good investment shall be the discount factor, discount profitability index and the NPV an expected outcome from the project to investor.

Discount factor can be calculated as:

$$DF(T) = \frac{1}{(1+r)^T}, \tag{17}$$

where, T - time period in our case it is 365 days.

r - annual discount yield.

The NPV will calculated as:

$$\mathrm{NPV}(i) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}, \tag{18}$$

where, t - the time of the cash flow

i - the discount rate

R_t - the net cash flow i.e. cash inflow – cash outflow, at time *t*.

Table 6. Estimated 10 years project Cash flow (US Dollars)

Source: Composed by the author

t (No. of periods)	Date	cash inflow	cash outflow	CF (Cash Flow)
0	01.01.2016	$ -	$ -9 660 000	$ -9 660 000
1	02.01.2017	$ 7 200 000	$ -4 668 000	$ 2 532 000
2	04.01.2018	$ 7 200 000	$ -4 668 000	$ 2 532 000
3	06.01.2019	$ 7 200 000	$ -4 668 000	$ 2 532 000
4	08.01.2020	$ 7 200 000	$ -4 668 000	$ 2 532 000
5	09.01.2021	$ 7 200 000	$ -4 668 000	$ 2 532 000
6	11.01.2022	$ 7 200 000	$ -4 668 000	$ 2 532 000
7	13.01.2023	$ 7 200 000	$ -4 668 000	$ 2 532 000
8	15.01.2024	$ 7 200 000	$ -4 668 000	$ 2 532 000
9	16.01.2025	$ 7 200 000	$ -4 668 000	$ 2 532 000
10	18.01.2026	$ 7 200 000	$ -4 668 000	$ 2 532 000
	Sums:	**$ 72 000 000**	**$ -56 340 000**	**$ 15 660 000**

The formulas are converted to excel format and calculated in spread sheet, values can be seen in Table 7.

Thus the calculations are made and when observing the values, if investor will invest in an Alucyc technology in 2016, then after 3 years 9 mounts 24 days payback period (PP) will be over. Starting from 2020 the invested capital will bring profits estimated on NPV indicator the value equals $ 14 756 711. The ROI indicator show that the project will be paid off on 162,11% and DPI shows us the rate of 2,53 it is the mean ratio of return on investment of the proposed technology.

The equation of DPI can be written as follows:

$$\text{Profitability index} = \frac{\text{PV of future cash flows}}{\text{Initial investment}} \quad (19)$$

The DPI has own rules how to estimate the project selection:

If DPI > 1 then the project can be accepted

If DPI < 1 then the project can be rejected

According to the DPI rule the Alucyc technology has 2,53 points , i.e. more than one, thus it is a good investment. It also has the added non-monetary value of being environmentally friendly.

Table 7. ROI, DF, PV, DPI (US Dollars)

Source: Composed by the author

ROI (return on investments in %)	Discount factor	NPV (Net Present Value)	DPI (discount profitability index or PI)	No. of periods after the payback period (payback period PP)	Date
	1,00	$ -9 660 000			01.01.2016
-73,79%	0,99	$ 2 515 258	0,26		02.01.2017
-47,58%	0,99	$ 2 498 608	0,26		04.01.2018
-21,37%	0,98	$ 2 482 077	0,26		06.01.2019
4,84%	0,97	$ 2465 656	0,26	4	08.01.2020
31,06%	0,97	$ 2 449 343	0,25	5	09.01.2021
57,27%	0,96	$ 2 433 138	0,25	6	11.01.2022
83,48%	0,95	$ 2 417 041	0,25	7	13.01.2023
109,69%	0,95	$ 2 401 050	0,25	8	15.01.2024
135,90%	0,94	$ 2 385 165	0,25	9	16.01.2025
162,11%	0,94	$ 2 369 385	0,25	10	18.01.2026
162,11%		**$ 14 756 711**	**2,53**		

The author will provide two figures which illustrate cash flow in the projects lifecycle. The Figure 16 shows the cumulative discounted cash balance and Figure 17 – the Net Present Value of the Alucyc technology.

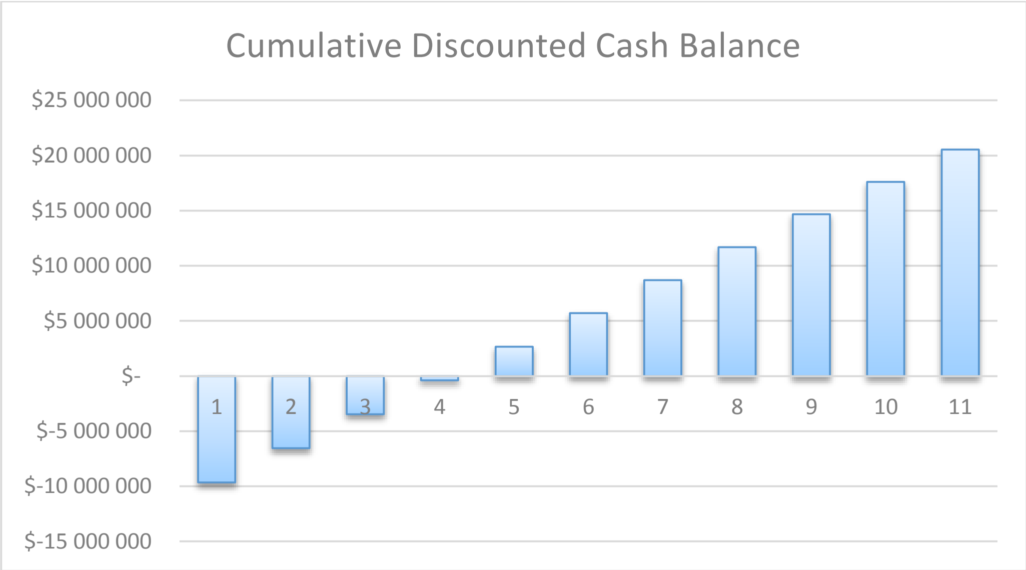

Figure 16. Cumulative Discounted Cash Balance (US Dollars)

Source: Composed by the author

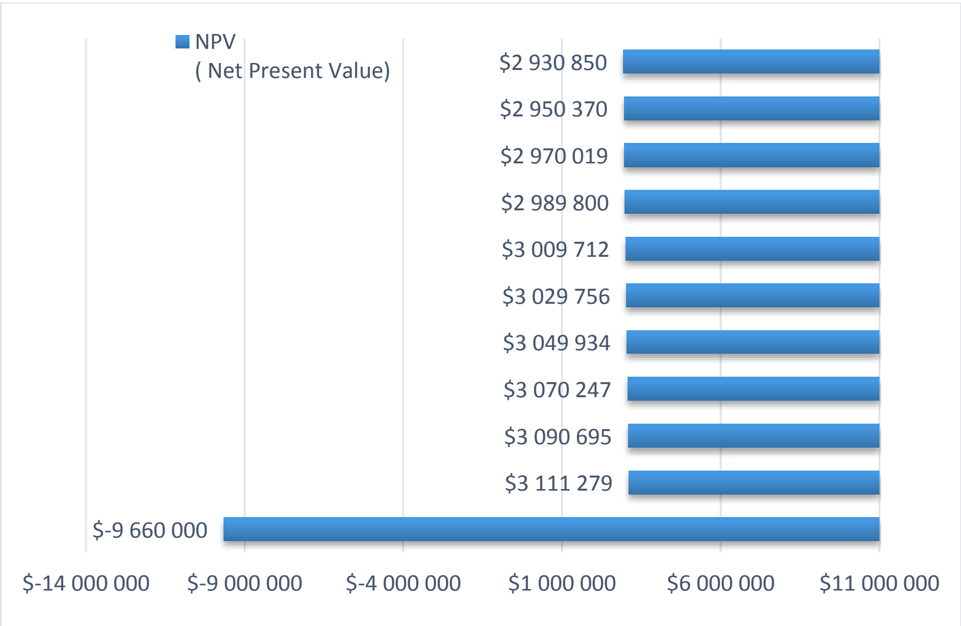

Figure 17. NPV (US Dollars)

Source: Composed by the author

Table 8. The calculated values

Source: Composed by the author

Number of years (n)	10,00
Net Present Value (NPV)	$ 14 321 343
Internal rate of return (IRR)	22,87%
Discount profitability index (DPI)	2,48
Return of investments (ROI)	162,11%
Payback period (PP)	3,82 3 years 9 mounts 24 days
Accounting rate of return (ARR)	52,42%
Average annually profit	$ 2 532 000

Now we will look more closely at the obtained values in Table 8 the NPV, PP, ROI, DPI indicators which were already explained above, thus we must assess ARR and IRR indicators.

ARR or accounting rate of return is an accounting instrument that provides ratio information about the average return during the specified period divided on offered capital investment.

The equation of the ARR can be written as:

$$\text{ARR} = \frac{\text{Average return during period}}{\text{Average investment}} \qquad (20)$$

An obtained value show us that the estimated rate of return will be 52,42% then it means that the project is expected to earn 52 cents out of each dollar invested yearly.

The Internal rate of return (IRR) is more specific terms, the IRR of an investment is the discount rate at which the net present value of costs (negative cash flows) of the investment equals the net present value of the benefits (positive cash flows) of the investment.

Because the internal rate of return is a rate quantity, it is an indicator of the efficiency, quality, or yield of an investment. This is in contrast with the net present value, which is an indicator of the value or magnitude of an investment. One of the uses of IRR is by corporations that wish to compare capital projects. For example, a corporation will evaluate an investment in a new plant versus an extension of an existing plant based on the IRR of each project. In such a case, each new capital project must produce an IRR that is higher than the company's cost of capital. Once this hurdle is surpassed, the project with the highest IRR would be the wiser investment, all other things being equal including risks (Yassin El-Tahir et al., 2014).

The IRR was calculated using excel functions. Where XIRR function was required to enter dates in addition to the cash flow values and the discount rate (Wittwer, 2009).
The values calculated in excel are similar to the values that were calculated by the author in the preliminary analysis.

All of the key economic indicators show that implementing the new technology is a worthwhile endeavor for the aluminium production companies based purely on the operative analysis. Here the author wishes to once again highlight the non-monetary environmental factor that adds value to the proposition.

Therefore, we need to mention the cryolite which will be mixed with the dross thus making a homogenous substance which can be used as a supplement in the production of the primary aluminium. These costs can be calculated as indirect benefits that should be taken into account by the investors – making the project more attractive to the industry. The price of 4 000 tons of alum earth or mixture of the minerals and cryolite can be calculated using equation (21).

$$\$ 400 \text{ t} \cdot 4\,000 \text{ t} = \$ 1\,600\,000 \qquad (21)$$

This is the extra indirect benefit that can be available if this mixture is reused in the production of primary aluminium. Thus the total profit for one working period will add up to $ 8 800 000 (this includes the $ 7,2 million (see equation 10) which is the price of the recovered aluminium).

This result highlights why the technology should gain popularity among the producers of aluminium. The payback period, when adjusted for indirect benefit, is improved as the tables below will illustrate. If we compare the last result with the more thorough calculations we have to emphasize the decrease of the payback period by almost two times.

The input data for calculation in the spreadsheet will change only in the cell – “cash inflow”. The whole calculation system will give us the adjusted numbers. The numbers that we received are clearly more attractive to investors. These calculations support the view that the company will increase its primary production capacity and its business efficiency using the new technology. Not forgetting about the environmental safety and decrease in environmental penalties owed to governmental regulatory bodies that can occur in future.

Table 9. Initial financial project data (US Dollars)

Source: Composed by the author

i (discount rate)	0,666%
Investing project costs	$ -9 660 000
cash outflows in each period	$ -4 668 000
cash inflows in each period	$ 8 800 000

In Table 9 as in the Table 5 we will present the numbers dealing with the discount rate, project costs for one plant and cash flow in each period. The author will make calculations for 10 periods. The length of one period will be one year.

In Table 10 below, we can see the values that will be attained in the period of 10 years in case of implementation the product in year 2016. If we compare them with Tables 6 and 7 we must admit that the cash outflow will not change, the yield in cash flow will increase to $ 15 000 000 being the gross profit of the technology in flowing 10 periods the money that we will save on cryolite that will be transferred directly to primary production. The ROI indicator also will grow from 162% to 327% which shows an increase by a factor of over two. The investor will triple his invested money in the 10 year period. The DPI shows an increase to 4,12 i.e. more than one, thus it is definitely a viable investment (twice as good when its indirect benefits are also taken into account).

Table 10. Estimated 10 years project Cash flow in China case (US Dollars)

Source: Composed by the author

Cash inflow	Cash outflow	CF (Cash Flow)	ROI (return on investments in %)	NPV (Net Present Value)	DPI (discount profitability index or PI)	Date
$ 88 000 000	$ -56 340 000	$ 31 660 000	327,74%	$ 30 185 913	4,12	18.01.2026

The numbers that are received in our second round of calculations are very optimistic and should provide a good response with the industry.

Therefore to complete the correct and objective decision making process from the standpoint of the investors we must calculate the efficiency of the technology with the adjusted data. The indicators of good investment shall be discount profitability index and the NPV an expected outcome from the project to investor. Thus the calculations are made and when observing the values, if investor will invest in an Alucyc technology in 2016, then after 2 years 4 months 12 days – the payback period (PP) will be over. Starting from 2019 the invested capital will bring profits estimated on NPV indicator the value equals $ 30 185 912. The ROI indicator show that the project will be paid off by 312,48 % and DPI shows the rate of 4,12 which is the mean ratio of return on investment of the proposed technology (Table 11).

Table 11. The calculated values for China
Source: Composed by the author

Number of years (n)	10,00
Net Present Value (NPV)	$ 30 185 912
Internal rate of return (IRR)	41,44 %
Discount profitability index (DPI)	4,12
Return of investments (ROI)	312,48 %
Payback period (PP)	2,34 2 years 4 mounts 12 days
Accounting rate of return (ARR)	85,55%
Average annually profit	$ 4 132 000

The author will provide two renewed figures which will illustrate cash flow in the projects lifecycle. Figure 18 shows the cumulative discounted cash balance and Figure 19 – the Net Present Value of the Alucyc technology.

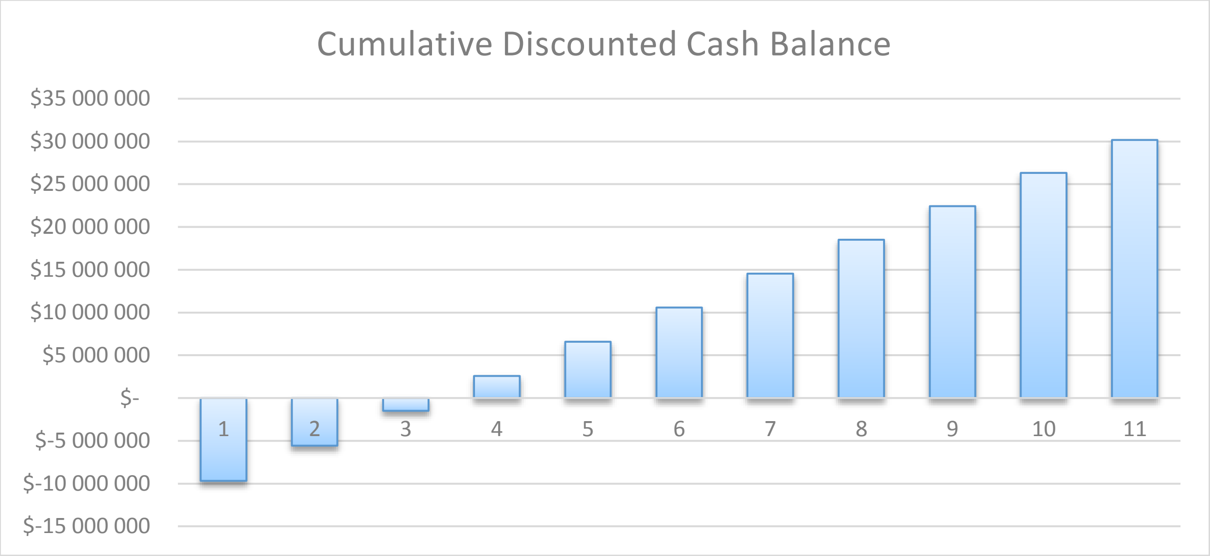

Figure 18. Cumulative Discounted Cash Balance – China case (US Dollars)

Source: Composed by the author

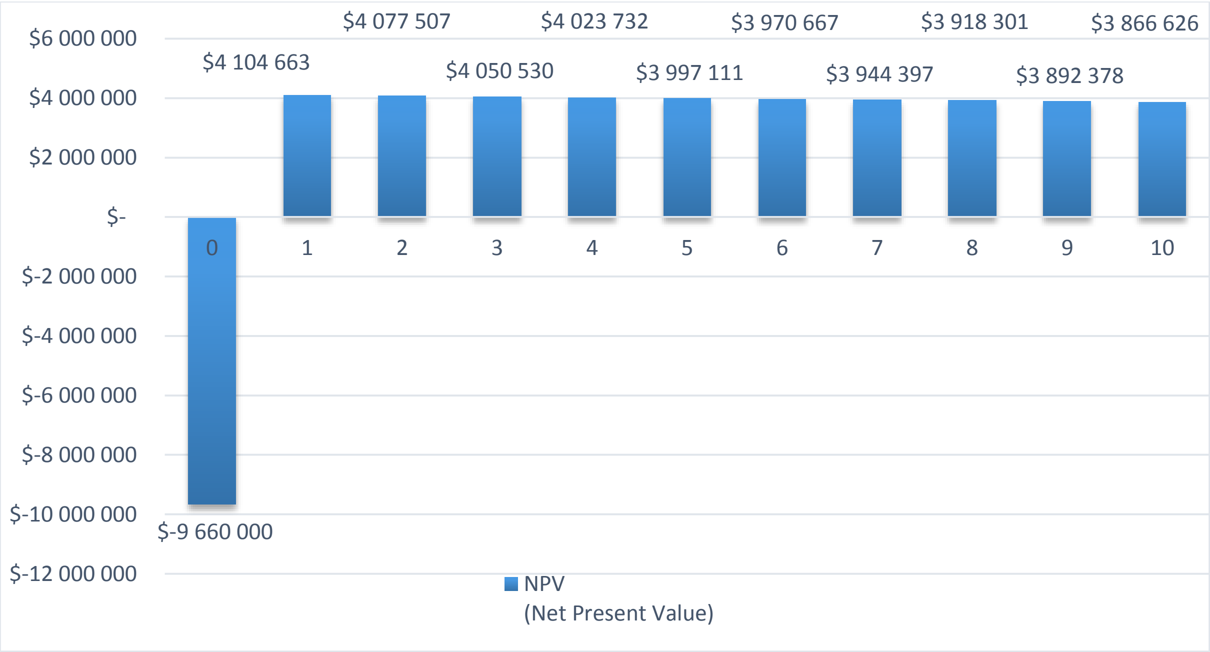

Figure 19. NPV graph – China case (US Dollars)

Source: Composed by the author

As we can see the NPV, PP, ROI, DPI indicators which were already explained above, thus, we must assess ARR and IRR indicators. ARR is an obtained value that show us that the estimated rate of return of 85,55% - this means that the project is expected to earn 85 cents for each dollar invested yearly. IRR is also increased in two times. All of the key economic indicators show that implementing the new technology is a good solution for the factories producing aluminium: the gross profit will increase; the environment will be better off; investors will be satisfied.

3.2 Analysis for Europe

In this chapter the author will calculate the efficiency of implementing of Metallurg Engineering furnace in Europe in Norway and Iceland. Firstly the author will estimate the financial model of the technology with a typical mathematical approach without using financial instruments: discount rate (i), net present value (NPV), internal rate of return (IRR), profitability index (DPI), return on investments (ROI), payback period (PP), accounting rate of return (ARR) and average return during period. After these numbers will be simulated in an excel spreadsheet to gain a wider understanding about the financial part of the project. The same steps as taken in case of China.

The volume of primary aluminium production in Western Europe is $3{,}775 \cdot 10^6$ metric tons annually. The formula is taken from equation (see equation 9).To estimate the slag formed during this process we need to multiply this number by 2,5% - which is the amount of slag produced on average as a byproduct of primary aluminium:

$$3{,}775 \cdot 10^6 \cdot 2{,}5\% = \frac{3{,}775 \cdot 10^6 \cdot 2{,}5}{100^2} = 14{,}25 \cdot 10^4 = 142\ 500 \text{ t} \qquad (22)$$

Thus Western Europe produces almost 142 500 metric tons of slag annually. As we know, from the input data a single Alucyc technology can recycle 8 000 tons of slag annually and refine 4 000 tons of liquid aluminium. The average aluminium price in 2014 on the London Metal Exchange stayed at the level of approximately $ 1 800 at the end of that year.

Cost of liquid mixture (cryolite) and electricity is estimated to be more expensive, because of higher standards of living – the price will stay at $ 605 per ton of slag and the overhead expenses are estimated at $ 215 per ton of slag. Total expenses are thus $ 880 per ton of slag. From this we can calculate profits when technology will be implemented.

To calculate the annual plant revenue we now must multiply the production capacity of liquid aluminium by the average price per metric ton of the product (see equation 10):

$$4\ 000 \text{ t} \cdot \$\ 1\ 800 \text{ t} = \$\ 7\ 200\ 000 \qquad (23)$$

We now calculate the expenses of the plant by multiplying the total costs for processing one ton of slag by the plant's annual capacity (see equation 11):

$$8\ 000\ t \cdot \$\ 820\ t = \$\ 6\ 560\ 000 \tag{24}$$

To calculate gross profit we subtract the received findings (see equation 12):

$$\$\ 7\ 200\ 000 - \$\ 6\ 560\ 000 \tag{25}$$

$$\Delta = \$\ 640\ 000$$

Continuing with the estimation of the Europe scenario with its slag production of 142 500 t/year. The price of a single 8 000 t/year plant is \$ 9 660 000. The equation will thus look as follows:

$$1plant – 9\ 660\ 000\ \$ \tag{26}$$

$$X\ plants – 1\ 326\ 150\ \$$$

$$X = \frac{1 \cdot 142\ 500}{8\ 000} = 17,8 \approx 18$$

Total revenue will be:

$$\$\ 640\ 000 \cdot 18 = \$\ 11\ 520\ 000 \tag{27}$$

And payback period for one plant is estimated by dividing cost of the plant by the revenue received per year:

$$\frac{9\ 660\ 000}{640\ 000} = 15{,}1 \text{ years} \approx 15 \text{ years and 4 mounts} \tag{28}$$

Therefore, we must not forget the European Union environmental regulations and the restrictions, if the company will not follow them then the regulating force will put penalties to companies, thus we must remember that the landfilling the waste after the refining process to eliminate the wastes company must create its own landfills or give wastes to specialized landfill sectors that take this waste at a cost to the producer, for example in Taiwan the average price to dump one metric ton of slag is \$ 150 - in Europe the price is at least \$ 300.

To calculate the expenses of landfilling the wastes:

$$142\ 500\ t/year \cdot \$\ 300\ t = \$\ 42\ 750\ 000 \tag{29}$$

Therefore we are keeping in mind that the cryolite cost. Alum earth or mixture of the minerals and cryolite which are occupied in substance are calculated in equation (21) the value is equal \$ 1 600 000. Thus, the obvious company benefit will be calculated just added the cryolite cost landfilling cost and revenue:

$$\Delta = \$\ 11\ 520\ 000 + \$\ 28\ 800\ 000 + \$\ 42\ 750\ 000 = \$\ 83\ 070\ 000 \qquad (30)$$

Thus, for example, in the first year of using of implementing eight Alucyc units in Norway the cost of three of those units will be recuperated. In two and a half years the project will earn through its direct and indirect benefits the project will earn \$ 186 907 500. The author can estimate that in this time period the company will returned own investments and starting from third time period will collect net benefits from the project.

This break-even point is a conservative estimate as the author has not studied the savings that can be achieved through lower environmental penalties that may be avoided by the companies implementing the Alucyc technology. These political and regulatory factors are difficult to accurately estimate but it can be safely assumed that the cost of these factors for the companies will only increase. Here the author wishes to once again highlight the non-monetary environmental factor that adds value to the proposition.

3.2.1 Calculations for Norsk Hydra

The total aluminium production of Norsk Hydra was $1{,}958 \cdot 10^6$ metric tons
Wastes produce (see equation 9):

$$1{,}958 \cdot 10^6 \cdot 2{,}5\% = \frac{1{,}958 \cdot 10^6 \cdot 2{,}5}{100^2} = 4{,}895 \cdot 10^4 = 48\ 950\ \text{t}. \qquad (31)$$

To maintain the dross capacity the Hydro Norsk is need to purchase six plants. Let us estimate that one plant will produce 4 000 t liquid and 4 000 t of mixture using a single Alucyc unit. The price of the refined primary aluminium is \$ 7 200 000 for each, if we take into account that there are six of them the total will add up to \$ 43 200 000 and the indirect savings from the cryolite mixture are \$ 1 600 000 per unit: \$ 9 600 000 for six units. Indirect costs will not be counted in this section, but will be counted in the complete analyses. The maintained cost is \$ 6 560 000 for a single unit, \$ 39 360 000 for six units. The delta will be \$ 640 000, or \$ 3 840 000 total for six units. Landfill cost which will be saved add up to \$ 2 400 000. Total cash inflow \$ 11 200 000 – for one plant annually, if we install six plants the value is \$ 67 200 000 and outflow cash will be equal to \$ 39 360 000. The author will put in Table 12 the calculated data for Hydro Norsk if the company will invest its capital into six electro slag furnaces.

Table 12. Cost estimation - Norsk Hydra (US Dollars)

Source: Composed by the author

i (discount rate)	0,666%
Investing project costs (IPV)	$ -57 960 000
cash outflows in each period	$ -39 360 000
cash inflows in each period	$ 67 200 000

The discount rate is taken from equation (16) which is counted as average standard rate for project. Thus the IPV for six Alucyc furnaces installed by Norsk will be in the range of 58 million dollars with cash outflows for their operation estimated at approximately 40 million dollars. The cash inflows attained through the benefits described above add up to 67,2 million dollars. Based on this input data we will now calculate the economic KPIs of the project.

Table 13. Economic efficiency (indicators) - Norsk Hydra

Source: Composed by the author

Number of years (n)	10,00
Net Present Value (NPV)	$ 210 508 105
Internal rate of return (IRR)	47,01 %
Discount profitability index (DPI)	4,63
Return of investments (ROI)	380,33 %
Payback period (PP)	2,08 2 years 1 mount 0 days
Accounting rate of return (ARR)	96,07%
Average annually profit	$ 27 840 000

Table 13 is showing the key economic indicators for the project as calculated from the source data. The results of the period for period economic analysis are presented in the Tables 14 and charts below.

Table 14. Estimated 10 years project Cash flow - Norsk Hydra (US Dollars)
Source: Composed by the author

Cash inflow	Cash outflow	CF (Cash Flow)	ROI (return on investments in %)	NPV (Net Present Value)	DPI	Date
$ 672 000 000	$ -451 560 000	$ 220 440 000	380,33%	$ 210 508 105	4,63	18.01.2026

The graphs for current case study present cash flow in the projects lifecycle. The Figure 20 shows the cumulative discounted cash balance and Figure 21 – the Net Present Value of the Alucyc technology.

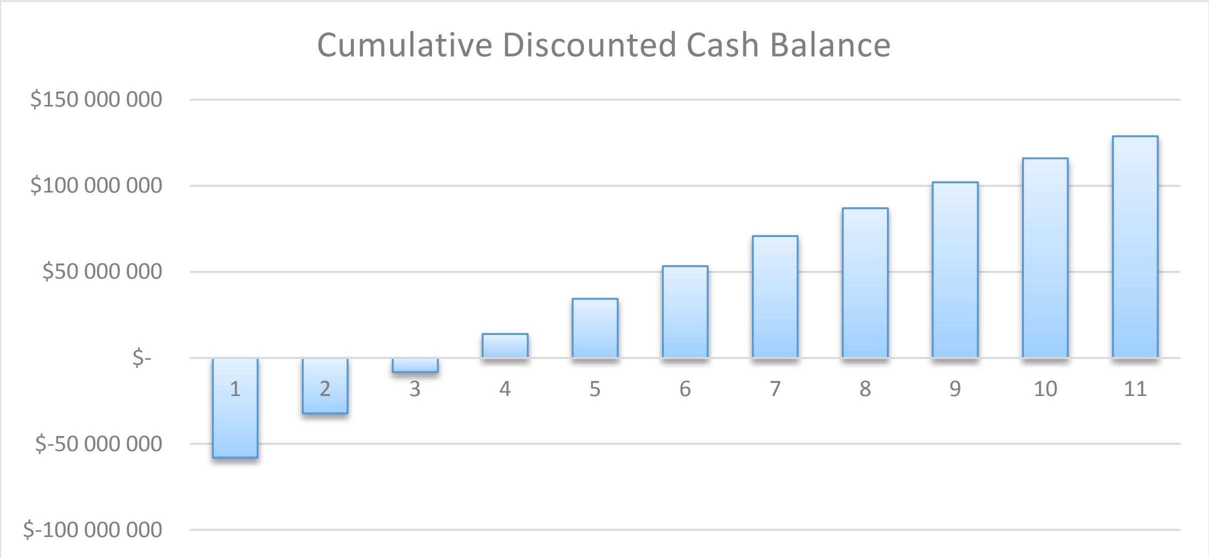

Figure 20. Cumulative Discounted Cash Balance – Norsk Hydra (US Dollars)
Source: Composed by the author

The direct and indirect benefits that will improve the production of primary aluminium as well improve the environmental indicators of the process which are not directly accounted for in the scope of this work.

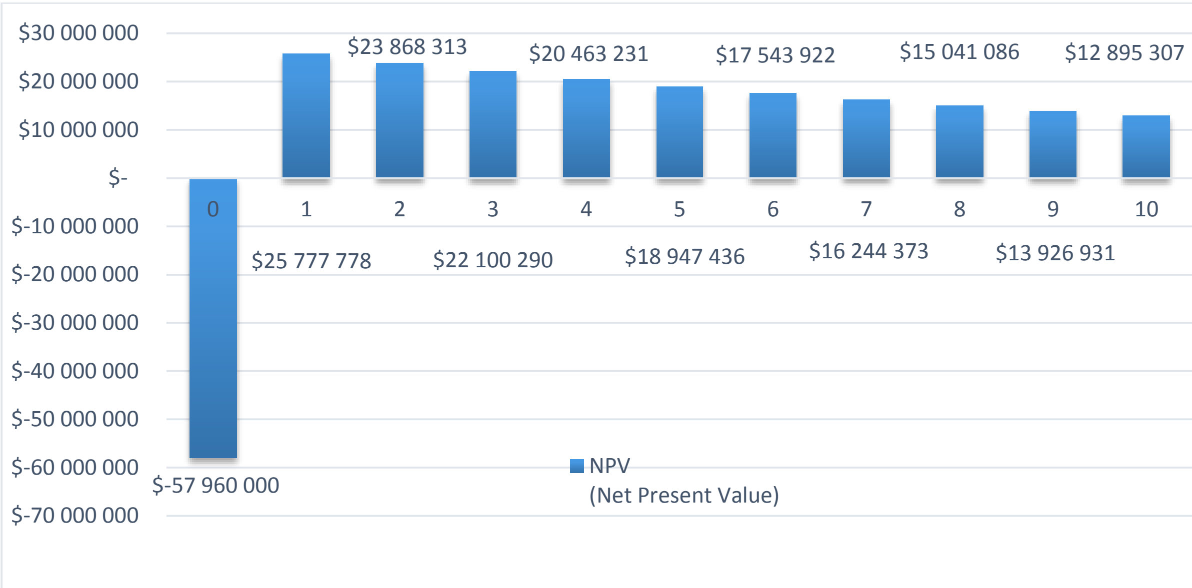

Figure 21. NPV graph – Norsk Hydra (US Dollars)

Source: Composed by the author

In final analysis for Norsk Hydra also shows the efficiency and the period of return on investments of three years. The investors in our case are planned as being Rio Tinto Alcan Inc. which has purchased Norsk Hydra recently and has installations in Iceland which can be used as test sites for the new technology. It is proposed to install the Alucyc pilot installation in Iceland at ISAL aluminium smelter. The smelter's capacity is just 189 000 tons of aluminium per year making it one of the smaller smelters under the flag of the Rio Tinto Inc. Thus the results of the impact of the pilot installation can be studied in more detail. It is noted that Rio Tinto Inc. is continually improve this plants technology in the recent years so it is a great place for Metallurg Engineering to promote their invention to the world market.

Also the author will analyze Iceland's aluminium smelting capabilities if Metallurg Engineering shows the efficiency of the new plant. In Iceland world leading companies in production of aluminium operate – among them Century Aluminum Company, Alcoa. Which is also a viable candidate for implementing Alucyc technologies in their new factories. Iceland in case of aluminium production may be viewed like a cluster where many world leading companies operate and implement new technologies. Thus, we will now take a closer look at the aluminium industry of this small island with big possibilities for kicking off the implementation of the Alucyc technology.

3.2.2 Calculations for Rio Tinto Iceland

In this chapter the author will calculate the efficiency of implementing of Metallurg Engineering furnace in Europe in Iceland. The author will not look on the whole of primary aluminium production in country, but only focus on the factory in Straumsvík - the plant name is ISAL which operates under the flag of Rio Tinto Alcan Inc. Firstly the author will estimate the financial model of the technology with a typical mathematical approach without using financial instruments: discount rate (i), net present value (NPV), internal rate of return (IRR), profitability index (DPI), return on investments (ROI), payback period (PP), accounting rate of return (ARR) and average return during period. After these numbers will be simulated in an excel spreadsheet to gain a wider understanding about the financial part of the project. The same steps as taken in case of China.

The volume of primary aluminium production in ISAL is 189 000 metric tons annually. To estimate the slag formed (see equation 9) during this process we need to multiply this number by 2,5% - which is the amount of slag produced on average as a byproduct of primary aluminium – will be 4 625 tons.

Thus the production needs only one Alucyc unit because it produces only 4 625 tons of slag annually and there is an opportunity to buy 3 375 tons more of dross from the aluminium cluster partners. As we know, from the input data a single Alucyc furnace can recycle 8 000 tons of slag annually and refine 4 000 tons of liquid aluminium.

One ton of “poor” dross of aluminium costs about $ 50. To fully load the Alucyc furnace Rio Tinto Alan Iceland will need to invest $ 168 700 annually.

From the invested $ 168 700 the company will refine liquid aluminium with a total market value of $ 3 037 500 which can be seen as direct profit and $ 675 000 as indirect profit which is due to the production as cryolite mixture (see equations 10, 11, 12, 21).

The values that we have received are concluded from the average aluminium price in 2014 on the London Metal Exchange which stayed at the level of approximately $ 1 800 at the end of that year.

Cost of liquid mixture (cryolite) and electricity is estimated as in the case of Norway: the energy price will stay at $ 605 per ton of slag and the overhead expenses are estimated at $ 215 per ton of slag. Total expenses are thus $ 880 per ton of slag. From this we can calculate profits when technology will be implemented.

To calculate the annual plant revenue we now must multiply the production capacity of liquid aluminium by the average price per metric ton of the product (see equation 10):

$$4\ 000\ t \cdot \$\ 1\ 800\ t = \$\ 7\ 200\ 000 \quad (32)$$

We now calculate the expenses of the plant by multiplying the total costs for processing one ton of slag by the plant's annual capacity (see equation 11):

$$(8\ 000\ t \cdot \$\ 820\ t) + \$\ 168\ 700 = \$\ 6\ 728\ 000 \quad (33)$$

To calculate gross profit we subtract the received findings (see equation 12):

$$\$\ 7\ 200\ 000 - \$\ 6\ 728\ 000 \quad (34)$$

$$\Delta = \$\ 431\ 300$$

And payback period for one plant is estimated by dividing cost of the plant by the revenue received per year:

$$\frac{9\ 660\ 000}{431\ 300} = 22{,}3 \text{ years} \approx 22 \text{ years and 6 months} \quad (35)$$

We must also not forget the European Union environmental regulations, also in Iceland case, and the restrictions, if the company will not follow them then the regulating force will place penalties to companies, thus we must remember that landfilling the waste after the refining process is mandatory for the companies – so to eliminate waste is a good long-term investment plan by itself. As a rule the company must create its own landfills or give wastes to specialized landfill sectors that take this waste at a cost to the producer, for example in Taiwan the average price to dump one metric ton of slag is $ 150 - in Europe the price is at least $ 300. To calculate the expenses of landfilling the wastes:

$$4\ 625\ t \cdot \$\ 300\ t = \$\ 1\ 387\ 000 \quad (36)$$

Therefore we are keeping in mind that the cryolite cost. Alum earth or mixture of the minerals and cryolite which are occupied in substance are calculated in formula (13) the value is equal $ 1 600 000. Thus, the obvious company benefit will be calculated just added the cryolite cost landfilling cost and revenue:

$$\Delta = \$\ 4\ 162\ 500 + \$\ 925\ 000 + \$\ 3\ 037\ 500 + \$\ 675\ 000 + \$\ 1\ 387\ 000 = \$\ 10\ 187\ 000 \quad (37)$$

Thus, for example, in the first year of using of implementing one unit Alucyc in Iceland the cost of it will be recuperated. In two and a half years the project will pay itself back through its direct and indirect benefits. The technology directly and indirectly will earn in 10 years $ 101 870 000. The author can estimate that in this time period the company will have returned own investments and starting from third time period will collect net benefits from the technology.

This break-even point is a conservative estimate as the author has not studied the savings that can be achieved through lower environmental penalties that may be avoided by the companies implementing the Alucyc technology. These political and regulatory factors are difficult to accurately estimate but it can be safely assumed that the cost of these factors for the companies will only increase. Here the author wishes to once again highlight the non-monetary environmental factor that adds value to the proposition.

Continuing the analysis in excel-spreadsheet also shows predictably favorable values that are illustrated below.

Table 15. Cost estimation - Rio Tinto Alcan Iceland Inc. (US Dollars)

Source: Composed by the author

i (discount rate)	0,666%
Investing project costs (IPV)	$ -9 660 000
cash outflows in each period	$ -6 728 000
cash inflows in each period	$ 10 187 000

The discount rate is in Table 15 is taken from equation (16) which is counted as average standard rate for project. Thus the IPV for one Alucyc furnaces installed by ISAL will be in the range of 9,66 million dollars with cash outflows for their operation estimated at approximately 6,8 million dollars. The cash inflows attained through the benefits described above add up to 10,2 million dollars. Based on this input data we will now calculate the economic KPIs of the project.

Table 16. Cash flow 10 years period Rio Tinto Alcan Iceland Inc. (US Dollars)

Source: Composed by the author

Cash inflow	Cash outflow	CF (Cash Flow)	ROI (return on investments in %)	NPV (Net Present Value)	DPI	Date
$ 101 870 000	$ - 79 940 000	$ 24 930 000	258,07%	$ 23 696 005	2,4	18.01.2026

Table 16 is shows the key economic indicators for the project as calculated from the source data. The results of the period for period economic analysis are presented in the Table17 and charts below.

Table 17. Economic efficiency (indicators) - Rio Tinto Alcan Iceland Inc.
Source: Composed by the author

Number of years (n)	10,00
Net Present Value (NPV)	$ 23 696 005
Internal rate of return (IRR)	33,87 %
Discount profitability index (DPI)	2,4
Return of investments (ROI)	258,07 %
Payback period (PP)	2,79 2 years 9 mount16 days
Accounting rate of return (ARR)	71,61%
Average annually profit	$ 3 459 000

The graphs for current case study present cash flow in the projects lifecycle. The Figure 22 shows the cumulative discounted cash balance and Figure 23 – the Net Present Value of the Alucyc technology. The direct and indirect benefits that will improve the production of primary aluminium as well improve the environmental indicators of the process which are not directly accounted for in the scope of this work.

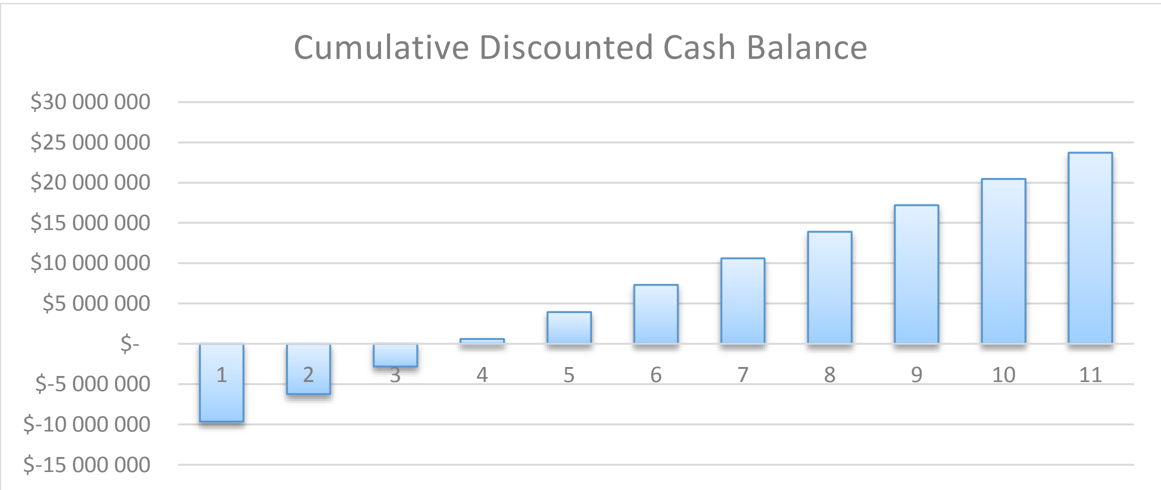

Figure 22. Cumulative Discounted Cash Balance – Rio Tinto Alcan Iceland Inc. (US Dollars)
Source: Composed by the author

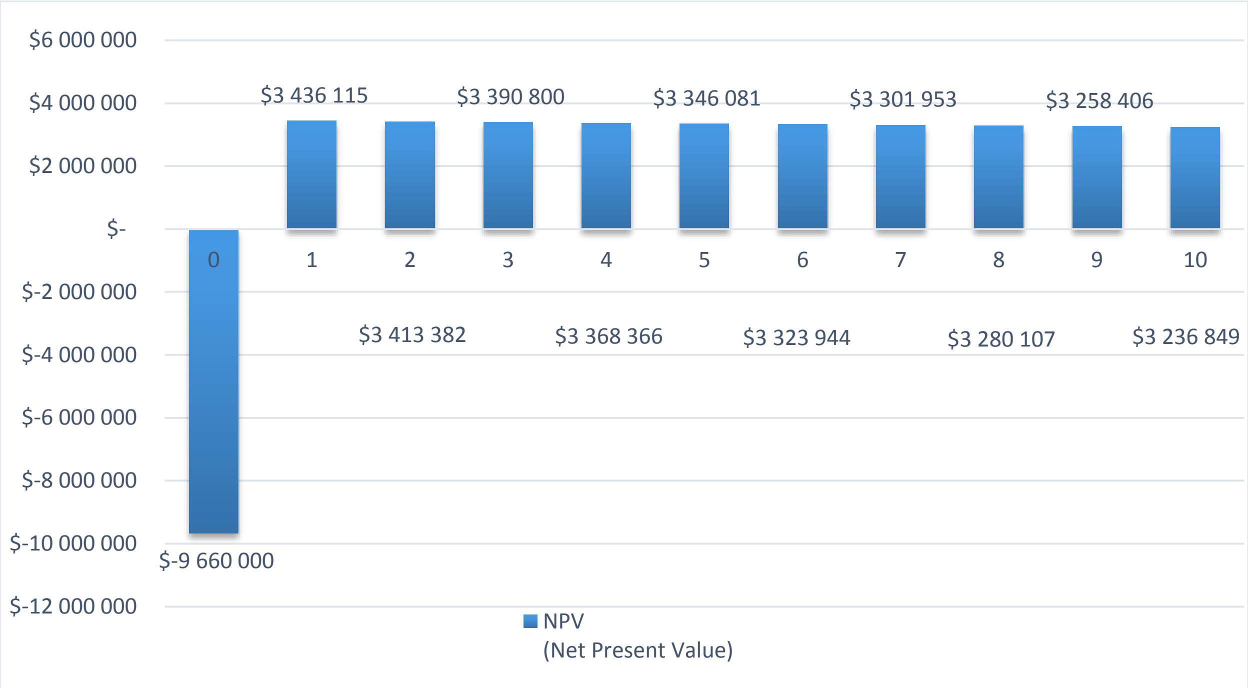

Figure 23. NPV graph - Rio Tinto Alcan Iceland Inc. (US Dollars)

Source: Composed by the author

In final analysis for Rio Tinto Alcan Iceland also shows the efficiency and the period of return on investments of three years. The investors in our case are planned as being Rio Tinto Alcan Inc. which has purchased Norsk Hydra recently and has installations in Iceland which can be used as test sites for the new technology. It is proposed to install the Alucyc pilot installation in Iceland at ISAL aluminium smelter. The smelter's capacity is just 189 000 tons of aluminium per year making it one of the smaller smelters under the flag of the Rio Tinto Inc. Thus the results of the impact of the pilot installation can be studied in more detail. It is noted that Rio Tinto Inc. is continually improve this plants technology in the recent years so it is a great place for Metallurg Engineering to promote their invention to the world market.

Also the author will analyze Iceland's aluminium smelting capabilities if Metallurg Engineering shows the efficiency of the new plant. In Iceland world leading companies in production of aluminium operate – among them Century Aluminum Company, Alcoa which is also a viable candidate for implementing Alucyc technologies in their new factories. Iceland in case of aluminium production may be viewed like a cluster where many world leading companies operate and implement new technologies. Thus we will now take a closer look at the aluminium industry of this small island with big possibilities for kicking off the implementation of the Alucyc technology.

3.3 Conclusions

The author’s analysis shows that:

- China produces almost 600 thousand metric tons of slag annually.
- Western Europe produces almost 142 500 metric thousand tons of slag annually,
- Improvement of production capacity of liquid aluminium which can be attained through the installation of just a single Alucyc unit (based on the average price of aluminium in 2014) is $ 7 200 000.
- The operational expenses that will be incurred by the plant with the adoption of a single Alucyc unit are estimated to be between $ 4 668 000- $ 6 560 000.
- Annual gross profit is thus estimated at $ 431 300- $ 2 532 000 for one unit.
- Payback period in every scenario is no longer than four years.
- Every scenario DPI index shows that the project is worth implementing.
- Alucyc will decrease the environmental footprint of the production process.
- Alucyc will produce energy savings.
- The reduction of landfills is an important economic and environmental benefit.
- Production capacity increase is estimated at a minimum of 4 000 metric tons of liquid aluminium for every installed Alucyc unit.

The author estimated slag production scenarios in China, Iceland and Norway. The technology will reduce the total impact on the environment and secure future revenues for aluminium factories. Every year regular money flow will be generated through the implementation of the technology.

Calculations showed that the technology will provide some extra capacity by improving the productivity of the process and reducing landfill costs. Cryolite mixture can be reused, which will further be very useful in bringing down costs and in improving long-term profits. This profit can be reinvested into further improvement of the quality and decrease in the environmental footprint of the production process. Regarding to the cryolite, it will be mixed with the dross, making a homogenous substance which can be reused as a supplement in the production of the primary aluminium. These costs can be calculated as indirect benefits that should be taken into account making the technology more attractive to the industry. The price of 4 000 tons of alum earth or mixture of the minerals and cryolite is minimum $ 1 600 000. In particular, the author emphasizes again the non-monetary environmental factor that adds value to the proposition.

In the following chapter the author will use the analysis above and the less quantifiable information available about the producers of aluminium. The aim is to explain where and how the Alucyc technology should be implemented to take the most advantage of the related factors while minimizing stakeholder risks associated with its implementations.

The competitors for the technology may be viewed only in the face of state of the art technology manufacturers. If the rotary furnace process is significantly improved in the near future, it may be regarded as direct competition. However, this proposition is highly unlikely. Presently, no information was found by the author concerning competitors using a similar approach to Alucyc or technologies which provide a yield rate and benefits as high as that of the Alucyc technology.

4. STRATEGY AND RECOMMENDATIONS FOR METALLURG EGINEERING

As was demonstrated in the previous chapter the project cash balance is very attractive and the company must promote their technology to the market under this flag. In this case company must have a direction that will lead its customers to realize additional financial and non-monetary value.

In other words the company management must consider the PESTEL analysis and be ready to respond to the signals that the market will have on the product supporting the aluminium industry – Alucyc.

The staff must clearly understand the mission and vision of the company and market the product accordingly. However, the management must realize which strategy to hold or have an understanding what they need not to cause any harm. The management also must perfectly aware the value creation process and how company will perform on the market. Above mentioned factors are illustrated in Figure 24.

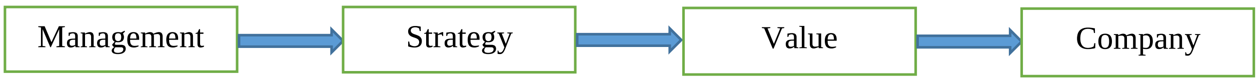

Figure 24. Company value creation chain

Source: Composed by the author

The chart that has been provided by author is the basis for company managers to engage in new markets with effective output. The author will give some recommendations on how to move and which goals to undertake to achieve the business goals of the company – Metallurg Engineering. The recommendations which will be given are based on the last chapters of this thesis including the scenario analyzes done by the author, environmental factors, as well as tools that support strategic decision making process. However, the author suggests that Metallurg Engineering should create a unique strategy for the product promotion and installation to highlight the great value that the new technology will bring to its customers.

The Alucyc technology in its present state with correctly outlined advantages and marketing terms can be a solid competitor to the traditional technology and can in a while become by itself an effective and profitable technic that will be viewed as state of the art by the industry. The first challenge for the managers is to create a reasonable pricing plan, provide high quality information for potential buyers and be fully mobile and flexible with the resource which will be engage in the work, providing customers with clearly defined plans for the implementation of Alucyc. The author has had many interviews with Metallurg Engineering management team and is of the opinion that it can create and find ways to make their product even better but first it must get the positive cash flow by making the technology self-sustainable through selling the proposed technology and highlighting its most important advantages. In the future it should be possible to maintain a competitive edge in the industry if the momentum from the beginning of the now unique Alucyc implementations is used well.

Therefore, good working conditions and cooperation with customers will lead to a successful environment if the right strategy is used. In other words the strategy must help managers assess the company's present situation, identify the direction the company should go, and determine how the company will get there. For the purpose of the thesis, we defined value as the measure of a firm's capability to sell what it makes for more than the costs incurred to make it (Daniels et al., 2007).

The authors cash flow analyzes showed the Alucyc technology are capable to show the good results at the work shop and be an effective part of the aluminium production process for the future customers of Metallurg Engineering.

The strategy that the author proposes for the injection of the Alucyc technology to the market is based on taking advantage of favorable starting conditions, i.e. handling the customers who not only have the need but the economic resources and a proven measure of social and environmental responsibility to handle the pilot implementations of the Alucyc technology in the aluminium production industry. As such it is proposed to first concentrate on Rio Tinto installation in Iceland which is a small factory that is a part of a large corporation interested in improving the efficiency of all of its operations and possessing apparent resources to handle the risk of testing the installation in one of its smaller plants. Iceland, as a region is also a home to many other leading aluminium companies such as Alcoa and the Central Aluminium Company. Thus, we can take advantage of a geographical clustering effect, wherein if results are seen in neighboring companies, managers in competing enterprises are sure to follow up with implementing the innovations in their own plants. Once the technology is proven in practice it can be implemented in larger plants such as those that are operated by Norsk Hydra, later taking a more global approach covering enterprises as far away as China the Americas and Russia.

CONCLUSIONS

The aim of the thesis has been achieved and the thesis questions have been answered. The objectives of the present thesis are the financial, environmental and technological feasibility of the technology and provision of recommendations for further technology development. To achieve the stated objective, the author has solved the following tasks:

1) give an overview of the traditional aluminium production technology;
2) give an overview on the formation and handling of slag using state of the art technologies;
3) analyze the effect of slag on the environment;
4) describe the Alucyc technology;
5) analyze the technology's economic feasibility;
6) analyze the environmental impact of the technology.

The author has given an overview of aluminium production lifecycle starting from bauxite. The author has described the slag formation and characterization, which contains the precious aluminium used in the aluminium alloy industry. The author analyzed semi-products and by-products which still contain aluminium and are presently lost when slag is disposed to the landfills. The slag amount which is generated during remelting slag is leaving the factory was taken into account. It was noted that the producer must incur the correlated utilization costs. Also, it was highlighted that the slag is classified as toxic and hazardous waste (highly flammable, irritant, harmful and leachable), its landfill disposal is forbidden in most of the countries of the world and it should be recycled as much as possible to minimize its impact to the environment. High energy consumption of the existing processes was pointed out. The technology that is used by most of the enterprises to handle slag is rotary furnaces.

Analysis of the current state of the art technologies of aluminium production in general and slag utilization in particular has shown that there is room for improvement. Improvements in the yield of the primary aluminium production process along with the reductions in waste and harmful emissions would be necessary not only by the direct stakeholders of the company but they also promise great benefits as far as the environment is concerned.

The implementation of the innovative Alucyc technology by the existing aluminium industry will change the utilization process of slag recycling, making improvements upon the existing technology, reducing costs of disposal and transportation and reducing the industry's environmental footprint. Analysis has also shown that the Alucyc technology is an economically viable solution for primary aluminium smelters.

The author estimated primary aluminium production scenarios by selected regions: Asia and Europe. In this analysis, the author studied China, as the world's primary aluminium production leader, and Norway and Iceland, as European leaders in primary aluminium production. Financial models and scenarios of the implementation of technology at factories were studied. To analyze the economic feasibility, the author used a typical mathematical approach and standard financial instruments: discount rate (i), net present value (NPV), internal rate of return (IRR), profitability index (DPI), return on investments (ROI), payback period (PP), accounting rate of return (ARR), and average return during period. The calculation values were simulated in an excel spreadsheet and based on the received information, the author has made his conclusions. The new innovative Alucyc technology is shown to be economically as well as environmentally viable. The technology will reduce the total impact on the environment and secure future revenues for aluminium factories. Every year regular money flow will be generated through the implementation of the technology.

The Alucyc technology will provide some extra capacity by improving the productivity of the process and reducing landfill costs. Cryolite mixture can be reused, which will further be very useful in bringing down costs and improving long-term profits. This profit can be reinvested into further improvement of the quality and decrease in the environmental footprint of the production process. Regarding the semi-product – cryolite – it will be mixed with the dross making a homogenous substance, which can be reused as a supplement in the production of the primary aluminium. These costs can be calculated as indirect benefits that should be taken into account, making the technology more attractive to the industry. The price of 4 000 tons of alum earth or mixture of the minerals and cryolite is an indirect profits minimum about $ 1 600 000.

Thanks to a high rate of refinement and yield of aluminium – the new technology helps to significantly lower the environmental impact of the primary aluminium production process. The author believes that the new technology has great potential to become the new state of the art in aluminium production and processing aluminium slag, helping companies who adopt it take a leading place on the market thanks to its economic advantages and in the ranks of social and environmental responsibility thanks to its ecological benefits. The natural environment of Europe is one of its most highly valued resources and a natural competitive advantage for many industries and sources of livelihood for the people living there. This fact is further highlighted by the various state and international regulations that are implemented to protect the natural environment of Europe. The economy must try to be ecological and cause as little harm to the environment as possible. The harm caused to the environment must be minimized where it is technically possible and economically rational to do so. New approaches will create much effort to limit harmful emissions and the amount of landfills as well as the ecological footprint that these landfills bring with them. The Alucyc technology that was discussed by the author solves many environmental problems faced by an important industry of the EU, decreasing the landfilling problems for the sector to nearly zero. The atmospheric pollution from the Alucyc technology will lower CO_2 emissions by seven tons per every ton of aluminium produced when compared with the state of the art production of primary aluminium. It was noted that the TLV values are well below the recommended levels for the relevant substances. To fully secure people and environment special plans of action have also been developed by the engineers of the Metallurg Engineering in the unlikely cases of any foreseeable emergencies, which would help minimize the ecological and financial cost in case something goes wrong.

The only one disadvantage that the author has found is generic financial risk related to any new enterprise. The financial risks mainly comprise macroeconomic risks that are a daily routine part of the business as it is. The risk of price fluctuations on the metal exchange is very difficult to predict and impossible to control, because the worldwide tendency shows the popularity to use aluminium in many aspects of production, the metal is easily recyclable and the price on the stock market should not fall below the current average level of 1 800 USD/ton and should probably grow.

Therefore, the only uncertainty remains that the prices will fluctuate due to an economic crisis, but as it is scientifically called acts-of-god-risks that are beyond of control of the project team. These risks are further underlined by the newness of the technology not only to the company but the industry as a whole. But this is a risk that comes along with the introduction of a potential competitive advantage and thus the company should take it based on a cold-headed analysis of the straightforward advantages that the technology will bring. The introduction of Alucyc into the production cycle should be viewed as an R&D expenditure, for which the research and development has been prepared for the aluminium producer. In particular, non-monetary environmental factor that adds value to the proposition should be highlighted again. If aluminium producers are interested in saving the environment, then the new approach of reducing of hazards waste is also a benefit of the technology on the whole.

Therefore, the author has proposed the Alucyc technology to be injected to the market. The technology is based on a technique to take advantage of the right starting conditions, i.e. handling the customers who not only have the need but the economic resources and a proven measure of social and environmental responsibility to handle the pilot implementations of the Alucyc technology in the aluminium production industry. However, according to the author’s belief, the implementation of the technology should be started in Iceland, specifically in the factories of Norsk Hydra and Rio Tinto. These factories are small but are part of larger corporations and have shown willingness to invest in new technologies while being capable of handling the risks associated with implementing an innovative technology such as Alucyc. As such, it is proposed to first concentrate on Rio Tinto installation in Iceland, which is a small factory. It is a part of a large corporation interested in improving the efficiency of all of its operations and possessing apparent resources to handle the risk of testing the installation in one of its smaller plants. Iceland, as a region, is also a home to many other leading aluminium companies, such as Alcoa and the Central Aluminium Company. Thus, we can take advantage of a geographical clustering effect, wherein if results are seen in neighboring companies, managers in competing enterprises are sure to follow up with implementing the innovations in their own plants. The author believes that once the technology has proven itself in practice, in several pilot installations and the environmental and financial advantages that are stated by Metallurg Engineering are realized at least in part – the Alucyc technology has full potential to become the new state of the art technology for processing slag from the primary aluminium production process, improving the overall yield and reducing waste and emissions related to that process. Based on the above, the author strongly supports the idea that the Alucyc technology should be brought to market.

Once the technology is proven in practice, it can be implemented in larger plants such as those that are operated by Norsk Hydra, later taking a more global approach covering enterprises as far away as China, the Americas and Russia.

The author believes that the work done will help Metallurg Engineering and the companies mentioned in the thesis understand the advantages of the Alucyc technology which will help make our planet safer and cleaner with the new technology.

ANNOTATSIOON

Magistritöös antakse põhjalik ülevaade alumiiniumi tootmistsüklist alates boksiidist kuni räbu ümbertöötluseni. Autor kirjeldab räbu formeerimist, samuti karakteristikuid. Räbus sisaldub märkimisväärses koguses alumiiniumi potentsiaalseteks rakendusteks alumiiniumisulamite tootmiseks. Ümbertöötluse puudumisel suunatakse räbu jäätmejaamadesse. Alumiiniumi tootmisel pöördahjus moodustub kuni 500 kg räbu ühe tonni alumiiniumi kohta. See viiakse tehasest välja, kusjuures tootja peab selle utiliseerimise eest kulutusi tegema. Magistritöös on samuti näidatud, et räbu on käsitletav kui toksiline ja keskkonnaohtlik jääde (kergesti süttiv, ärritava toimega, leostuv jms). Alumiiniumi tootmise räbu jäätmejaamad on keelatud enamikes maailma riikides, mistõttu räbu peaks olema ümber töödeldud nii palju kui võimalik minimeerimaks selle kahjulikku mõju keskkonnale. Töös juhitakse tähelepanu ka sellele, et kaasajal kasutatavate tehnoloogiatega kaasnevad suured energiakulud. Selletõttu enamik alumiiniumi tootvaid ettevõtteid kasutavad alumiiniumi tootmisel räbu ümbertöötlemist pöördahjudes.

Innovatiivne Alucyc tehnoloogia, mis on välja töötatud Eesti ettevõtte Metallurg Engineering OÜ poolt, muudab alumiiniumi tootmise valdkonda räbu ümbertöötlusprotsessi modifitseerides. Uus tehnoloogia vähendab märkimisväärselt kulusid utiliseerimisele ja transpordile ning vähendab ökoloogilist jalajälge.

Autor annab hinnangu primaaralumiiniumi tootmisprotsessile erinevates riikides ning kasutas finantsinstrumentidena tüüpilist matemaatilist lähenemist: diskontomäär (i), ettevõtte tulevaste tulude praegune, diskonteeritud väärtus (NPV), sisemine tasuvuslävi (IRR), tasuvusindeks (DPI), investeeringutasuvus (ROI), tasuvusaeg (PP), arvestuslik tasuvustegur (ARR) ja laekumiste keskmine suurus perioodi jooksul.

Eelnimetatud finantsinstrumente simuleeriti kasutades Exeli tabelit projekti finantsosa paremaks mõistmiseks. Uue Alucyc tehnoloogia rakendamine vähendab mõju keskkonnale ning kindlustab alumiiniumi tootjate kasumi. Tehnoloogia kasutuselevõtt tagab ettevõtetele iga-aastase regulaarse rahavoo.

Arvutused näitasid, et Alucyc protsessi rakendamine ettevõtetele annab täiendava võimekuse tänu tootlikkuse suurenemisele vähendades samal ajal jäätmekäitlusega seotud kulusid. Krioliidi segu on võimalik taaskasutada, mis võimaldab kokku hoida tootmiskulusid

ning tagada pikaajaline kasum. Kasumit saab reinvesteerida parandamaks toodangu kvaliteeti ning vähendamaks ökoloogilist jalajälge.

Ümbertöötlemise protsessis krioliit segatakse alumiiniumi tootmisel moodustuva räbuga. Saadud homogeenset produkti on võimalik taaskasutada lisandina primaaralumiiniumi tootmisel. Tootmiskulusid on võimalik käsitleda kaudse tuluna muutes uudse tehnoloogilise protsessi tööstusele atraktiivsemaks. Arvutused näitavad, et 4 000 tonni alumiiniumi tootmise tooraine – krioliidi ja mineraalide segu – maksumus on vähemalt 1 600 000 USD. Autor rõhutab veelkord, et Alucyc tehnoloogia rakendamisega seotud mittemajanduslikud aspektid suurendavad innovatiivse tehnoloogia väärtust veelgi.

Euroopa looduskeskkond on kõrgelt väärtustatud ja konkurentsivõime oluline aspekt paljudes tööstusharudes. Looduskeskkonna puhtuse aspekt on fookuses mitmetes riiklikes ja rahvusvahelistes regulatsioonides, millised on välja töötatud kaitsmaks Euroopa looduskeskkonda. Tootmine peab olema majanduslikult otstarbekas kuid silmas peab pidama ka ökoloogilist aspekti, st tootmine peab põhjustama ümbritsevale keskkonnale võimalikult väikest kahju. Teiste sõnadega, keskkonnale põhjustatud kahju tuleb minimiseerida nii tehnilisi võimalusi kui majanduslikku ratsionaalsust silmas pidades. Uudne Alucyc tehnoloogia, mida autor oma töös käsitleb, lahendab mitmeid keskkonnaprobleeme, vähendades alumiiniumi tootmisjäätmete (jäätmejaamade) probleemi peaaegu nullilähedaseks. Sealhulgas õhu saaste tehnoloogia rakendamisel on tunduvalt väiksem kui primaaralumiiniumi tootmisel tavatehnoloogiat kasutades.

Autor näitab oma töös, et ükski kahjulike jäätmete piirväärtus ei ületa lubatud piirmäärasid. Ettevõtte Metallurg Engineering inseneride poolt on välja töötatud spetsiaalsed tegutsemisstrateegiad ettenägematute hädaolukordade tarvis juhuks, kui need peaksid aset leidma.

Tänu alumiiniumi tavatehnoloogiaga võrreldes suuremale saagisele alandab uudne tehnoloogia märkimisväärselt mõju keskkonnale primaaralumiiniumi tootmisel. Käesoleva töö autor loodab, et uuel tehnoloogial on suur potentsiaal muutuda uueks alumiiniumi tootmise ja tootmises moodustuva räbu ümbertöötlemise standardiks. See aitaks firmadel, millised uudset tehnoloogiat rakendavad, saavutada turul juhtiv positsioon tänu majanduslikele, samuti lisaväärtusena sotsiaalsetele ja ökoloogilistele eelistele.

Autor hindab samuti riske, millised kaasnevad uue tehnoloogia evitamise faasis. Finantsriskid hõlmavad peamiselt makroökonoomilisi riske, millised on samas äritegevuse tavapäraseks aspektiks. Turuhindade muutumise riske metallide tootmises on väga raske prognoosida ja juhtida. Põhjuseks on alumiiniumi populaarsuse pidev kasv erinevates kasutusvaldkondades. Alumiinium on kergelt taaskasutatav ning selle turuhind mitte ainult ei lange tulevikus alla taseme 1 800 USD/tonn vaid tõenäoliselt peaks pigem kasvama. Seetõttu ainsaks ebamäärasuseks on võimalikest majanduskriisidest tingitud hinnakõikumised. Seda võib piltlikult nimetada „jumala tahteks“ – risk, mis ei ole tehnoloogiaarendajate ja rakendajate kontrolli all.

Eelnimetatud uue tehnoloogia rakendamise riskid rakenduvad nii ettevõtetes kui ka alumiiniumi tootmise valdkonnas tervikuna. Firmad peavad sihikindlalt tuginema tehnoloogiliste uuendustega kaasnevatele analüüsidele. Alucyc tehnoloogilise protsessi evitamist ettevõttes tuleks käsitleda kui investeeringut teadus- ja arendustegevusse. Selline investeering on tehtud alumiiniumisulameid tootvas ettevõttes Metallurg Engineering.

Käesoleva töö autori poolt pakutud uue tehnoloogia turul rakendamise strateegia baseerub kasusaamisel õigeaegsest stardipositsioonist. Alucyc tehnoloogia rakendamisest huvitatud ettevõtted peavad väärtustama nii uudse arenduse majanduslikku poolt kui ka sotsiaalset vastutust ning muret keskkonnamõjude pärast. Üheks võimalikuks pilootettevõtteks on Rio Tinto Alcan Inc. tehas Islandil. See on väike metallurgiaettevõte, mis on osa suuremast korporatsioonist. Viimane on huvitatud tootlikkuse suurendamisest alumiiniumi tootmisel. Suurkorporatsioonid on altimad võtma uudsete tehnoloogiate rakendamisega seotud riske ühes korporatsiooni väiksemas ettevõttes. Island regioonina on koduks veel mitmele alumiiniumitootjale, sealhulgas Alcoa ja Central Aluminium Company. Seega Islandi puhul on tegemist geograafilise klastri efektiga, kus uue tehnoloogia rakendamisega seotud positiivne tulemus hakkaks silma ka naaberfirmadele. Niipea kui innovatiivne tehnoloogia on end väikeettevõtte praktikas tõestanud, on seda kergem rakendada suurettevõtetes, sellistes nagu Norsk Hydra. Edasised rakendused võiksid olla juba globaalsed sellistes riikides nagu Hiina, Põhja- ja Lõuna Ameerika ning Venemaa.

Autor usub, et käesolev töö, mis on valminud koostöös ettevõttega Metallurg Engineering, aitab kaasa uut tehnoloogiat rakendades muuta planeet ohutumaks ja puhtamaks.

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APPENDIX 1. ALUCYC TECHNOLOGY 3D MODEL