GREENER AGGREGATE INDUSTRY

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ABSTRACT

Tampereen Ammattikorkeakoulu
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HASARI, MIIKKA: Greener Aggregate Industry

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The aim of this final thesis was to gather background information and come up with development proposals for improving the environmental performance of aggregate production. The thesis was commissioned by NCC Roads Oy and it will act as a basis for the company's 'Green Aggregate' business concept. The concept deals with three environmental aspects regarding the production of aggregates. These are the transportation of the aggregates, emissions and other impacts of extraction and crushing as well as the non-production and subsequent uses of the quarry sites. This thesis concentrates on impacts due to transportation and production.

The local impacts include dust and noise, while globally the greenhouse gas emissions are considerable. Various ideas and methods for reducing these impacts were discussed. The available options for controlling the local impacts include different types of noise damping technology and dust suppression systems. The greenhouse gas emissions of the production can be reduced by using equipment that is powered by electricity instead of diesel. The electricity must come from renewable sources. The possible developments regarding transportation include EcoDriving training courses, alternative fuels, using belt conveyors for internal transportation, proper stacking of storage piles and co-operating with other lines of business on-site.

Many of the discussed ideas and methods were not feasible to implement, at least not at the moment, or needed further testing. It became clear that general and comprehensive guidelines for a 'Green Aggregate' concept are difficult to declare, but the activities should be considered case-by-case. Practical testing of the methods and monitoring the results are necessary for follow-up. NCC Roads Oy plans to utilize an upcoming aggregate site in the city of Loviisa as a pilot-case quarry for the concept. The conclusions of this thesis include suggestions of what kind of actions could be tried and tested for example in that site.

Key words: Aggregate production, environmental impacts

TIIVISTELMÄ

Tampereen Ammattikorkeakoulu
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HASARI, MIIKKA: Ympäristöystävällisempää kiviainestuotantoa

Opinnäytetyö 49 s., liitteet 3 s.
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Tämän opinnäytetyön tavoitteena oli koota taustatietoa sekä kehitysehdotuksia joiden avulla kiviainestuotantoa voisi viedä ympäristöystävällisempään suuntaan. NCC Roads Oy tilasi työn pohjustamaan yrityksen 'Vihreä Kivi' –liiketoimintamallia. Tämä konsepti pyrkii kehittämään kolmea ympäristöön vaikuttavaa osa-aluetta kiviainestuotannossa. Nämä ovat tuotteiden kuljetus, tuotannonaikaiset päästöt sekä ottoalueella tapahtuva muu toiminta ja alueen jälkihoito. Tässä opinnäytetyössä on keskitytty näistä osa-alueista kahteen; logistiikkaan ja tuotantoon.

Kiviainestoiminnan paikallisia ympäristövaikutuksia ovat esimerkiksi pölypäästöt ja melu. Lisäksi kasvihuonekaasupäästöt ovat merkittäviä sekä varsinaisesta tuotannosta, että tuotteiden kuljetuksesta. Työssä on käsitelty erilaisia ajatuksia ja keinoja näiden vaikutusten vähentämiseksi. Paikallisia vaikutuksia voidaan hallita erilaisilla melunvaimennus- ja pölynsidontatekniikoilla. Tuotannon kasvihuonekaasupäästöjä saadaan vähennettyä korvaamalla dieselmurskaimet sähkökäyttöisillä laitteilla. Käytettävän sähkön tulee olla uusiutuvista energianlähteistä. Logistiikkaan liittyviä mahdollisia kehitysideoita ovat EcoDriving -kurssit, vaihtoehtoiset polttoaineet, liukuhihnojen käyttö alueen sisäisessä kuljetuksessa, varastokasojen optimoitu muotoilu sekä yhteistyö muiden toimialojen kanssa ottoalueella.

Monet käsitellyistä kehitysideoista vaativat lisää testausta tai eivät olleet lainkaan sovellettavissa kiviainestuotantoon ainakaan nykymuodossaan. 'Vihreä Kivi' –konseptiin on hankala asettaa yleispäteviä ohjeita, vaan käytettävät tekniikat ja keinot tulisi aina arvioida tapauskohtaisesti. Käytännön kokeilut ja tulosten tarkkailu ovat välttämätöntä jotta konseptin toimivuus varmistuu. NCC Roads Oy aikoo kokeilla konseptia Loviisassa sijaitsevalla tulevalla ottoalueella. Tämän työn johtopäätöksiä –kappaleesa on esitetty joitain ehdotuksia toimintamalliksi esimerkiksi kyseiselle ottoalueelle.

Avainsanat: Kiviainestuotanto, ympäristövaikutukset

FOREWORD

I did my practical training for NCC Roads Oy and also part-time work between the training periods, so after more than one year of employment the next step was naturally the final thesis. The company had thought of planning and implementing an environmental business concept that later became known as 'Green Aggregate', which would go well under the 'NCC Green' development programme that applies to the whole NCC group. The topic seemed interesting right from the start, but also difficult and broad. I wanted to go for it anyway, because I liked the idea of laying groundwork for a concept that would be long-term and developed continuously and might even lead to changes in the attitudes towards the industry.

Due to the vast and previously mostly uncharted topic, I came up with less conclusions and suggestions that I initially hoped for. However, I still feel that this thesis is a good foundation for initializing the concept and helpful for the further development that hopefully will continue within the company. I would like to thank all the people at NCC Roads Oy, especially its development manager Taina Piiroinen for guidance during the challenging task and Juuso Lukkarinen for providing comments and suggestions.

Special thanks also to Kai Ylä-Outinen and Juhamatti Heikkilä of Metso Minerals for valuable source material and comments from the viewpoint of the component manufacturer.

Thanks to the former head of my study programme Marjukka Dyer for suggesting that I would apply for the training placement at NCC Roads back in 2009 – that is why I am here now. Thanks also to the current head of the programme Eeva-Liisa Viskari for being the thesis supervisor and also commenting on the work as a person outside the aggregate industry.

Finally, thanks to my friends and family for supporting me during the writing process.

TABLE OF CONTENTS

1 INTRODUCTION

Aggregate production provides raw materials that are required in various types of construction targets, such as drains, foundations, roads and railroads. The materials include sand, gravel and crushed stone. Aggregate particles can also be further processed into paving asphalt together with bitumen. The production takes place in a quarry that is located in an area where the quality of the bedrock is suitable. In some cases also natural sand and gravel are mined.

PICTURE 1. Aggregate production site (NCC Roads)

In Finland, around 100 million tons of aggregates are used yearly to meet the demands of construction and maintenance. Around 80% of the used material comes from extraction sites that are subject to permits and the rest is gathered as a side product of construction sites. The used amount per inhabitant is the largest in Europe. The difference to other countries can be explained for example by the local climate which requires structures and buildings to be able to withstand frost. As the gravel resources are diminishing in Finland, the emphasis is gradually shifting towards crushed stone. Technological development has also contributed to the feasibility of using crushed stone as a construction material. (Maa-ainesten kestävä käyttö 2009, 9-10; Maa-ainesten ottaminen ja ottamisalueiden jälkihoito 2001, 7.)

There are around 7000 valid land extraction permits in Finland, half of which are active. The extraction sites in these permits cover merely 0,01 % of the whole area of Finland. More than half of the used materials are refined by screening or crushing. (Kaikki perustuu kiviainekseen 2008, 3.) The land extraction permit is based on the Land Extraction Act and the Finnish legislation usually requires an additional environmental permit which is based on the Environmental Protection Act. There are also various other laws controlling aggregate production. Environmental Impact Assessment is often required when the projects are substantial and long-term. The EIA procedure provides valuable information concerning the environmental aspects of the projects as well as different alternatives for how the extraction could be carried out.

PICTURE 2. Aggregate crusher (NCC Roads)

The green ideology has already spread in the construction industry and such ideas and solutions should also be addressed in the infrastructure field. The Finnish branch of NCC Roads has set out to form and develop a ‘Green Aggregate’ (‘Vihreä Kivi’) concept that aims to improve the aggregate business towards a more environmental and sustainable direction. The concept addresses the environmental impacts of aggregate transportation, the subsequent and non-production uses of the quarry sites as well as the actual production itself.

This thesis will be a basis for that concept and it is commissioned by NCC Roads Oy. The thesis concentrates on two sectors out of the three; local and global impacts of the production and transportation. Different approaches and possible solutions to these issues are compared and discussed in chapter 5. This thesis mostly handles quarry operations, but with further planning the concept could be expanded to gravel pits and asphalt production as well. The ‘Green Aggregate’ aims for continuous development and so this thesis will be merely a starting point. The ideas and strategies that this kind of a concept promotes are voluntary for the aggregate companies, but they are nevertheless very important when considering the total environmental impacts of the industry.

2 PROCESS DESCRIPTIONS OF AGGREGATE PRODUCTION

A common way to produce aggregates is a technique called bench stoping that is carried out in an open pit and in multiple sequential layers from top to bottom. It begins with preparatory tasks such as removing the overburden and mining a pit which is then expanded as the extraction of the first layer begins. Bench stoping is illustrated in appendix 1. In the actual production process the material is extracted from bedrock by the use of explosives and this is usually followed by processing it further with crushers and other types of equipment. The whole process can be roughly divided into two phases; extraction and crushing. Additionally there might be also other types of on-site refining. Between and after these two phases loading, transporting and storing of the material takes place. A graphical process description of the production can be found in appendix 2.

The extraction phase consists of drilling, charging, blasting, stone removal and fragmentation of the larger particles. Multiple holes are drilled and charged with an adequate amount of explosive, which depends on the quality of the rock and the planned height of the extraction bank amongst other things. After the blasting the aggregate material is removed from the extraction bank and, if necessary, scalped to smaller pieces for the ease of loading, storing and refining.

Crushing is usually done multiple consecutive times before the desired grain size is acquired; the reduction in diameter can be as much as a hundredth of the original size (Jaakonmäki, Johansson, Mäkinen, Räsänen, Ulvelin & Vennelä 2009). The pre-crushing process makes it possible to transport the material via conveyor belts and process it further. The intermediate crushing can already produce various finished aggregate products, but it can also prepare the material for the tertiary part - fine crushing. The crusher equipment can be stationary or mobile and according to Jaakonmäki et al. (2009), the latter has become a more and more popular choice over the years. The parts of a crushing plant include feeders, crushers, screeners, sieves and transportation systems.

3 ENVIRONMENTAL ISSUES REGARDING AGGREGATE PRODUCTION

Aggregate production affects the environment in various ways, both directly and indirectly. The extraction always affects the scenery and causes changes in the geological and biological qualities of the area. The additional impacts and risks include effects on water quality and groundwater level, dust and noise emissions, vibration, and waste. When compared to stone quarries, gravel extraction has a higher risk of water contamination and unplanned gravel pits have already caused shortages of groundwater in some regions of Finland. Planning the subsequent use of the land in question is also of high importance, as deficiencies in this matter can cause serious and permanent alterations to the natural conditions of the area. As defined in Maa-ainesten kestävä käyttö (2009, 8), the post-treatment of quarries and pits aims to adapt the site to the surrounding nature, decrease the risk of groundwater contamination and enhance the security in the site. At best it can also create new properties and uses for the area once the extraction has come to an end.

3.1 Related legislative issues in Finland

The Land Extraction Act and Environmental Protection Act are the most common legislative acts that are related to the environmental impacts of aggregate production in Finland. Professional production requires usually both land extraction permit and environmental permit, which are separate and do not depend on each other. The main points of these acts and permits are listed in Figure 1. An Environmental Impact Assessment is also often required and water permit can be necessary when extracting on a groundwater area. Information about these can be found in Figure 2. Additional legislation regarding aggregate production includes the Land Use and Building Act 132/1999 and in some cases also Forest Act 1093/1996, Act on Water Resources Management 1299/2004, Highways Act 503/2005, Railways Act 110/2007 and Antiquities Act 295/1963 (Maa-ainesten kestävä käyttö 2009, 18).

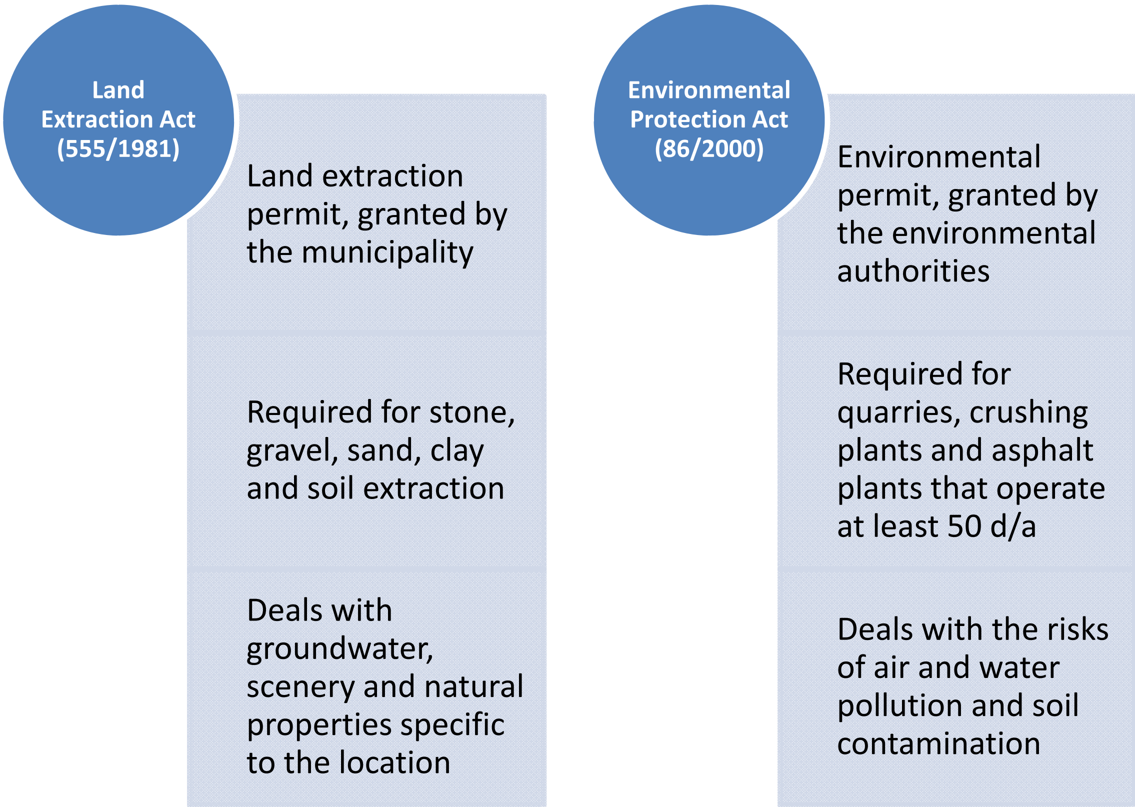


FIGURE 1. The main legislation and permits for aggregate production in Finland

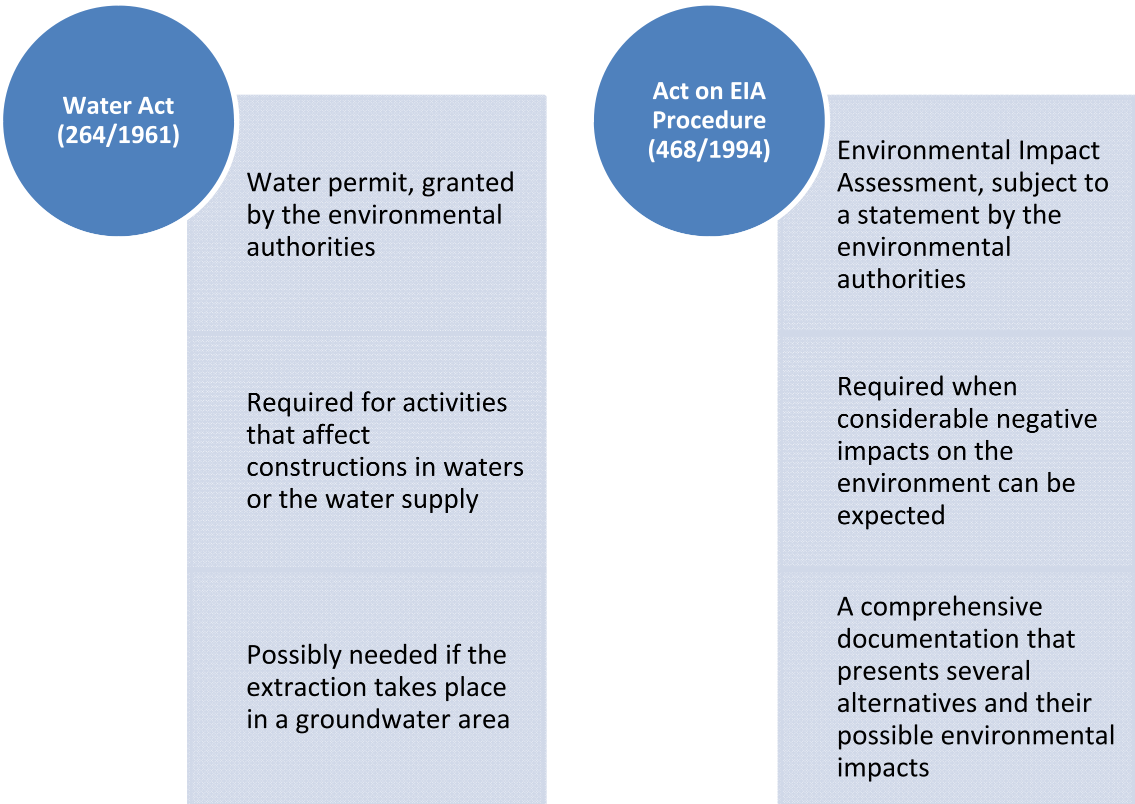


FIGURE 2. Additional legislation regarding aggregate extraction in Finland

3.2 Environmental impacts and risks

Since the legislation and its monitoring are of high importance in Finland, the risk of environmental contamination or other catastrophes due to aggregate production is considerably small. The permits are not easily granted, and often the Act on Environmental Impact Assessment Procedure requires the applicant to carefully study the impacts and risks and present the results before the authorities make their decisions regarding the permits. However, not all of the impacts are taken into account or even mentioned in the environmental permit procedure. For example the atmospheric emissions are of great importance and offer a lot of challenges when developing a green aggregate concept. The various impacts and risks are discussed in chapters 3.2.1 – 3.2.9.

3.2.1 Dust

The fine particle emissions can occur in all stages of aggregate production but the most significant sources are the stages in which the rock material is either dropped or moved. The factors affecting the amount and occurrence of dust particles in aggregate crushing include the hardness, grain size, density and dampness of the rock material. As the volume of the production increases, so does the amount of dust. Further factors are weather and production conditions as well as the equipment used. The dispersion of the particles depends not only on atmospheric conditions, but on the magnitude and height of the mixing as well. (Toivonen 2010, 36; 38-42.)

Weather is a factor that affects the particle emissions considerably. Strong wind can cause a vast spread of dust from the extraction site. Rain on the other hand constrains the dust, as water binds the particles after which they are no longer airborne. Water is in fact a commonly used means to reduce dust emissions in Finnish aggregate sites. Other techniques include encapsulation of the production devices and various kinds of filtering equipment.

The particles that cause the most significant health impacts are PM10s, which can be inhaled by humans. PM2.5 particles penetrate even deeper in the lungs. (Lahdensivu, 2002.) Particles with smaller masses can also travel longer distances in the atmosphere via wind.

According to Toivonen (2010, 124), aggregate crushing is not likely to produce significant dust emissions outside a 500 m range from the quarry. Evaluating the dispersion and its effects has proved to be quite difficult by both the aggregate companies and authorities in Finland. Used methods include modeling the dispersion and measuring the particle count with various devices, but the reliability of these methods has been under question.

3.2.2 Noise

Together with dust, noise is the other immediate and clear environmental impact of aggregate production. There are various sources of noise in aggregate production and these are listed in table 1. Some of these phases are not always present in the production process.

TABLE 1. Noise sources in aggregate production (Kahri 2009, 22-27)

Source	**Type of noise**
Drilling	Constant
Blasting	Impulse
Scalping	Impulse
Crushing (and screening) • Crushers • Screens • Loading	Partly impulse
Construction equipment • Loading • Storing	Constant
Transportation traffic	Constant

The noise from the initial stages of aggregate production depends on the quality of the bedrock, the mass that is to be detonated and charging of the explosives. Drilling produces constant noise from both the arm of the drill and the compressor along with its motor. (Kahri 2009, 23-24.) Explosions produce clearly distinguishable impulse noise that could sometimes cause the most significant noise emission to an outsider; the blasting can often have a startling effect on the observer. The brinks of a quarry can act as noise barriers, which can especially reduce the noise of procedures that take place close to them. These include removal of the stone material and scalping.

The noise sources of the crushing phase are the crushers and screeners as the aggregates go through them. The differences in the noise emitting properties of different equipment can vary a lot; some crushers are equipped with softer material on these parts for noise reduction purposes. According to a noise modeling report of a crusher plant (Promethor 2008), a mobile crusher produces less noise than a stationary one. The fact that the noise sources of the mobile crushers are located closer to the ground allows a 2 dB reduction in noise levels. The smaller size of these crushers makes it easier to control the noise. (Kahri 2009, 26.)

Loading and unloading the material with excavators and wheel loaders also produces noise as the shovels and scoops hit the aggregate piles or platforms. The wheel loaders also emit alarm signal while in operation. The noise from transportation depends greatly on the amount of traffic and the location of the site. If the site is near a busy road or other significant external noise source, the transportation of aggregates does not increase the noise levels considerably. The truck traffic can vary between 1-50 loads per day, depending on the location and product demand.

The Finnish Council of State has issued reference values for environmental noise. The values are utilized when planning traffic, land use or construction, but also in permit application processes of construction and aggregate production. In case of impulse-like or low frequency noise, 5 dB is added to the results before comparison with the reference values. The values are presented in table 2.

TABLE 2. General reference values of environmental noise (Melutason ohjearvot, 2011)

	L_{Aeq} max.	
	Daytime (7am-10pm)	**Nighttime (10pm-7am)**
Outdoors		
Residential areas, recreational areas inside and near population centres, nursing home and school areas	55 dB	45-50 dB*⁾**⁾
Vacation settlement areas, camping sites, recreational areas outside population centres, conservation areas	45 dB	40 dB***⁾
Indoors		
Residential rooms, sickrooms, accommodation facilities	35 dB	30 dB
Classrooms, conference rooms	35 dB	-
Office premises	45 dB	-

*⁾ With newly established areas the value is 45 dB

**⁾ The nighttime value is not applied to school areas

***) The nighttime value is not applied in such conservation areas which are generally used only during daytime

3.2.3 Vibration

Vibration can occur when a certain force is applied to a system that can oscillate. The magnitude of the vibration is usually larger near the source which emits the oscillating force. In aggregate production, these sources include explosions and the transportation. (Aatos 2003, 94-95.)

The magnitude is measured using a unit of mm/s, which describes the particle velocity during the vibration. This is analyzed in three separate directions; horizontal, vertical and the direction to which the oscillation is proceeding. Explosions cause impulse-like vibration that is at its strongest for only a very short period of time, usually less than one second. Explosions also cause air oscillation, which has a frequency that is partly in the hearing range of humans and partly below it. This oscillation varies a lot between blasts and is greatly affected by its direction, weather, type of terrain and obstacles. There are no limit values in the Finnish legislation for this oscillation, but it is estimated that when the peak value exceeds 1 kPa, weaker windows will start to break. (Aatos 2003, 94-95; 100.)

Transportation causes smaller vibration than explosions, but its duration is longer. The frequency is often between 5 and 20 Hz. According to Pöllä, Kärnä, Vuolio, Paavola & Räsänen (1996, 9), a fully-packed lorry can cause particle velocities of 4-5 mm/s when measured at a close range. However, transportation of aggregate production rarely causes any damage to structures. (Tiainen 2010, 26.)

3.2.4 Effects on groundwater

The bedrock, overburden and vegetation act as a protecting buffer for the groundwater resources below. As the aggregate extraction begins, this buffering capacity is reduced and thus changes both in the formation of groundwater and in the quality of groundwater can occur. In addition to these direct impacts, aggregate production can cause also indirect impacts to groundwater. These include leaks of fuels and other oil products to the groundwater. The use of explosives also increases the risk of groundwater contamination in an aggregate site. Emissions to groundwater vary between quarries and gravel pits. In gravel pits, the production can cause increases in electrolyte, iron and turbidity levels of the groundwater. However, monitoring activities in the aggregate sites have shown that these impacts are restricted to the production sites and do not cause groundwater changes in the surrounding areas. (Laurila 2009, 115-116.) In quarry operations the risk of groundwater impacts increases when the extraction is done below the groundwater level. The level can decrease considerably in the aggregate site and sometimes also in the surrounding areas. Since the protecting buffer is removed, the risk of contamination is also present. (Laurila 2009, 28-29).

Prohibition on altering groundwater is included in the Finnish Water Act (264/1961). This applies also to the extraction of materials from the ground and therefore aggregate extraction cannot cause reductions in the yield or quality of groundwater that is used as household water in someone else’s property. A water permit might be required if the neighboring estates use groundwater resources that are connected to the extraction site.

3.2.5 Effects on surface water

The surface waters are affected by runoff from the surrounding catchment areas. Different substances from wastewaters, airborne fallout and rain can alter the water quality. Impacts of aggregate production to surface water quality are usually not significant, but the risk of contamination increases considerably. The risk is caused by transportation traffic and possible fuel leaks. The production can also change the amount and direction of surface water runoff. Moreover, this runoff might include nutrients and particulate matter. (Hasari 2009, 6; 28-31.) The runoff can be collected in a settling tank, in which the particulate matter falls to the bottom and does not transport into the surrounding nature. The water from the settling tank can be further utilized in dust protection.

3.2.6 Waste

The waste that is produced in an aggregate site can include municipal waste, iron and steel waste as well as hazardous waste such as batteries and oil waste. The waste amounts depend highly on the volume and nature of the activity. The environmental permit regulations require that a specific area is reserved for waste in the aggregate site, in which the waste is stored before it is transported to the proper treatment facility. Hazardous waste should be stored in a container that has a lock, proper air conditioning and a large enough settling basin. (Suomen Ympäristökeskus 2010, 49.)

3.2.7 Atmospheric emissions

The aggregate business as a whole produces a significant amount of greenhouse gas emissions, including CO_2, CO, CH and NOx. These originate from the production itself, from the traffic at the site and from the transportation of the aggregates. The atmospheric emissions of natural stone extraction sites are listed in table 3. The data is gathered from questionnaire answers of infrastructure construction companies in Finland. Information regarding explosives and fuels is based on data from the manufacturing companies. For electricity and heat production the average emission profiles of Finland were used. With refinery and quarry + refinery cases the calculations only take into account the emissions from electricity production and off-site transportation. (Aatos 2003, 157; 160.)

TABLE 3. Atmospheric emissions per 1 t of aggregate (Aatos 2003, 161-163)

	Quarry	Refinery	Quarry + Refinery
CH_4	1,9-6,7 g	249,0 g	80,2-675,6 g
CO	5,8-416,6 g	211,0 g	0,48-10,58 kg
CO_2	0,996-29,16 kg	85,98 kg	56,2-245,4 kg
CO_2-foss.	2,79-3,37 kg	22,73 kg	5,22-12,75 kg
Heavy metals	0,3-1,1 mg	41,7 mg	12,4-177,9 mg
Particles, dust	10,4-14,4 g	260,9 g	84,0-683,1 g
NOx	48,3-302,5 g	531,6 g	0,4-1,35 kg
SO_2	2,9-11,0 g	170,9 g	63,3-425,5 g
VOC	3,5-8,6 g	274,5 g	87,2-809,9 g

3.2.8 Effects on landscape and nature

In addition to the emissions and energy consumption, aggregate production has also obvious effects to the nature and landscape of the area where the site is located. Both visual and biological changes take place during the production. Impacts to the biodiversity are also possible and the prosperity of the area can become reduced.

A large amount of soil waste is produced in quarry operations. The removed overburden and vegetation together with minerals of no value require storage piles and proper handling. In Finland, this soil waste is often utilized as noise barriers for the site. The habitats around the site can also become affected due to the impacts to the surrounding waterways, such as erosion and increased turbidity. The surface of groundwater in the surrounding areas can also decline due to water being pumped out from the quarry holes.

The sites are often in such locations where proper road networks might not exist. Thus starting a new aggregate quarry might require road construction to the site. This can cause changes in drainage patterns, soil moisture, and vegetation growth, therefore affecting the local ecosystems. When the road is in use, there are various traffic-related contaminants that include heavy metals, road dust, exhaust gas emissions, oils, deicing salt and litter. (Viskari 2002) The routes that are built specifically for transportation to and from an aggregate site do not have similar traffic conditions as regular roads. The traffic consists almost exclusively of transportation of products and materials, while private transportation is at its minimum. However, a site producing approximately 375 000 t/a can have up to 80 trucks visiting daily. In addition to contaminants, the transportation causes also noise emissions.

PICTURE 3. Removal of the overburden layer (NCC Roads)

4 GREEN AGGREGATE

4.1 Background

The construction business has already utilized various types of green technology and environmental business models. This is not surprising when looking at the emissions and resource-use of buildings; in United States, residential and commercial buildings are responsible for one third of all CO_2 emissions and their annual total energy and electricity demand take 39% and 68% of the total consumption respectively. It is also worth noting that these numbers include only the use of the buildings, not the production of the materials or the construction phase. (Yudelson 2007, 7.) Implementing environmentally friendly methods can reduce various emissions, improve the municipal water use and produce less landfill waste. One important benefit for a corporation is enhanced public image due to environmental values. Sustainability and green ideologies can act as efficient marketing tools that seem to become more and more important to the customers. Aggregate production consumes a natural resource that is not renewable, always affects the nature and has a bad reputation as a source of dust and noise emissions; therefore an environmental facelift for such a company and the whole industry could prove to be essential.

Many of the environmental issues within aggregate production are also closely linked to work safety. According to the Occupational Health & Safety Act (738/2002), the employer must determine and recognize the health impacts and risks that the work causes to the employees. The employer must also actively aim for reduction and removal of these impacts and risks. In aggregate sites, the noise and dust emissions are not only big environmental factors, but also important issues when it comes to occupational health & safety. Therefore developments regarding dust and noise emissions of aggregate production will benefit both of these sectors.

NCC Construction has set out an EkoConcept partner scheme that relates to the lifecycle development of buildings. The concept connects design, construction and maintenance into a single entity and does not only lead to environmental benefits, but aims to improve cost-efficiency as well. (NCC Construction Oy 2011.) This is one example of how the environmental issues can be seen beneficial in a modern company. Sustainable and ecological construction often leads to many reductions in various costs.

NCC group has had four environmental targets for some time now; healthy environment construction, reduction of climate impacts, decreasing the use of harmful substances and improvements in recycling. While there are already some implementations in the Construction –subsidiary, the infrastructure field needs new methods as well. NCC Roads is therefore planning a 'Green Aggregate' concept which would reduce the environmental impacts of the infrastructure construction. This bachelor's thesis acts as a basis for the concept, but developing the related ideas and innovations should be a continuous process.

The 'Green Aggregate' concept was set out in August of 2010 when the city of Loviisa started a project called 'Green Highway'. This project aims to combine various green technologies that are related to highways (eg. eco-friendly cars, green building, alternative energy sources etc.) under one concept. The target road in question is a part of the E18 highway between the cities of Loviisa and Hamina. After the pilot phase this concept would be applicable also elsewhere. NCC Roads owns a region in the Vanhakylä district of Loviisa, which is located near the highway. The company has applied for and obtained an environmental permit for aggregate production in that region and is in the middle of the application process for the land extraction permit. An idea came up of a more ecological extraction site; a concept that would go well together with the 'Green Highway' project.

As the 'Green Aggregate' concept can essentially be considered as an Environmental Management System, the reasons for implementing such a concept are similar to those that are suggested in EPA's guide "Environmental Management Systems: An Implementation Guide for Small and Medium-Sized Organizations":

EMS is beneficial if the company has to comply with environmental laws and regulations, is looking for ways to improve environmental performance, the environmental affairs of the company are a significant liability, there is not enough time or resources to effectively manage the environmental obligations or the relationship between the company's environmental goals and other goals is unclear. The same publication states many benefits that an EMS can provide: improved environmental performance, reduced liability, competitive advantage, improved compliance, reduced costs, fewer accidents, employee involvement, improved public image, enhanced customer trust, more favorable credit terms and meeting customer requirements. (Stapleton, Glover & Davis 2001.) A successful implementation of 'Green Aggregate' can help the company to achieve all these goals.

The improvement in environmental performance should already be an intrinsic value for a modern corporation, but a concept like 'Green Aggregate' will certainly bring also other benefits along with it. The ability to adapt to new situations will be enhanced and meeting the legislative demands as well as the permit regulations becomes easier. The risks of hazards, contaminations and spills are reduced, as are various costs that are related to environmental aspects. The efficiency of the company is improved as resources such as energy are used in an improved manner. The public image revamp will most likely bring new customers or even open up new markets.

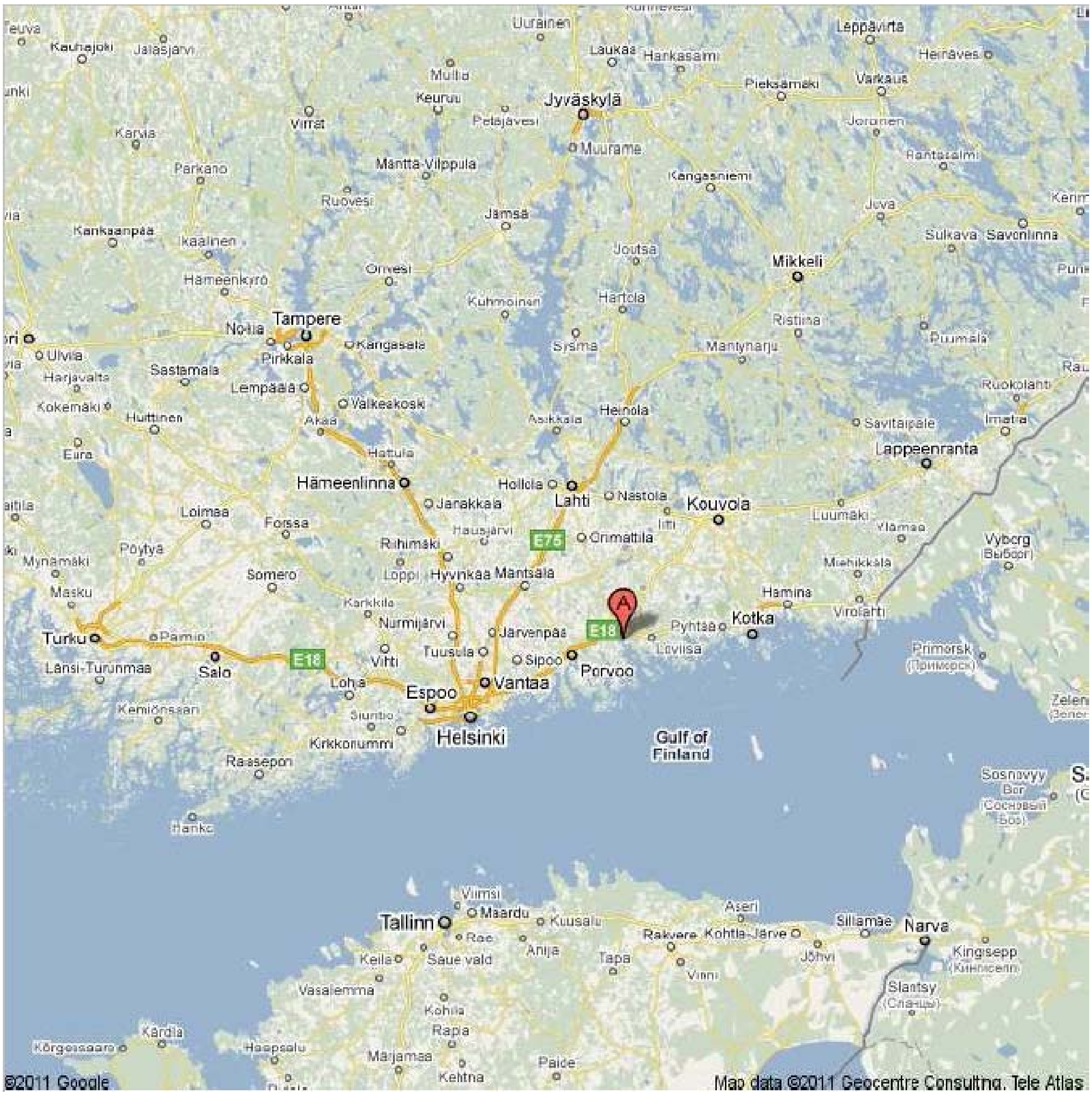
4.2 The three sectors

The emissions and the effects on nature and landscape are issues that cannot be completely avoided in aggregate business. Even a significant reduction of these impacts requires a totally new way of doing things and various solutions that are both technical and ideological. The most important factors and development areas should be identified for a successful and functional 'Green Aggregate' concept. This has proven to be problematic due to the vast spectrum of factors involved.

In the autumn of 2010, the 'Green Highway' project staff in the city of Loviisa and NCC Roads held a meeting where the possible targets of 'Green Aggregate' concept were discussed. The group came into conclusion that the most important environmental factors were the transportation of aggregates, emissions and contaminations due to the production and impacts on landscape and nature. These three sectors came to be the basis of the 'Green Aggregate' concept.

4.3 Pilot case: Aggregate site in Vanhakylä, Loviisa

The site is located in Peppars estate of Vanhakylä district in the city of Loviisa. The area has been classified as suitable for aggregate extraction by the environmental administration of Finland. NCC Roads has a valid environmental permit for this kind of activity and the application for land extraction permit is being processed.



PICTURE 4. Location of Vanhakylä (Google Maps 2011)

PICTURE 5. Aerial image of the Peppars estate (NCC Roads 2006)

PICTURE 6. Vegetation in the Peppars estate (NCC Roads 2006)

The environmental permit allows extraction of 375 000 t/a on average and a maximum of 500 000 t/a. The area for which the permit is applied for covers 22,5 ha. The nearest Natura 2000 site is Pernajanlahti, which is located 1 km south. The surrounding areas are dispersed settlements with agriculture and forestry activities. The distance to the nearest residential building is 600 m. (NCC Roads Oy 2006.)

An Environmental Impact Assessment has been conducted for aggregate production in the Peppars estate. According to the results, the nature surrounding the area will not be significantly affected due to the activity. The running waters in the site are initially filtered by a marsh that is located inside the area and then passed to the settling tank before the release into nature. There are no groundwater areas within the site and the activity will not affect the surrounding groundwater conditions. (Insinööritoimisto Paavo Ristola 2006.)

4.4 Assessment and auditing

Monitoring the 'Green Aggregate' concept is vital for both the functionality assessment and the development of the concept. PDCA is a commonly used management process for various business operations and it is usable also with the 'Green Aggregate'.

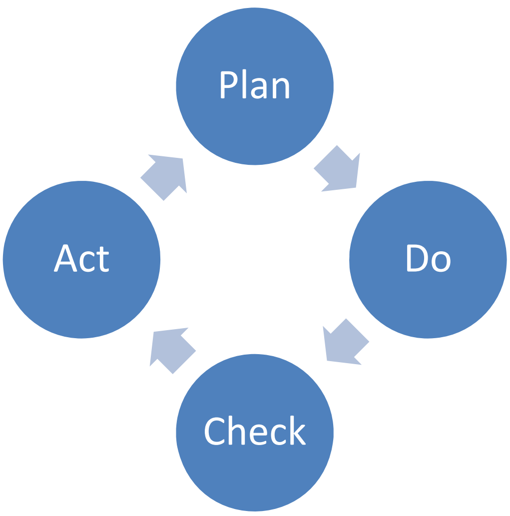


FIGURE 3. The four steps of PDCA

PDCA consists of four phases; Plan, Do, Check and Act. In practice this means that at first the required objectives are defined and the methods to achieve these objectives are established. The implementation of the methods is initially done on a small scale if possible, so that the effects can be tested properly. The results are assessed and evaluated and then compared to the expected output. If the methods did not work as expected, reasons for this are considered. It is important to identify the phase where the possible errors have occurred. Once the source of the problem is found, some kind of modification to the process is necessary. When this is discovered and applied, the PDCA cycle starts over again until improvement is achieved.

In the ‘Green Aggregate’ concept, the practical uses of PDCA include for example trying out new ideas and methods for dust protection. In this case the objective is to cut down dust emissions by a certain amount. This objective has to be defined clearly, i.e. stating the target levels for dust emissions as well as how and where the measurements are done. Some suggestions for methods and techniques to reduce dust emissions are described in chapter 5.2.1. If possible, the chosen method is first tested on a smaller scale to prevent unnecessary investments. Once a feasible amount of statistical data is gathered, the evaluation can begin. If the results do not meet the target levels, the problem could be in the method itself, in the planning, in the implementation or even in the measurement phase. At this point, changes to the process can be adopted or the whole method can be abandoned. If the results are satisfying, the chosen method can be tried out in a bigger scale and the PDCA cycle starts again from the beginning. Since the PDCA development is continuous, constant measurements are required throughout the whole production time. The permit regulations demand various kinds of impact monitoring on a regular basis, and this surveillance data can also be utilized with the PDCA assessment. Depending on the process, some additional monitoring might be necessary.

5 DEVELOPING TRANSPORTATION AND PRODUCTION

5.1 Transportation

On a global scale, the greenhouse effect is one of the primary concerns regarding road transport. Traffic-based greenhouse gas emissions include carbon monoxide, carbon dioxide, nitrogen oxides and hydrocarbons. Other GHG's, such as methane, are not significantly related to transportation. (Ryynänen, 2002)

When considering the emissions of aggregate business as a whole, transportation is a key factor. Transporting 100 000 t of aggregates for 10 km produces 48 t of CO_2, 0,24 t of CO, 0,10 t of CH and 1 t of NOx (NCC Roads 2010). The internal traffic of a site is also significant, although the distances are short. Vehicle industry is constantly moving towards eco-friendly technology, but so far this development seems to concentrate more on passenger cars. Biodiesel, electric engines and other alternative solutions are difficult to apply to trucks due to the demands of heavy weight loads and size of the trucks. Driving arrangements and optimization are also things that affect the environmental impacts of transportation, but there is little room for improvement in these areas.

5.1.1 The locations of the sites

The location of the aggregate site is crucial when discussing the effects of transportation. If a suitable aggregate site is near an urban area, it is difficult to utilize due to the immediate local impacts, such as noise and dust emissions. Additionally, the extraction might lower the comfortability of a residential area. There can also be conflicts regarding the use of land; various activities and lines of business are often competing over the same estates and resources. These different entities include community infrastructure, outdoors and recreational activity, nature and landscape conservation and groundwater protection. (Maa-ainesten kestävä käyttö 2009, 11.)

Other factors that affect the location of aggregate sites include the actual amount of rock or gravel that could be extracted, as well as the quality. As the aggregate resources have diminished over time, shortages of good quality material have already emerged near the big population centres. This has resulted in longer and longer transportation distances between the production sites and the end-use locations. (Maa-ainesten kestävä käyttö 2009, 10.) Taking these things into account, the aggregate companies cannot be very selective when it comes to choosing the location. However, in some cases choosing a certain location over another can result in shorter transportation distances and thus reduce both environmental impacts and transportation costs.

5.1.2 EcoDriving

EcoDriving is a course that trains drivers to cut down unnecessary emissions and fuel consumption. This does not only reduce environmental impacts of transportation, but also leads to significant savings for the companies. Carbon dioxide emissions are reduced 300-800 kg/a depending on the magnitude of driving. The courses are available in driving school around Finland. (EcoDriving Oy 2011.) If there is a lot of internal traffic in an aggregate site done by the company itself, it might be feasible to utilize EcoDriving courses. For example, idle running of wheel loaders can cause severe unnecessary fuel costs and emissions. Since the transportation of the finished products is mostly handled by outside companies, the aggregate company has little effect on the driving methods of the external logistics. However, when selecting a transportation partner the idea of EcoDriving could be brought up in negotiations. Some of these companies might already utilize it, for example Volvo Trucks in Finland has begun their own training program that uses the principles of Heavy EcoDriving methods (Virtanen 2009).

One problem with EcoDriving is related to the possible attitude problems that driver personnel might have. People who have been in the business for a long time might not want to change their working habits, even if it was an official company policy. Driving behavior is very difficult, if not impossible, to monitor. There are some vehicle-tracking devices on the market, such as MapFactor VTU 009. The tracking is done by utilizing GPS-positioning and wireless GSM/GPRS mobile networks and sends the information to a server. Software can be used to monitor the vehicle in real time. In addition to the location, available information includes the vehicle's speed and altitude as well as probe and alarm data. (Microdata Finland Oy 2007.) While this kind of applications might be useful in cargo transportation, they are not strictly usable in aggregates logistics due to the varying nature of the transportation.

5.1.3 Alternative fuels

Finnish Neste Oil –company manufactures renewable diesel titled NExBTL that can be used as such in a diesel engine, or as an admixture with petrodiesel. Tests have proven that the fuel is also compatible with truck engines. (Daimler AG 2011.) Neste stations already sell the NExBTL + petrodiesel mixture and the Helsinki area buses have been running with this fuel.

With the use of NExBTL, the CO_2 emissions can be reduced 40 to 60 percent compared to conventional diesel. However, this depends on the raw material and its place of production. The studied feedstock options include rapeseed in EU area and overseas as well as Malaysian palm oil with the following land use scenarios: natural forests, food oil and coconut production. All of these options have advantages over diesel fuel, but the degree varies considerably. For example, fuel originating from European rapeseed results in net energy savings of 32 GJ and 2 t of CO_2 eq. GHG reduction. Overseas rapeseed has minor benefits due to a lower yield per hectare and a longer transportation route. (Gärtner, Helms, Reinhardt & Rettenmaier 2006, 16-18.) The benefits of fuel from palm oil depend on the manner of production and there is controversy related to the use this feedstock as a raw material for the fuel. Even though it is often claimed that palm oil production aims to reduce greenhouse gas emissions, in practice the results might be opposite and more GHG's are actually produced than saved. A study shows that producing 1 kg of palm oil can emit 2,8-19,7 kg of CO_2 eq., although this conclusion depends on a number of assumptions

(Reijnders & Huijbregts 2006). Additionally, there is also the question of biodiversity if for example rainforests are cut down to make room for oil palm plantations.

Ethanol gasoline RE85 is another option for an alternative fuel in trucks. The fuel consists 85% of ethanol and 15% of gasoline. The use of this fuel requires a specifically manufactured engine and the suitable vehicles are called flexible-fuel vehicles (FFVs). So far there are only passenger cars and light duty pickup trucks available as FFVs, but in the future also heavy duty transportation trucks might become available. ST1 energy company is planning to start selling RE85 fuel all over Finland – so far it has only been available at few gas stations in Helsinki. (Heikura 2010.)

Natural gas vehicles use compressed natural gas as a fuel and compatible engines are available also for heavy duty transportation. Many of the buses in the United States run with natural gas and forecasts predict that the worldwide number of NGVs will be 17 million by 2015 (Green Car Congress, 2009). A comparative study between diesel, biodiesel and natural gas refuse trucks showed that the global environmental impact of CNG trucks was the lowest of the three (López, Gómez, Aparicio & Sánchez, 2009).

Alternative modes of transportation include ship and railroad transportation, out of which railroad transportation is more usable on a local scale. Ship transportation could also be applicable in some cases, such as transporting aggregates from Loviisa to Helsinki area via the Gulf of Finland. However, the costs are relatively high with both of these modes.

5.1.4 Internal traffic

Internal transportation of an aggregate site could largely be handled with belt conveyors instead of vehicles. The initial investment is obviously high when building a long and enduring conveyor, but once in operation the energy demand of the internal transportation reduces significantly. Additionally, the amount of personnel needed for transportation declines. Assuming that transporting 1 t of aggregates for 700 meters requires 0,2 l of fuel and transporting the same amount by conveyor consumes 0,5 kW of electricity, the costs for truck and conveyor transportation are in this case approximately **0,273 €** and **0,034 €** respectively. Details about this calculation can be found in appendix 3.

PICTURE 7. Internal transportation by a belt conveyor (NCC Roads)

The energy demand of the internal traffic can also be reduced by an appropriate forming of the storage piles. It also helps to keep different products separated and all produced material available for sell. There are also advanced equipment for stacking, such as the one in picture 8.

PICTURE 8. Telestack conveyor (Powerscreen Ireland http://www.powerscreenireland.ie/stock/stockpilers.htm)

5.1.5 Co-operation

If both internal and external traffic of an aggregate site are difficult to reduce, one option would be co-operation with other activities and lines of business. If the site has enough space, various joint operations could take place that would be able to utilize the trucks used in aggregate transport. In practice this would mean that incoming trucks would bring something to the site and then take the aggregate products while leaving, leading to compensation in transport-related emissions. Examples of possible co-operation include:

- Energy production (for example from biomass)
  - Requires a plant that usually consists of two digester units and storage tanks for input and output materials. The plants can utilize energy crops, manure or various kinds of waste as a substrate. (Ahrens 2011.)

- Snow dumping site
    - Should be on a pervious surface and not near any water resources. The snow is filtered into the soil and the remaining solid material can be removed after the melting. (MassDEP 2011.)
- Landfill for clean overburden
    - The soil could be utilized in the site's landscaping process during and after the aggregate production
- Asphalt production
    - Could utilize aggregates from other sources as well
- Recycling centre (for example for aggregates, asphalt, glass, bricks, paper etc.)
    - Possible co-operation with local waste management

5.2 Production

5.2.1 Local impacts

In addition to logistics, the location of a quarry also plays an important role when minimizing the local environmental impacts of the production. An ideal location does not have groundwater areas or residential buildings nearby and there are no protected animal habitats around. Whenever possible, a 'Green Aggregate' –site should be located in this kind of an ideal area, but obviously it is often difficult in practice. The local impacts can however be reduced or even eliminated with various solutions.

If there is a groundwater area or wells that are in use within 500m range from the center of a new site, a study about the groundwater conditions is essential. The study should determine the groundwater level in the extraction site and in its vicinity, the main directions of the flow, location of the wells as well as the catchment area and the movement of surface waters. This research provides valuable background information for preventing groundwater contaminations during the production and also helps in the permit application process. The environmental authorities will give instructions and regulations regarding the groundwater and surface water surveillance in the permit.

Noise from aggregate extraction can be reduced with alternative means of production and with noise damping technology. Planning the placement of crushing equipment and using noise barriers, such as heaps of removed overburden, are the basic ways to decrease noise emission from the site. The crushers can also be equipped with rubber parts that produce less noise when the aggregate material hits them. These include liners in the feeder bottom and feed hopper. Noise reduction tents and curtains have also been tested with varying results. (Ylä-Outinen 2008.)

The dust that is released due to aggregate production can be prevented from spreading into the environment by using water that is gathered into the site, eg. rainfall and melted snow. Dust protection can also be done within the production equipment with the use of water spraying pipes and nozzles, discharge hoods, dust covers and dust removal units. Units like High Pressure Dust Suppression System are efficient in dust removal, but can require as much as 650 liters of water per one hour in a three phase crushing. However, a regular low pressure spraying would consume 3000 liters per one hour. (Ylä-Outinen 2008.)

The important factors with dust removal include the velocity of collision between the dust particles and water drops, the size of both the particles and the drops and the spraying pressure. The removal is more effective with a high collision velocity and an optimal pressure. The best results are gathered with a pressure range of 6,9-55 bar and 27 bar seems to be an optimal value. Laboratory tests have shown that dust particles of 2-3 micron size can be efficiently captured by water drops that are around 100 times larger. A three phase crushing would require 20 nozzles and a water pressure of 30 bar. The HPDS can operate in -10°C temperature, but the pipes need to be dried with compressed air after use. De-icer is also necessary. (Ylä-Outinen 2010.)

Other means to control dust emissions include capturing it with specifically manufactured dust foam. The reductions in dust amount have been measured as high as 80-95%. Although the foam is a chemical product, no negative impacts have been discovered either to environment or to the manufactured aggregate product. The foam technique requires around 2 liters of water per 1 ton of aggregates and compressed air with a consumption of 1800 liters per minute. Examples of used chemicals include citrus oil and aliphatic acids. The foam protection can function even in -12°C temperature, although with less satisfying results. (Lindahl 2004.) It can be argued that consuming a significant amount of water in dust protection is not sustainable or environmentally friendly and therefore in contrast with the principles of ‘Green Aggregate’. Assuming a production capacity of 150 tons per one hour, the foam protection requires 300 liters of water for that period of time. It is less than half of what HPDS requires.

5.2.2 Global impacts

There are various emission sources within the production process. The used vehicles and machines include dumpers, excavators, drilling equipment, loaders and diesel compressors. The site also requires a significant amount of energy and fuel in different forms, as is describe in table 4. These values can vary between different sites depending on rock type, topography, the available equipment and range of products amongst other issues.

TABLE 4. Energy and fuel consumption of aggregate extraction per 1 t (Aatos 2003)

	Quarry	**Refinery**	**Quarry + refinery**
Electricity	2,8-10,1 kWh	372,2 kWh	0,94 MWh
Liquid gas	6,3-46,8 g/l		1,05 kg
Fuel oil	9,49-9,6 l	12,4 l	14,09-56,11 l
Diesel	0,93-1,07 l	8,58 l	2,08-4,65 l
Gasoline		1,49 l	0,21 l

Diesel produced from natural gas, 100% RME or fish oil –based diesel could be considered as alternatives for regular diesel in crushers, but the utilization costs can be unfeasible and the need for maintenance increases (NCC Roads 2009).

The crushers used in an aggregate site are often diesel-powered, but also electric crushers are available. Available models can be around 25%-40% more expensive than regular diesel crushers, but the energy costs per produced ton can be lower with electrical devices. Electrical mobile crushers can provide better efficiency than the diesel ones and their energy supply could be provided by more environmental means; there are various eco-friendly energy solutions available. Eco-friendly electricity could also be used in other electrical needs of the site, such as the office and personnel quarters.

The Finnish Association for Nature Conservation manages an EKOenergy label that is an indication of sustainable production of renewable energy, consumption of that energy or energy saving. Strict criteria apply to the label and they are designed for sustainability in Finland. The accepted sources include solar energy systems, wind power, hydropower and biofuel. Peat, fossil fuels, nuclear energy and waste incineration do not qualify as EKOenergy. However, even the renewable energy has its impacts on the environment and these are taken into account with the label. FANC assesses the label applications on a case-by-case basis to ensure that even the acceptable energy sources meet additional criteria. For example, wind power facilities cannot be located in nature reserves, in landscapes that carry national and/or provincial value or in important international and national sites used by birds. (Finnish Association for Nature Conservation 2009.)

One diesel engine consumes around 400 g of fuel per one ton of aggregates crushed. 1 liter of diesel fuel has an approximate weight of 0,85 kg which produces about 2,64 kg of CO_2 when burned. Therefore crushing 1 ton of aggregates produces 1,24 kg of CO_2 from one diesel engine. (Ylä-Outinen 2010.) With a three phase crushing and a production capacity of 375 000 t/a, the yearly CO_2 emissions reach 1395 tons. The fuel consumption is overestimated here, as in practice the machines are not constantly running at their full capacity. The environmental benefits are still substantial when choosing electric crushers and renewable energy over traditional diesel crushers.

5.3 Recycling of materials

Since aggregate materials are non-renewable and a diminishing resource, the role of recycling increases constantly. Recycling is therefore an important part of a ‘Green Aggregate’ concept as well. In addition to the reduction of non-renewable resource use, it has also various other benefits concerning environment: habitat and biodiversity impacts are reduced, transportation distances become shorter and improvements in energy-efficiency and finished product application are possible. Possible direct benefits for aggregate companies include cost reductions of transportation and savings over natural aggregate production. The possibilities of recycling do not limit to reuse of old aggregates; other materials can be substituted for natural aggregates too. (Calkins 2009, 242-243.)

Recycling also saves energy, which is beneficial both environmentally and financially. Recycling of aggregates consumes approximately 30% less energy than producing virgin material. This is because recycling does not require the blasting phase and only half of the crushing and screening work. (Murén 2011.)

Integrating recycling to the other activities within the site is crucial; reusable material could be processed and refined in the site but the transportation should be joined to the logistics of the natural aggregate production. In practice this would mean that incoming trucks would deliver recyclable material and swap that for finished products when they leave. Additional traffic should be avoided; otherwise both the environmental and financial benefits of recycling could be decreased due to the extra transportation.

Byproducts of aggregate production should be utilized on-site as much as possible. Rock, soil and water are examples of materials that can be reused in the production processes. The topsoil that is removed in the preparatory works and unsuitable rock material can be stacked to heaps that act as barriers which reduce the noise emissions from the production. If possible, this material should be utilized also in the post-treatment of the site to ensure the continuity of the natural conditions. The incoming waters of a site, including rainfall and melting snow and sometimes also groundwater that needs to be pumped out of the quarry, can be used in dust protection. These methods have double benefits: they make use of the byproducts and help to control emissions. This kind of utilization has in fact become common within Finnish aggregate industry.

6 CONCLUSIONS AND SUGGESTIONS

Many of the ideas and methods discussed in the previous chapters still require a lot of additional testing before conclusions regarding their functionality can be made. Some of the possible solutions are not applicable to aggregate production in Finland at least at the moment, but all of them seem worth developing further and possibly they will become feasible options in the future. This goes to show a proper ‘Green Aggregate’ site still requires further studying and testing, which can be handled for example in future final theses.

Based on the ideas in the previous chapters, the figure 4 depicts a possible practical implementation of ‘Green Aggregate’ concept with respect to the sectors that are discussed in this thesis.

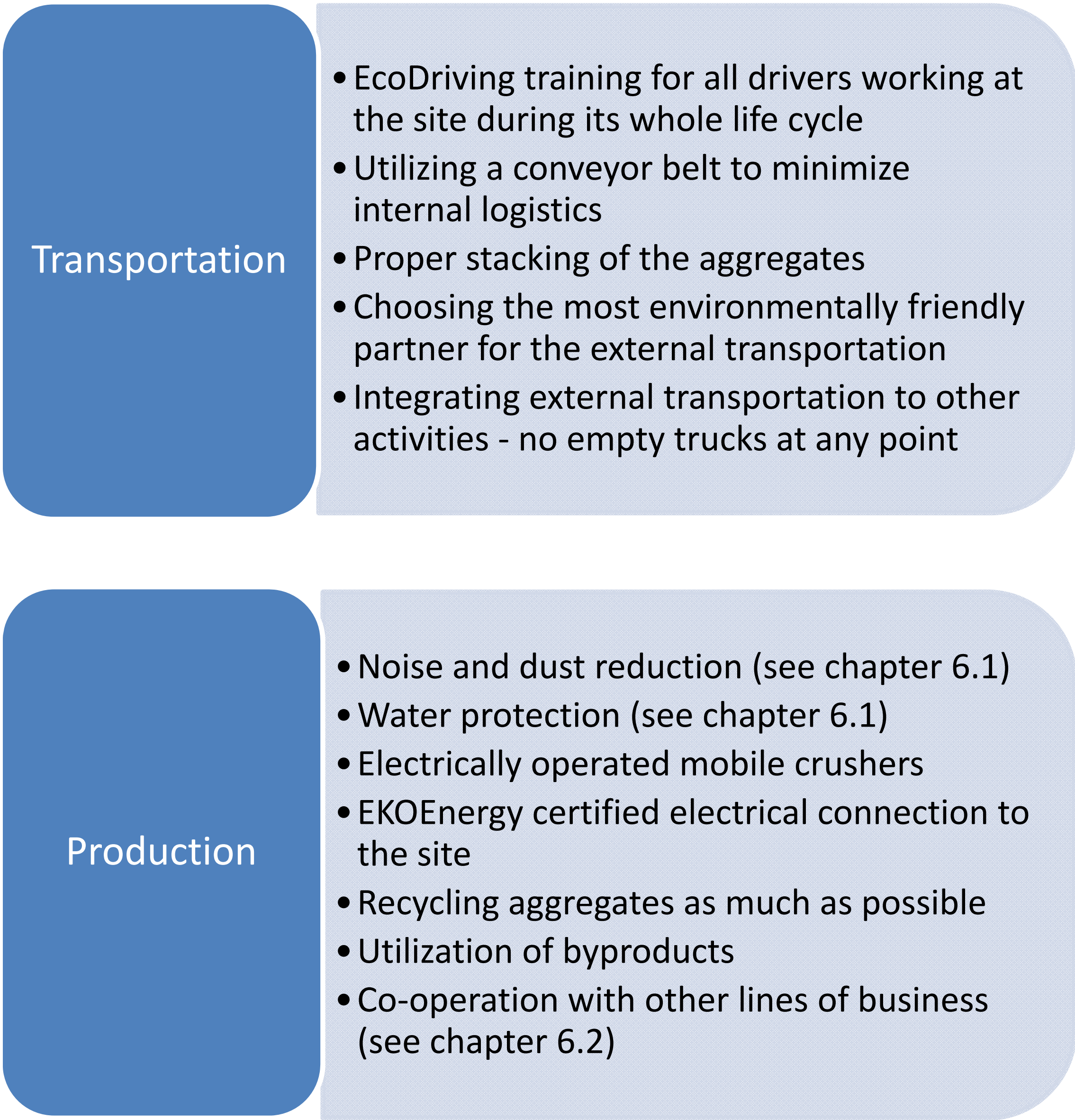


FIGURE 4. Example of a practical implementation of the ‘Green Aggregate’

6.1 Noise and dust reduction and water protection

The location of a crusher at the site should be planned so that it is near the bank of the bedrock and noise barriers should be located between the crusher and the closest outside entity. Rubber parts are used in the crusher and noise tents or curtains should be tested and evaluated based on the PDCA principle. The foam technology is utilized in dust protection. Rainfall and melted snow is used as much as possible for providing the water required for the process. The remaining amount is taken from water pipeline.

The groundwater protection is done according to suggestions by Laurila (2009, 26): On-site waste management and fuel storing are done according to Best Available Techniques, the equipment and gear that are used at the site are maintained regularly and properly, a protective layer should be applied on top of the possible groundwater area at the site, the explosives are handled with extra care and the post-treatment of the site is thoroughly planned and properly carried out.

6.2 Possible co-operation

As mentioned in chapter 5.1, there are various possibilities of co-operating with other lines of business within the aggregate site. Examples include energy production, snow dumping site, landfill for clean soil, asphalt production and a recycling centre for various types of waste. The partners for these co-operations can be from both the public and private sectors, and for example in the Loviisa site the city might be interested in a snow dumping site that is not very far.

As far as the whole ‘Green Aggregate’ concept is concerned, many types of co-operation and consulting are necessary. Outside business partnership, working together with the environmental authorities and organizations is vital. When the concept is put to reality in a site, the other parties should be consulted already in the planning phase. If the concept is realized as described in figure 3, the following list states some possible co-operations that could be established:

Planning:

- Local environmental authorities, already before the permit application process
- Local environmental organizations, such as FANC
- Local residents
- Other companies that would operate at the site
- Consultants in environmental and recycling affairs

Implementation (in addition to the ones already mentioned):

- EcoDriving course providers
- Manufacturers of conveyor belts, stackers, noise and dust reduction equipment and crushers
- EKOEnergy supplier
- Environmental engineering companies for monitoring and measurements

6.3 Motivation and commitment

A fully functional 'Green Aggregate' site requires personnel that are experienced in aggregate-related environmental issues and management systems. Preferably there should be an assigned team that handles the development of the concept as well as the practical implementations and project management in the aggregate sites. In addition to the expertise, motivation of the team members is essential. Environmental aspects in aggregate production, as in any industry, can be seen as a burden and something that is merely a necessary task. As a concept such as 'Green Aggregate' is voluntary for a company, there should be a genuine interest within the personnel to actually carry out the development and implementation.

In addition to the team or personnel that are actually working with the concept, also other employees must be involved in the implementation. This can prove to be problematic as not all people find this kind of development necessary and can even neglect the whole concept as worthless extra work. Fear towards changes in job routines and new responsibilities can become barriers for the functionality of 'Green

Aggregate' concept at the sites. Therefore it is essential to raise awareness in the whole company and make sure that everyone understands why the new methods are put to use. The possible new responsibilities and roles of all the employees should also be stated early in the process.

Top management commitment is also crucial, for applying the concept requires vast amount of resources and investments from the company. The benefits of this kind of concept must be made clear to the management and the requirements have to be known too. Therefore the limitations and defects of the current business concept must be pointed out and show why exactly is 'Green Aggregate' a better alternative. Key issues regarding the benefits of such a concept are discussed in chapter 4.1.

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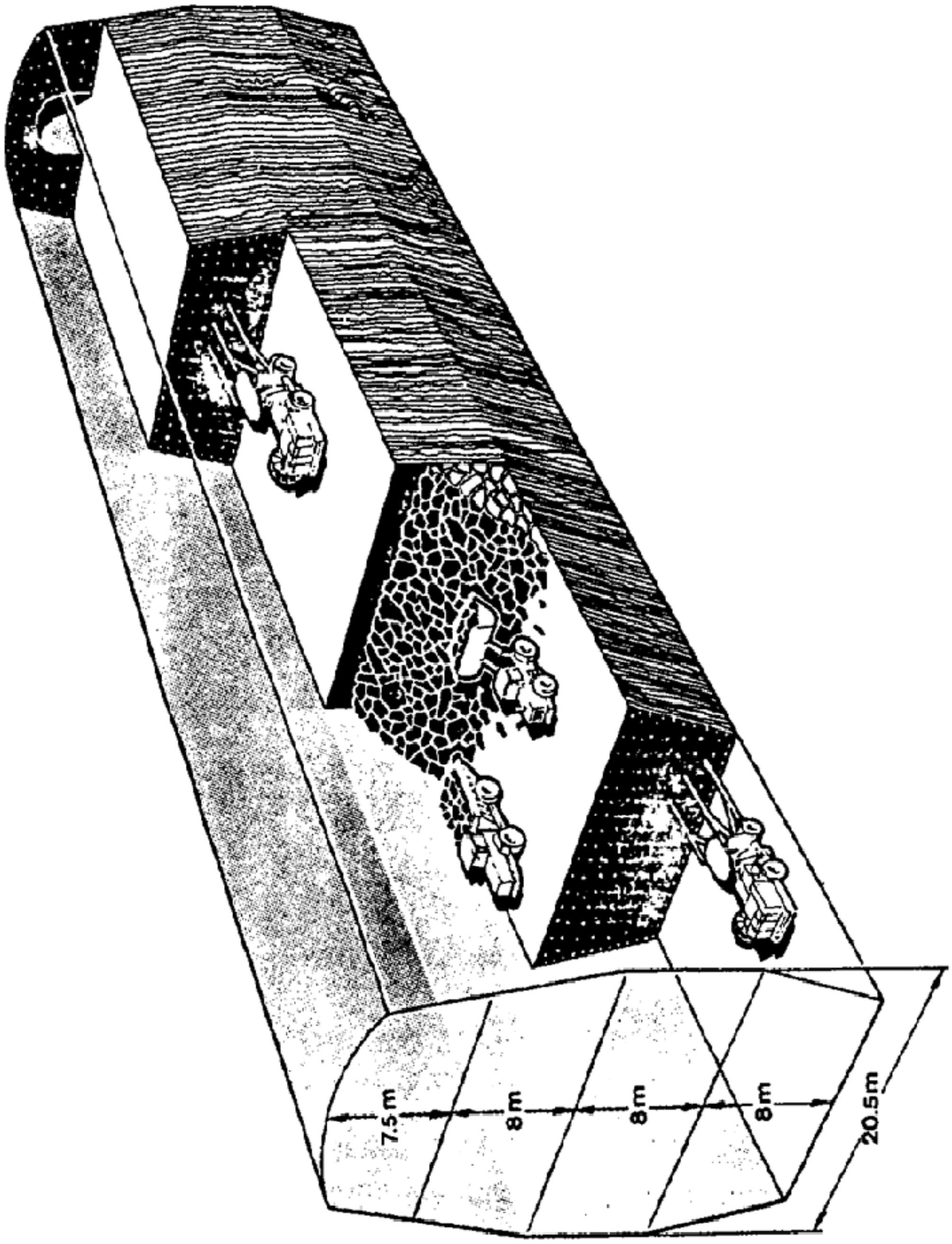
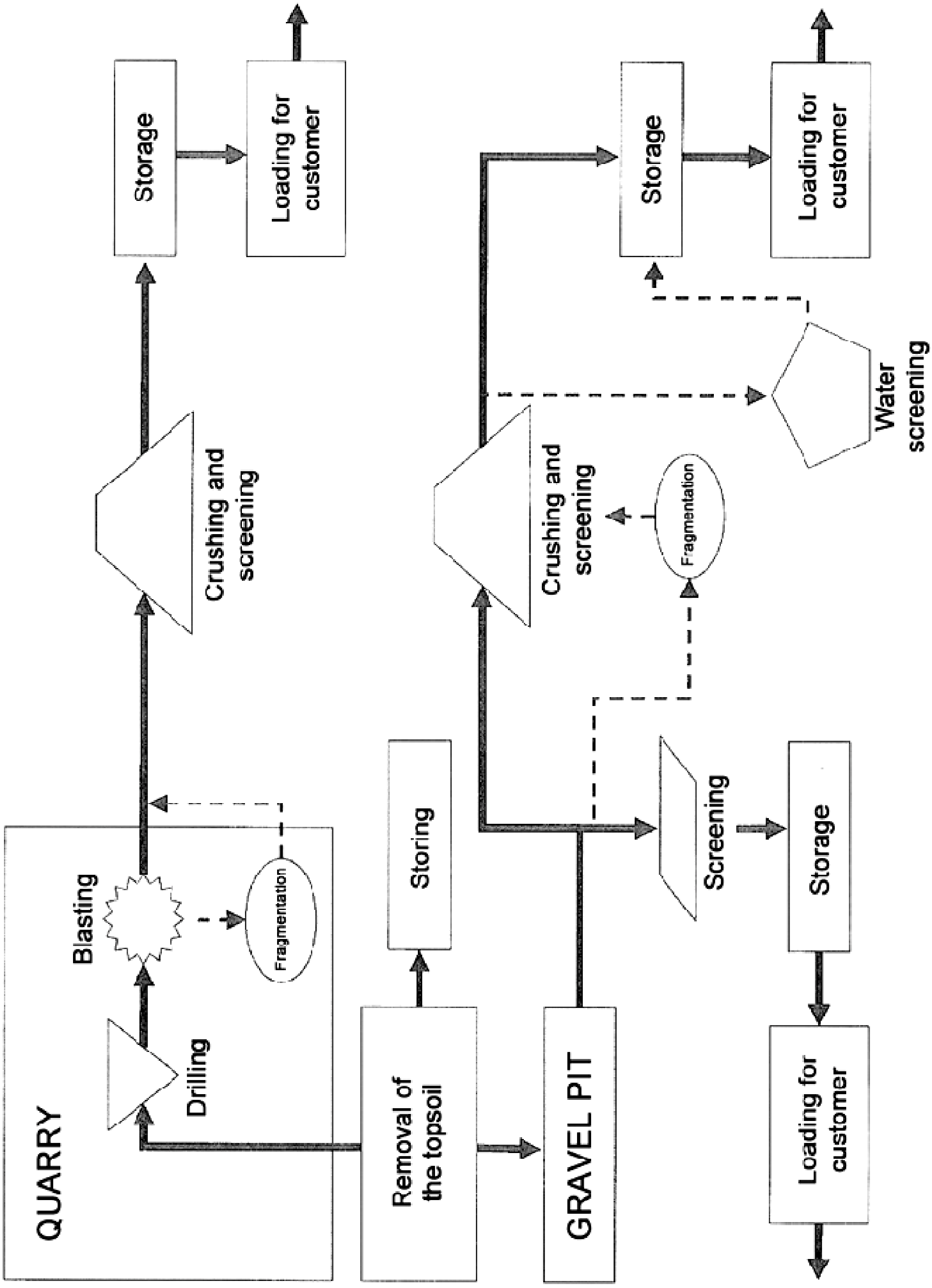
APPENDIX 1

Simplified illustration of bench stoping (Vuolio 2008, 112).



APPENDIX 2

Process description of aggregate production (Suomen Ympäristö 2010, modified)



APPENDIX 3

Calculating the costs of internal transportation

According to internal calculations by NCC Roads in Sweden, transporting 1 ton of aggregates with a truck for 700 meters consumes 0,2 l of fuel and transporting the same amount via a conveyor belt consumes 0,5 kW of electricity.
A website http://www.polttoaine.net provides information about the mean fuel prices around Finland. In this calculation the mean price of Diesel in Helsinki region on 12th of April 2011 was used. This was 1,365 €/l. The price of electricity was gathered from an offer by E-ON Finland regarding EKOenergy electricity for the Vanhakylä site in Loviisa. In this offer the price was 5,85 snt/kWh.
Assuming a conveyor speed of 20 meters per minute, the energy cost for the 700 m transportation 0,034 €. The diesel fuel cost for the same distance is 0,273 €.

It is worth noting that this calculation should only be used an indication, because it is based on mere assumptions concerning the prices of fuel and electricity, as well as the speed of the conveyor belt.