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Concepts for the logistics of excavated material at a power plant construction

Diploma Thesis

Field of Study

Production Science and Management

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Thomas Riesenhuber

Acknowledgements

First of all I want to thank Mr. Kurt Bernegger, owner of the Bernegger GmbH, for offering me the chance to start working in his company during my studies and to apply the theoretical knowledge in industry. One of the interesting projects I had the chance to work on was finally extended to this diploma thesis.

For the company-internal support I want to thank Mr. Dipl.-Ing. Johannes Koppler, who always inspired me to think out of the box and who never stopped giving me useful advice.

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I also want to thank my parents to offer me the chance for studying on Graz University of Technology. My whole family supported me in every situation during my studies.

Kurzfassung

Die Bernegger GmbH plant, in Zusammenarbeit mit einem österreichischen Energieversorgungsunternehmung, ein Pumpspeicherkraftwerk am Betriebsgelände des Standortes Molln in Oberösterreich zu errichten. Die erste Idee zur Errichtung eines solchen Speicherkraftwerkes entstand im Jahre 2006. Seit dieser ersten Idee entwickelte sich das Projekt nicht nur in der Detaillierung, sondern auch die Dimensionen des Projektes vergrößerten sich, bis schließlich 2011 mit der Einreichplanung für das Vorhaben begonnen wurde.

Die Besonderheit an diesem Projekt ist, dass nicht nur der Verbindungsstollen zwischen oberem und unterem Speicher künstlich angelegt ist, sondern auch die beiden Wasserspeicher selbst. Durch das künstliche Anlegen des gesamten Projekts ergibt sich eine Ausbruchsmenge von ca. 6.600.000 Tonnen Kalkgestein. Der Transport dieser Menge wird mit ca. 271.000 LKW-Fuhren bewerkstelligt.

Der Ausbruchszeitraum des gesamten Projekts beläuft sich auf etwa 4 Jahre. Ungefähr 97 % des gesamten Ausbruchmaterials kann als hochwertiger Rohstoff verwendet werden, wobei ein geringer Anteil für den Bau des Vorhabens verwendet wird, und der Rest des Materials in den Rohstoffgewinnungsprozess der Bernegger GmbH integriert wird.

Aufgrund der enormen Mengen an transportiertem Material ist es von großem Interesse für die Firma Bernegger, ein detailliertes Logistikkonzept zu erstellen. Neben den finanziellen Interessen der Firma wird dieses Logistikkonzept auch für die Einreichung des Projekts benötigt.

Im Zuge der Diplomarbeit werden Rahmenbedingungen wie Ausbruchsmengen, verfügbare Lagerflächen, Transportmittel, sowie der Rohstoffverbrauch in den einzelnen Werken erarbeitet.

Die verschiedenen Bauabschnitte des Projekts können zu Einheiten zusammengefasst werden. Die für diese einzelnen Teilbereiche erarbeiteten Logistikkonzepte werden mittels Nutzwertanalyse verglichen. Aus dieser Bewertung wird eine Handlungsempfehlung an die Firma Bernegger abgeleitet. Aus den Teillösungen wird ein gesamtheitliches Logistikkonzept entwickelt, in welchem die detaillierten Massenströme und Zwischenlagerflächen dargestellt werden. Als Abschluss der Diplomarbeit wird eine Empfehlung für das weitere Vorgehen betreffend der Transportlogistik des Projektes gegeben.

Abstract

Bernegger GmbH has planned to build a pumped storage hydro power plant on its company grounds in Molln, Upper Austria. The idea for this project first came up in the year 2006. Since this first idea the project not only grew in feasibility, but also in its dimensions. In 2011 the project was detailed in its dimensions to start a permit application design.

Not only the water pipe, but also the upper and the lower reservoir have to be made artificially. Due to that fact and due to the large dimensions of the project, the total amount of excavated material can be estimated at about 6.600.000 tons. The transportation effort for this big amount of material can be numbered at about 271.000 truckloads that are needed for transportation from point A to point B.

All the excavation works of “Energiespeicher Bernegger” are done within a timespan of four years. 97 % of the excavated material can be used as a high valuable commodity. A small percentage of material can be used for the construction works of the project, while the rest of the material is implemented in the daily business of Bernegger GmbH.

Due to the big amount of excavated material it is of high economic interest for Bernegger GmbH to develop a sophisticated logistic concept for the disposition of the material. Not only the financial aspects of the logistics are of interest, but also the material-flows have to be displayed for the submission of the project.

In this diploma thesis the framework, such as the amount of the excavated material, available storage spaces, means of transportation, and raw material consumption of the different production sites of Bernegger GmbH are evaluated.

The different construction stages can then be summarized to units. For every unit there are worked out some basic concepts for transportation of the material. These concepts are then evaluated by the use of value benefit analysis. A recommendation for action is then given for every unit of “Energiespeicher Bernegger”. These partial solutions are then summarized to an overall logistic concept, in which the material flow and the development of the storage areas are displayed. Finally this diploma thesis gives a recommendation for action for the future of this project concerning the logistic efforts.

Contents

1 Introduction

This chapter gives a short introduction about the history and the development of Bernegger GmbH. It also gives a basic overview of the project “Energiespeicher Bernegger” and the task of this diploma thesis in connection to the project.

1.1 About Bernegger GmbH

1947 Karl Bernegger founded a lime kiln as sole proprietorship which was situated in Molln. Since that date the company developed in following steps:

1955: The company was extended by the fields of earthworks

1959: Conversion of the lime kiln into a lime and gravel plant

1965: Opening of a trout farm

1967: Opening of a processing plant for sand and gravel in Ternberg

1969: Integrating the production of ready-mix concrete

1981: Acquisition of a processing plant for sand and gravel in Steyrling

1985: Foundation of the “Bernegger Kraftwerks GesmbH”

1986: Conversion of the sole proprietorship into “Bernegger Bau GesmbH”

1989: Construction of a lime grinding plant in Molln

1990: Entering the field of construction material recycling

1995: Purchasing of a plant for ready-mix concrete in Linz

1997: Handing over the company to Karl and Kurt Bernegger

2004: Opening of the quarry “Pfaffenboden” in Molln

2008: Renaming of “Bernegger Bau GesmbH” into “Bernegger GmbH”

With about 530 employees and about 700 construction machines the Bernegger group’s business is nowadays located in the fields of the construction industry, commodities and environmental technologies. The headquarters of the company is still situated in Molln / Upper Austria.

A total turnover of about 95 Million Euro is generated by “Bernegger GmbH”, “Kies- und Transportbeton GmbH”, “Ebenseer Carbonat GmbH” and “Technische Behandlungssysteme GmbH”. These companies are situated in ten locations (Molln, Spital/Pyhrn, Klaus, Micheldorf, Steyrling, Ternberg, Dietach, Linz, Enns and Ebensee).

In addition to that business Bernegger GmbH is invested in four holdings. All of the locations of Bernegger are situated in Upper Austria as seen in Figure 2.[1]

In Figure 1 the structure of Bernegger GmbH and its subsidiaries is displayed.

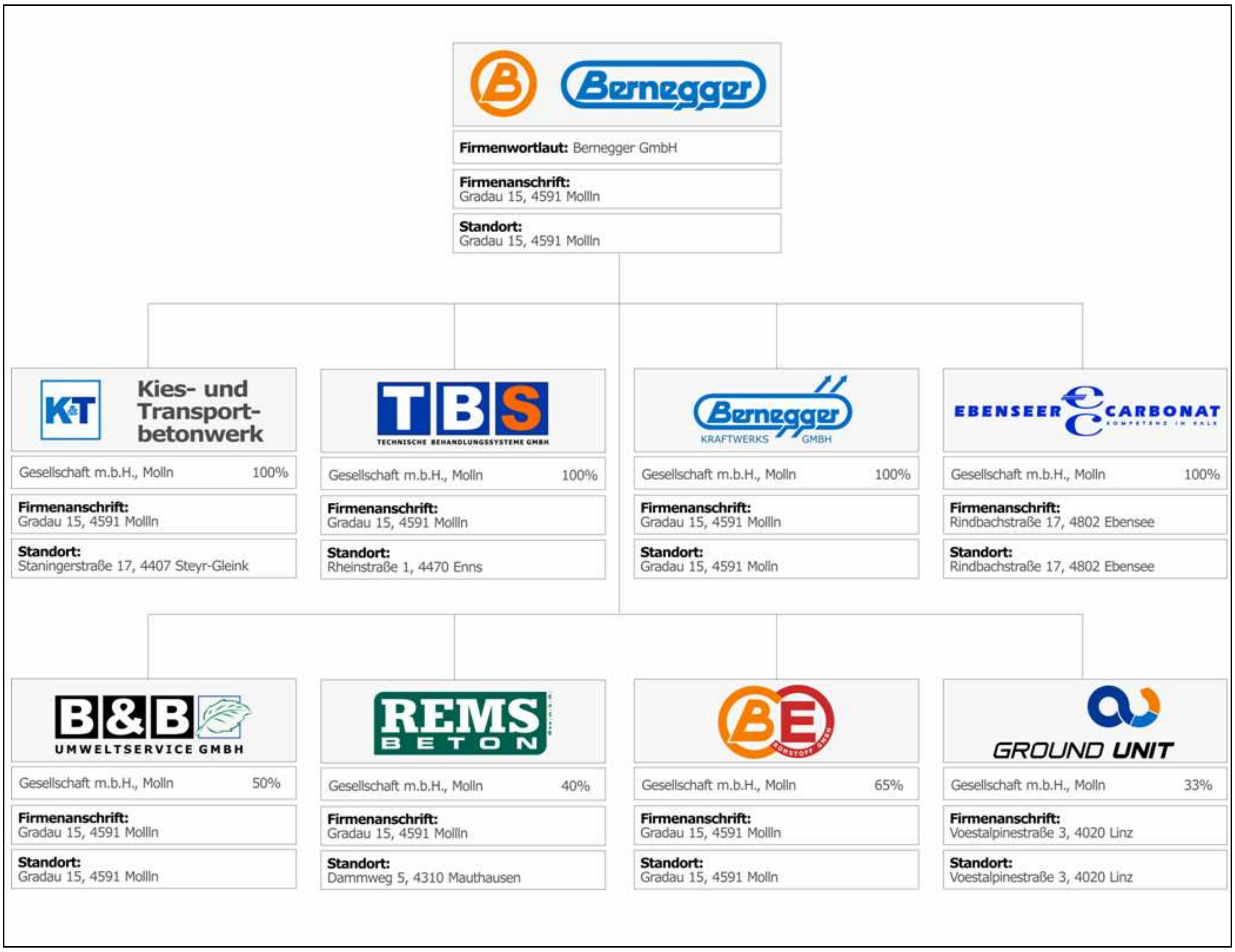

Figure 1: Structure of Bernegger GmbH[2]

K&T

The “Kies- und Transportbetonwerk” was founded in 2002. Nowadays it generates a turnover of 7 million [€] in the year 2010. At the location in Dietach a gravel pit is situated where the commodities for a ready-mix concrete plant and a ravel plant are mined.

[1] Cf. Weilguni (2009), p 7
[2] Intranet Bernegger (2003), access date: 07.07.2011

TBS

“Technische Behandlungssysteme GmbH” was founded in 2005. The main field of this company is to process shredded cars and to separate this material into its ingredients. With these activities it was able to generate a turnover of 6 million [€] in the year 2010

Bernegger Kraftwerks GmbH

Founded in the year 1985, this company runs three hydro power plants, which are situated along the rivers “Steyr” and “Krumme Steyrling”. In the year 2010 the company was able to generate a turnover of 30.000 [€].

Ebenseer Carbonat

This company was gained through an acquisition in 2008. The main business of this company is to produce goods for the animal-feed industry. In the year 2010 this company was able to generate a total turnover of 1,4 million [€].

A fundamental aspect of the company philosophy can be found in the integrated environmental-, quality-, and safety management. The certificates for EMAS, V.EFB, ISO:9001 and SCC** are important and essential guidelines for daily business and workflow.[3]

In the year 2003 Bernegger succeeded in realizing a project to exploit highly pure limestone within the next 90 years at the “Trichterabbau Pfaffenboden” which is located in Molln. Currently about 500,000 tons of the limestone are processed at the factory in Molln and transported all over Austria.

The exploiting system and the evacuation of the limestone are a good example of the innovative company-know-how through which the environmental impact and the use of energy are highly reduced. The uniqueness of this exploiting lies in a conveying system, which leads through the 3,5 km long “Elfi-Tunnel” and produces up to 482 [kW/h] clean Energy by the usage of the braking power generated by the material-flow of a constant 15% downhill descent. This tunnel connects the quarry Pfaffenboden with the plant in Molln. The natural altitude difference was also the basic idea for a pumped storage hydro power station.

[3] Cf. Weilguni (2009), pp 1

Figure 2: Overview of the plants of the Bernegger group[4]

[4] Intranet Bernegger (2003), access date: 01.06.2011

To show the fast growing rate of Bernegger GmbH, some basic facts about the company are displayed for the year 2007 and for the year 2010 as seen in Table 1.

Year	2007	2010
Turnover	63 Million [€]	95 Million [€]
Employees	450 Persons	530 Persons
Locations	9	11
Commodities mined in Molln	2,1 Million tons	2,2 Million tons
Concrete produced in Molln	230.000 [m³]	230.000 [m³]
Landfill on disposal sites	230.000 [m³]	250.000 [m³]

Table 1: Facts about Bernegger GmbH

1.2 About the project “Energiespeicher Bernegger”

For realizing this project, the company “Energiespeicher Bernegger GmbH” was founded in the year 2010.

Pumped storage hydro power stations can be seen as an essential contribution to the stability of our electricity system. It is necessary that exactly as much energy is produced by the power stations as the end customers consume at the same time. The big problem within this fact is that big power plants have a very slow response characteristic to changes of the amount of needed power. Because of this reason the modern electricity grid is equipped with very elaborate feedback control systems to provide stability. But these control systems can compensate the variation of currency only to a small amount. Due to the fact that during night-time the energy consumption is lower than in the morning and at mid-day, there is a need for other systems to compensate for these energy differences. Pumped storage hydro power stations can be seen as the only solution to store energy in such high amounts.[5]

[5] Cf. Giesecke / Mosonyi (2009), p. 114

While there is a low need of energy by end customers, big amounts of water are pumped from a reservoir with lower elevation into a basin with higher elevation. When peaks of energy usage are reached the direction of water- and energy-flow can be turned around and the water is used to produce energy. Although the electrical energy has to be converted into static energy and vice versa with all the energy losses you have to overcome, it is still the only reasonable process to store this static energy.[6]

With the steady progressive expansion of the wind energy network, the need for storage capacity also increases, because wind energy is hard to forecast and to control. In this case you can also overcome the difference between energy-supply and –demand by using pumped storage hydro power stations.[7]

Because of the increase of required control energy in future times and the ideal environmental situation at the location in Molln, Bernegger is planning to build a pumped storage hydro power station with a peak output of 300 [MW]. The power plant will be in Austria’s top ten pumped storage hydro power plants in means of power output, and has an extension of about 4,2x1,0 [km].

Figure 3 shows the first design of the power plant, which is located in Molln, Upper Austria.

It is essential that the power plant is state of the art and should give very little impact to the environment during the construction and the operation phase. To minimize the influence to the environment, main parts of the power plant are built underground. All of the parts which have to be built for the power plant are on the property of Bernegger GmbH. This fact eases the administrative procedures for planning the project. But in terms of construction of the whole project it is of big advantage, because the infrastructure is already given in a very good manner.

Also the excavated material, which would normally be waste in this process, can easily be implemented into the operational process of Bernegger GmbH, and becomes therefore a very valuable commodity.

The lower reservoir, which is the only part of the project that can be seen on the terrain surface, is integrated into an existing gravel pit of the company. This gravel pit is just extended to the needed size of the later basin, and then sealed with asphalt. The rest of the power plant can be accessed by various tunnels which serve as transportation tunnels during the construction phase and as access tunnels during the operational phase.

[6] Cf. Giesecke / Mosonyi (2009), p. 115
[7] Cf. Erdmann / Zweifel (2008), pp. 294

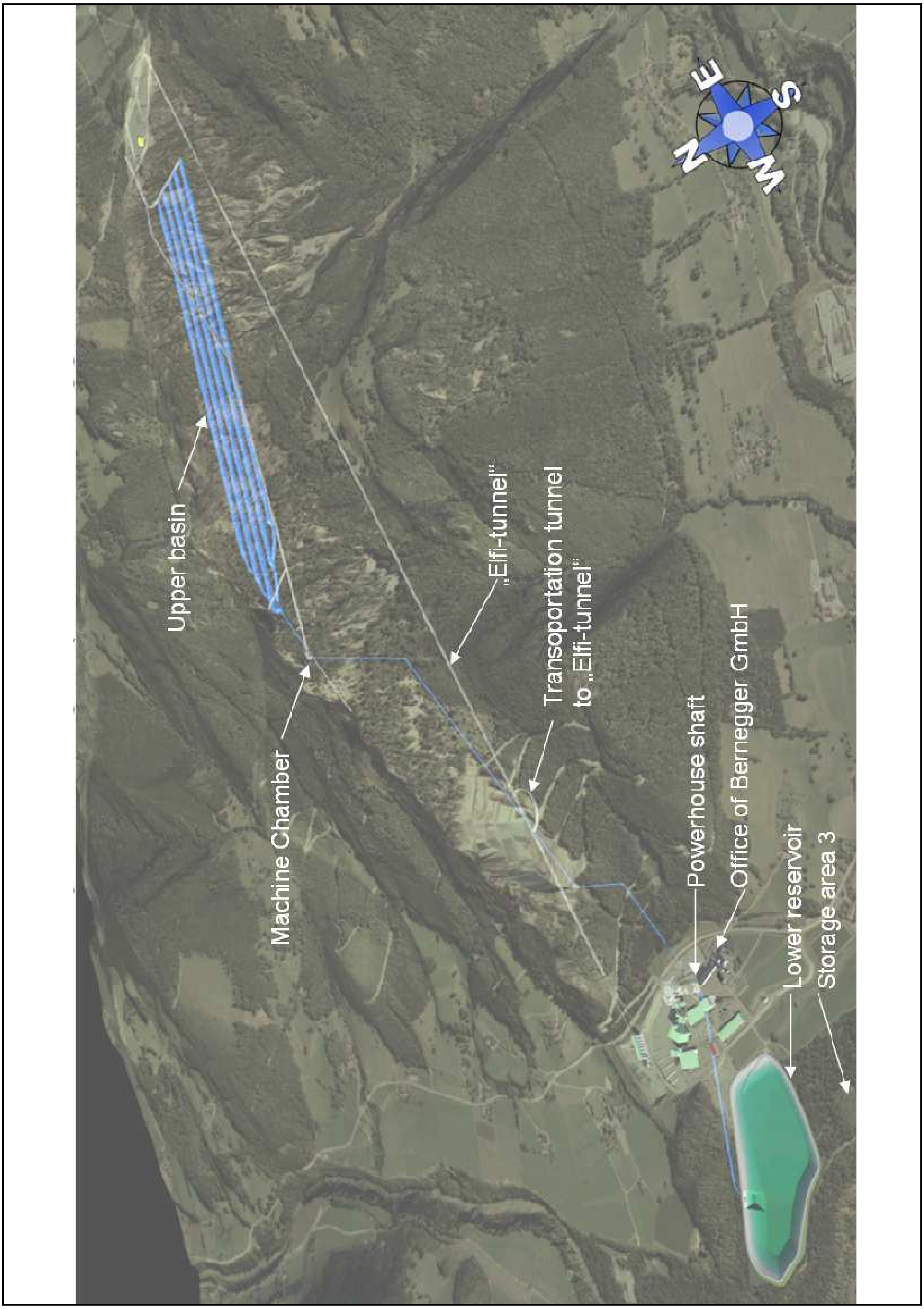

Figure 3: Project area of the pumped storage hydro power plant

The whole power plant is a hydraulically isolated system. The water which is needed to be pumped between the lower and the upper reservoir is taken from the river “Steyr”, which is near the company grounds. Taking out the water of the river is therefore only necessary once after the construction phase.

The key facts of the project are displayed in Table 2.

Construction site	Molln, Upper Austria
Client	Energiespeicher Bernegger GmbH
Project start	2011
Completition	2016
Investment volume	300 Million [€]
Energy output / input	309 / 317 [MW]
Max fall in height	654 [m]
Amount of transferred Water	1,43 Million [m³]
Maximum flow of water	57,4 [m³/s]

Table 2: Overview about Energiespeicher Bernegger

The time which is needed for building this power plant will be about four years from the beginning of excavation works to the first test run of the machines.

1.3 Problem description and target definition

Due to the fact that the amount of excavated material in this project is enormous and the cost of transportation makes a high percentage of total cost, it is essential to deal with the logistic problems that occur during the construction of the project.

The task of this diploma thesis is to develop a concept for the handling of material that will be excavated during the construction process of “Energiespeicher Bernegger”. This excavated material should not just be brought to a disposal site. It is aim of the company to implement the material into the production process and to use the material as a high value commodity.

As seen in Figure 4 the material should be integrated into a sustainable cycle for the usage of commodities. This cycle represents the mentality of the company to take care of the nature whenever possible. Of course also the financial situation could be improved by using the commodities to its full extents.

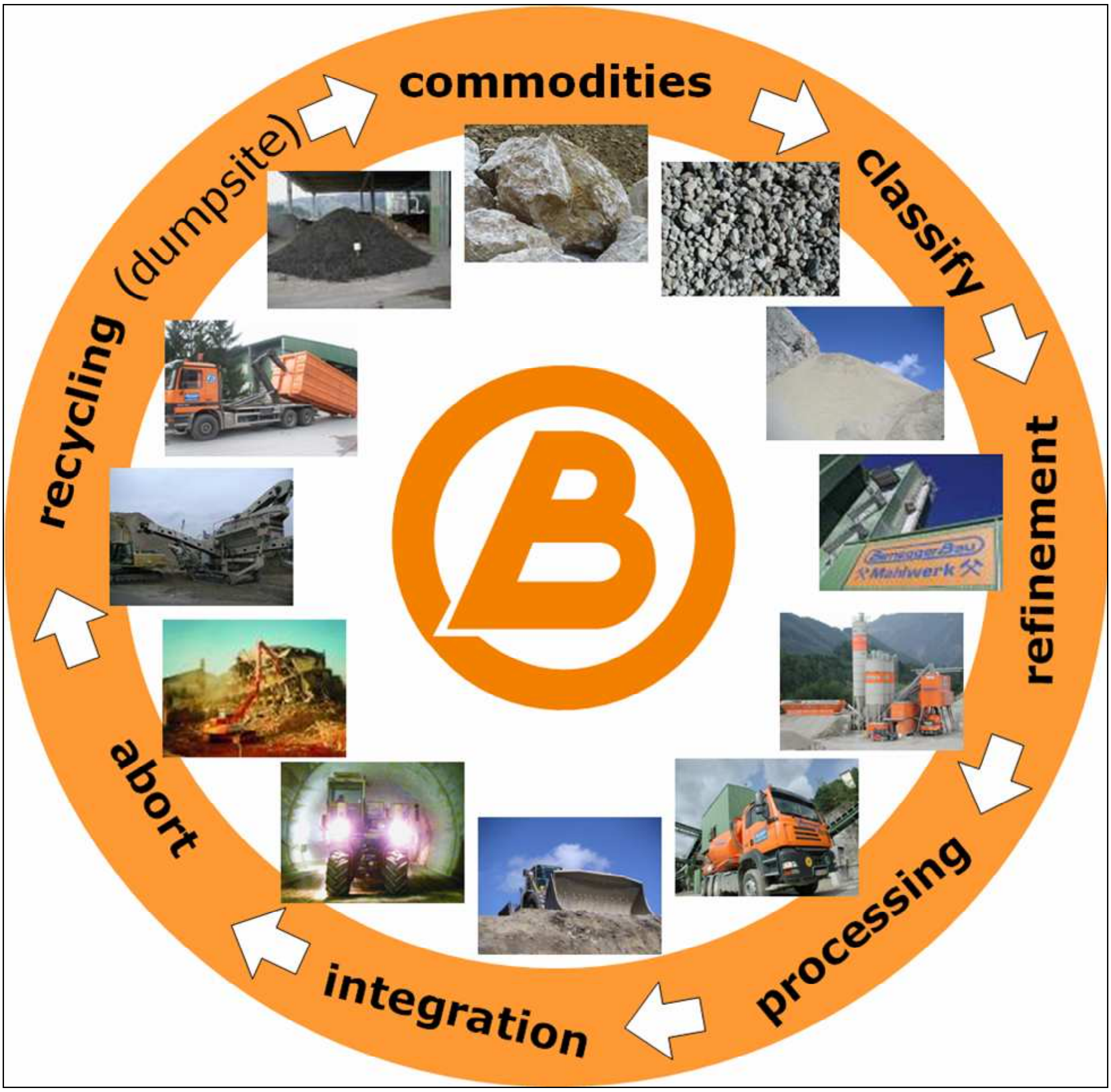

Figure 4: Commodity cycle of Bernegger[8]

First of all, the amount of excavated material in the whole production process has to be calculated. After calculating the amount of the excavated material, the single parts of

[8] Intranet Bernegger (2003), access date: 06.07.2011

the project have to be summarized to project regions. These regions can be seen as the points where the material is transported to the surface.

For temporarily storage of the excavated material, storage spaces of suitable size, reachability, and distance to the excavation points must be found.

For the logistic situation it is also very important to elaborate the annual consumption of commodities in the different production sites of Bernegger. It is also important to elaborate, if the storage time has influence on the material properties.

The means of transportation has to be investigated to provide the material transport from the excavation points to the storage spaces and then to the different production sites.

The goal is to work out two logistic concepts for the excavated material of the project “Energiespeicher Bernegger”. These concepts should be evaluated with the use of value benefit analysis. The most favorable of the concepts should then be worked out in detail by implementing the costs for transportation.

The process for this concept should be illustrated in a flow diagram and the absolute amounts of transportation should be visualized in a sankey diagram.

For maximizing the benefit to Bernegger GmbH, a recommendation for action should be given and the critical areas of the process should be pointed out.

1.4 Procedure model of the diploma thesis

The structure of this diploma thesis bases on the scientific norm that is explained in the "Industriewissenschaftliches Forschungsmanual". There are two reasons why the structure of the work had to be changed a bit. On the one hand the theme of the diploma thesis is very application oriented. The second reason can be found in the fact that Bernegger needed the results of the diploma thesis in a very early stage of the project. Therefore the rough structure can be separated into following points:

- Problem description and target definition
- Dealing with problems by the empirical survey of relevant matters
- Design of two concepts
- Evaluating the concepts and detailing the most favorable
- Outlook

- Literature research[9]

The detailed schedule and steps of the diploma thesis are displayed in Figure 5.

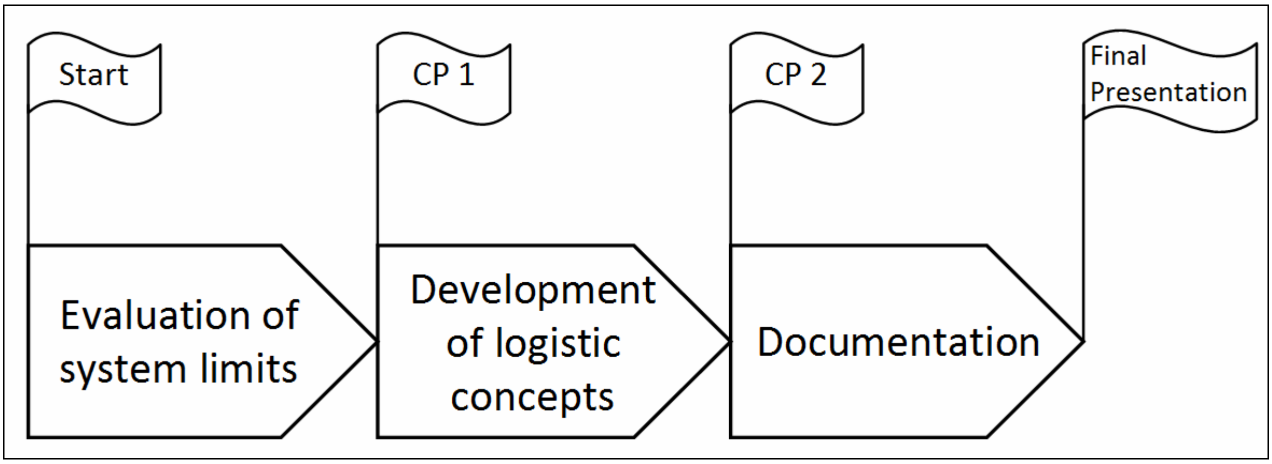

Figure 5: Procedure model of the diploma thesis

After the start of the diploma thesis the system limits were evaluated. This numbers and information was needed for further proceeding in the diploma thesis. In the first presentation of checkpoint one the proceeds to this stage of the thesis were presented and further action of the thesis was discussed.

This information and the setting of the procedure was the basis for the next stage of the diploma thesis, where the detailed logistic concepts for different areas of the project were elaborated and presented in checkpoint two.

The last action of the thesis was to elaborate the theory to logistics and to document the work which was done during the process.

The detailed steps regarding the procedure model are as follows:

Evaluation of system limits

- Calculating the amount of excavated material
- Calculating the useable storage volume
- Actual situation of raw material usage
- Sankey diagram of current status

[9] Cf. Wohinz (2007), p. 11

Development of logistic concepts

- Further detailing of the outcome by combining the different variables of the material flow
- Evaluation of the different solution approaches
- Working out a cost model for one approach
- Working out a recommendation for action

Documentation

- Documentation of the elaborated logistic concepts and writing of the diploma thesis

The procedure model for this diploma thesis worked out very well and the time schedule which was aimed to fulfill the requirements of the company was reached.

2 Logistics management

Logistics management is one of the oldest activities that are needed to enable any production process. The need for transportation of raw material and manufactured goods is the basis of every manufactured good.[10]

Normally it is aim of the logistic management to homogenize the material flow and to minimize the needed storage.[11] But in this project the material flow is given by the output of excavated material, therefore the logistics have to adapt to this general condition. Also the storage space has to fulfill the requirements of the enormous output of this project.

2.1 Origin of the word logistics

The word logistics can be associated with some different meanings according to different fields in which it is applied.

In the field of science the word can be associated with mathematical and symbolic logic.[12] Also mathematical functions that are modified exponential functions are named logistic functions. Such functions are used for displaying the population growth.[13]

In military the word logistic is used as collective expression for the tasks that can be seen as support for the armed forces, which includes the flow of material (weapons), the supply of troops and the maintenance and supply of machinery.[14]

Starting in the military field, the term was transferred to the economic science. In this field the term only represents the flow of material and the associated information flow.[15]

2.2 Definition of the term logistics

A definition of the Council of Supply Chain Management Professionals for the word logistics management is: *"Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and*

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[10] Cf. Singh / Kundu / Singh (1998), p. 1
[11] Cf. Singh / Kundu / Singh (1998), p. 3
[12] Cf. Behrendt (1977), p. 21
[13] Cf. Pfohl (2010), p. 11
[14] Cf. Krulis Randa (1977), p. 39
[15] Cf. Pfohl (2010), p. 11

reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements."[16]

2.3 Goals of logistics

Due to PFOHL, the main goal of logistics is to provide the transportation of specific goods that are needed at

- a certain location
- when required
- in useable condition
- and for the lowest cost.[17]

As in every other field of industry, different companies have to compete to each other to prevail on the market. The goal of every company is to be leader in the market. This leadership can be reached by increasing the competitive advantage in logistics, which can be gained by cost advantage, value advantage, or a combination of both. [18]

For being successful in the market, it is also essential that the involved companies of a logistic network are agile. To be agile means to try to gain knowledge and competence all the time.[19]

2.4 Scope of logistics and construction logistics

In the literature the definition for logistics differs a bit to the field of construction logistics. There are some fields that are equal in both definitions, but there are also some specialties in construction logistics.

As seen in Figure 6, logistics can be distinguished into the fields of procurement, production, distribution and disposal logistics.[20] The figure has been simplified from its original version to display the basic information and to make it comparable to the fields of construction logistics.

[16] Council of Supply Chain Management Professionals (2011), acess date 23.06.2011
[17] Cf. Pfohl (2010), p. 12
[18] Cf. Singh / Kundu / Singh (1998), pp. 1
[19] Cf. Schönsleben (2007), p. 63
[20] Cf. Blom / Harlander (2003), pp. 325

There are two different basic concepts for the logistic process. On the one hand there is the system of single unit production, where the products are only produced on a specific order. On the other hand there is the system of mass production, where the products are produced on stock.[21]

For single unit production the whole logistic process starts with an information flow from the customer to the company. This first information flow is the order for a new product. The sales department then gives the order to the production department to manufacture the product. For manufacturing the product there are raw materials needed. Therefore the production department checks the stocks for raw material. If nothing is in stock, an order for the raw material has to go out to the supplier.[22]

This procedure starts the material flow from supplier to the procurement department, from there to the production department and as final product to the distribution department. Information about the status of the delivery is sent forward all the time, therefore the flow of information extends to both sides. The scrap in this production process is used again within the production process whenever possible. The waste that cannot be used in the production process again is either recycled or has to be disposed of. In mass production there is no initial information flow from the customer to the company in terms of an order. In this field the company produces on forecast of the sales department. Therefore the whole process which is explained above starts with the order of the sales department to the production department.[23]

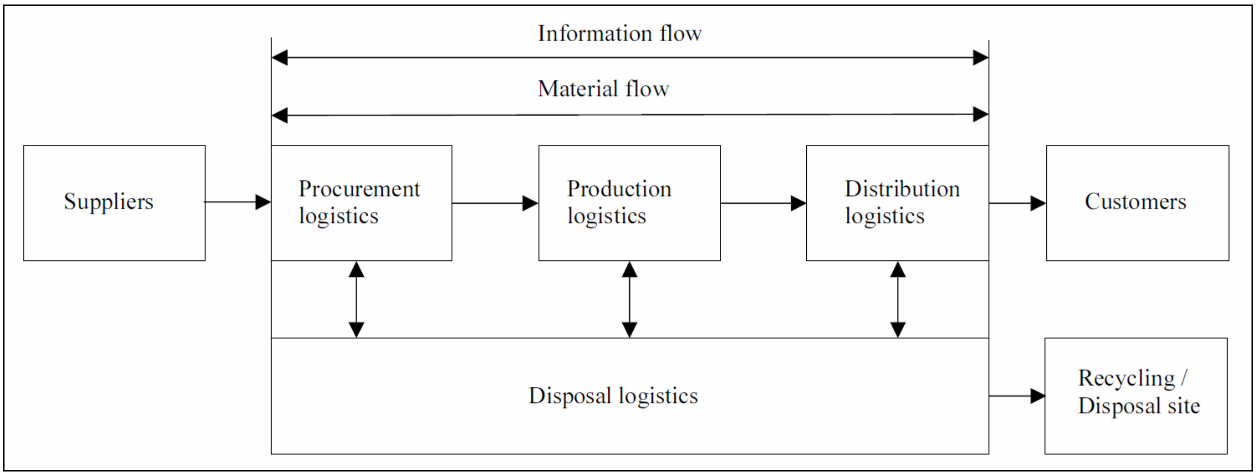

Figure 6: Fields of logistics[24]

[21] Cf. Mertins / Krause / Schallock (1999), p. 410
[22] Cf. Mertins / Krause / Schallock (1999), p. 411
[23] Cf. Mertins / Krause / Schallock (1999), pp. 412
[24] Cf. Pfohl (2010), p. 19

As seen in Figure 7 the field of construction logistics differs from that of the logistics for the production industry, because usually there are no goods produced that can then be sold on the market. Therefore this type of logistics is always developed as single unit production. The material that comes up during the construction process of a building can either be recycled, or has to be deposited. This fact influences the economic efficiency very badly. Figure 7 has also been adapted from its original version to get a consistent layout for the different logistic applications.

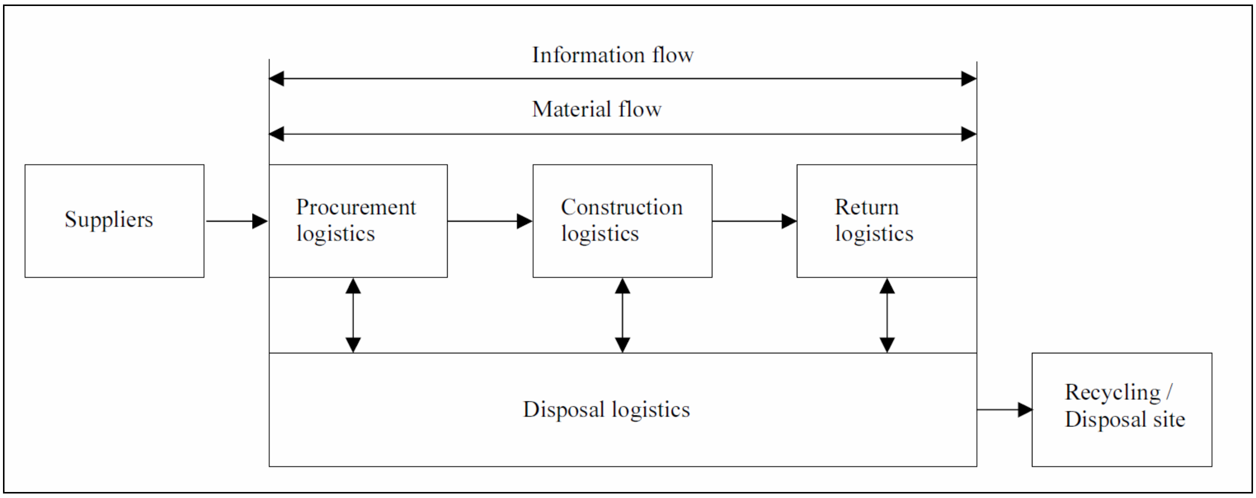

Figure 7: Fields of construction logistics[25]

For the construction of the project “Energiespeicher Bernegger”, Bernegger GmbH tries to overcome this economic disadvantage by using the excavated material in the production process. With this goal, the excavated material would not be waste that has to be deposited, but can be sold as a highly valuable commodity.

Therefore the construction of this project has its origins in the construction logistics, but uses the advantages of production logistics to be competitive on the market. The logistic process functions as seen in Figure 8. This figure has been developed to show the connection to the fields of logistics, that are described in the literature. It can be seen as mixture of the different areas which are described in Figure 6 and in Figure 7. In opposite to production logistics, the material which is sold to the customers is not produced on demand, but comes up during the construction process. Therefore it has to be put in storage areas.

[25] Cf. Judmaier (2010), p. 6

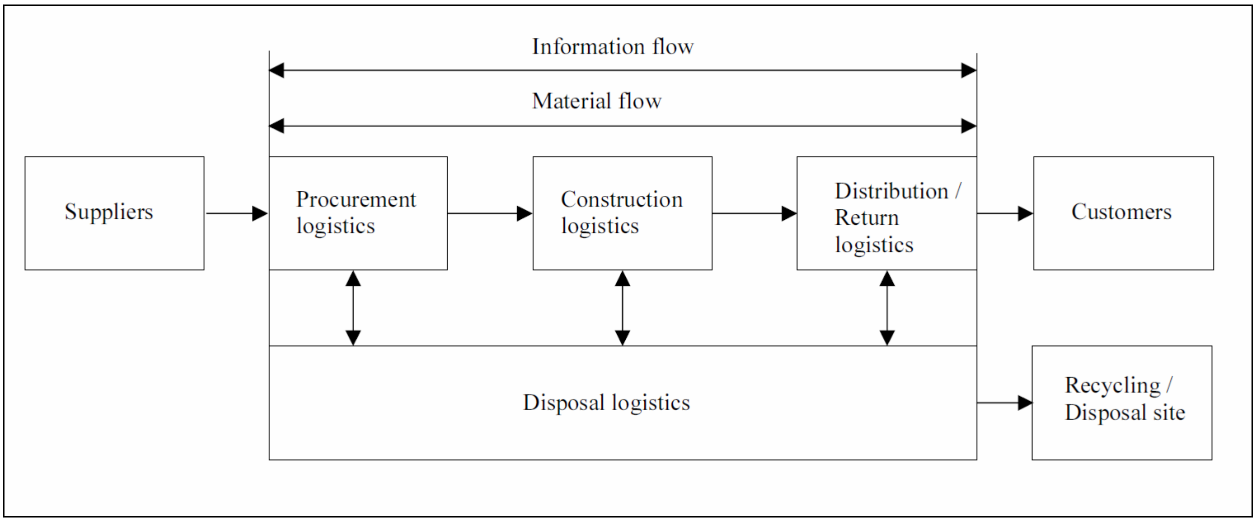

Figure 8: Logistic process in the construction of "Energiespeicher Bernegger"

2.4.1 Procurement logistics

The field of procurement logistics covers the flow of material and information between the delivering market and the procurement department of a company.[26]

Starting in the 1960s, this field of logistics developed due to the start of price comparisons and supplier evaluations. In the 1970s a lot of companies realized that the procurement department gives an essential contribution to the success of a company. Due to fact the procurement logistics got more important for a lot of companies, they started to keep an eye on continuous material and information flow and the tasks of procurement and logistics were separated.[27]

Since that time a lot of effort was put into expanding the knowledge and the tools for evaluation to be successful in this market. In many sectors with mass production, it is now state of the art that the procurement logistics is just in time delivery with a stock that reaches only for a few hours to a few days.[28]

2.4.2 Production logistics

The field of production logistics covers every logistic step that is made from the inbound of raw material to the shipping department of a company. The main goals of production logistics are short throughput times and a high schedule reliability. These goals are set

[26] Cf. Blom / Harlander (2003), p. 33
[27] Cf. Blom / Harlander (2003), p. 33
[28] Cf. Blom / Harlander (2003), pp. 34

to fulfill customer demands and also to increase the planning reliability. Also the product cost can be kept to a minimum by increasing the utilization of machines, which could be reached by minimizing the throughput times. It is also one of the main goals to keep the stores as small as possible and still guarantee the least possible delivery delay of the manufactured goods.[29]

2.4.3 Distribution logistics

Distribution logistics covers the transportation from the shipping department of a company to the end customer. The goal of distribution logistics is the distribution of a produced product on the adequate basis of time and amount. The shipment of a product to the customer can either happen directly or via intermediate nodes. The advantage of the use of these nodes is to use economies of scale and to reduce the impact of demand uncertainty.[30]

2.4.4 Disposal logistics

The traditional fields of procurement production and distribution logistics can be extended by the field of disposal logistics which covers the disposal of waste that accrues in any process within the lifetime of a product. The main goal of the disposal logistics is to integrate the economic aspects of logistics into the ecological requirements that are prescribed in laws.[31]

2.4.5 Return logistics

The aim of return logistics is to integrate the waste into the construction process. This aim is of economic interest for a lot of companies, because it helps to reduce the cost for commodities and also to reduce the cost for disposal of the material. Also from an ecological viewpoint it makes sense to minimize the waste. But within a lot of construction sites it is impossible to reduce all the waste. Therefore a big amount that cannot returned into the production process has to be transported to disposal sites.

[29] Cf. Nyhuis / Wiendahl (2009), pp. 9
[30] Cf. Brandimarte / Zotteri (2007), pp. 8
[31] Cf. Blom / Harlander (2003), pp. 325

2.5 Economic influence of logistics

To show that the type of product that is manipulated has a big influence on the logistic costs, Figure 9 displays the cumulative logistic costs and the total product cost of a manufactured product in different production stages. This figure can be equaled to a supply chain, where value is added to a certain product at every production step.

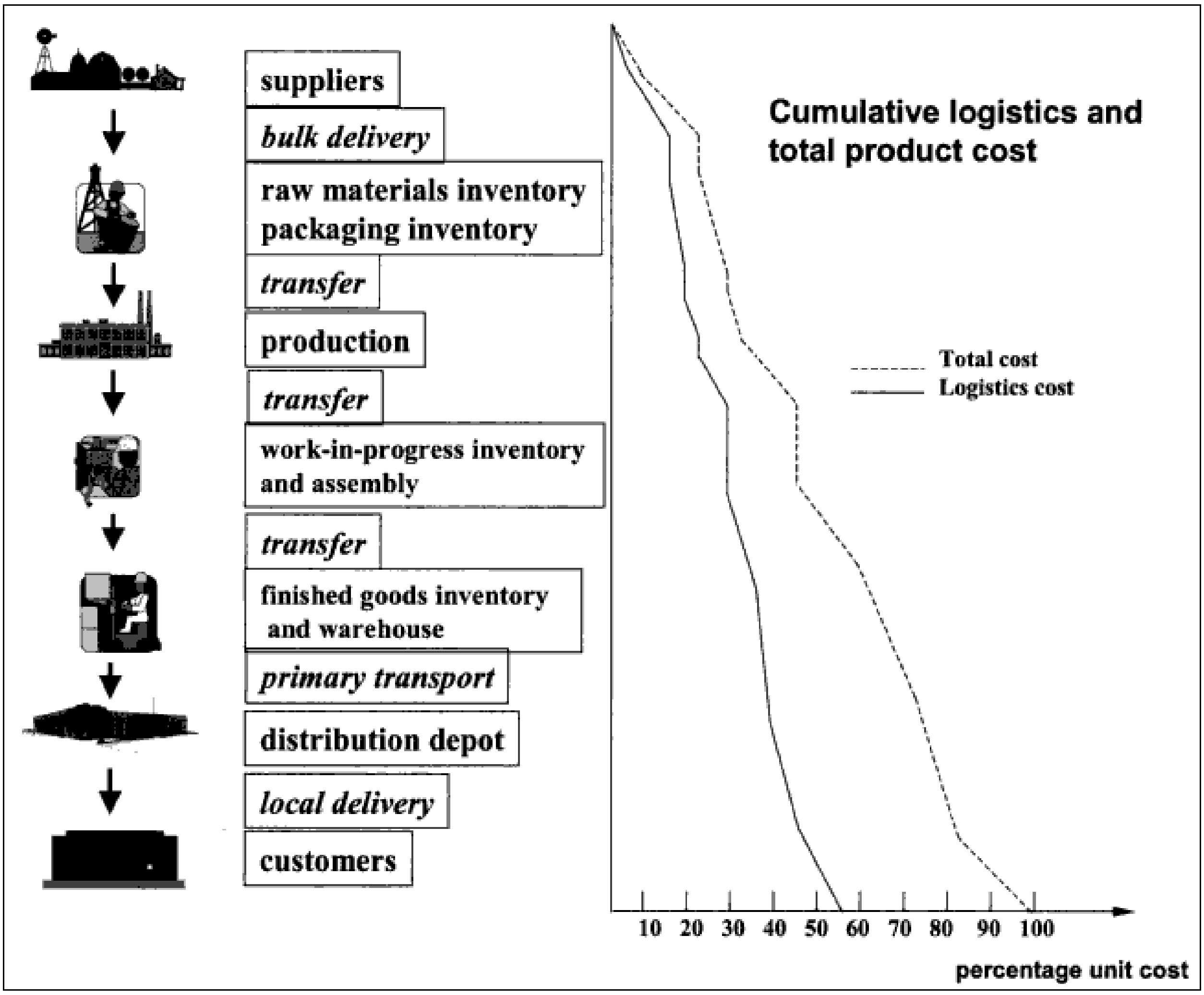

Figure 9: Physical flow of material from suppliers to customers[32]

At the beginning of the production process the added value to the product is very low, and therefore the percentage of logistic costs in comparison to the percentage of total cost is very high. As the product is refined during the production process it gains in value and the percentage of logistic costs in comparison to total costs decreases. The spread of this curve is dependent on the value of the product in comparison to its

[32] Rushton / Croucher / Baker (2006), p. 14

weight. Products that have high value and low weight have very little transportation costs in comparison to the total costs. Therefore this products can easily be transferred over large distances and still be affordable. On the other hand there are products which are of low value and high weight. The transportation of these products is very cost intensive and therefore transportation should be kept at a minimal level. Examples for these products are commodities which are not processed in any facility, but directly transported to the end customers. All the products of Bernegger GmbH can be counted in this product family. Therefore it is essential for Bernegger to be competitive in the field of transportation and to have a logistic concept that that is planned carefully.[33]

A very important figure for evaluating the economic viability is the return on investment. As seen in Figure 10 the logistic costs do influence the return on investment on various points. First of all it influences the profit, because the transportation const can make a high percentage of all costs. As the overall costs are subtracted from the sales, it is aimed to reduce the overall costs and therefore also the transportation costs. But logistics also has an big influence on the capital employed, because the depots and warehouses that are required have to be paid.

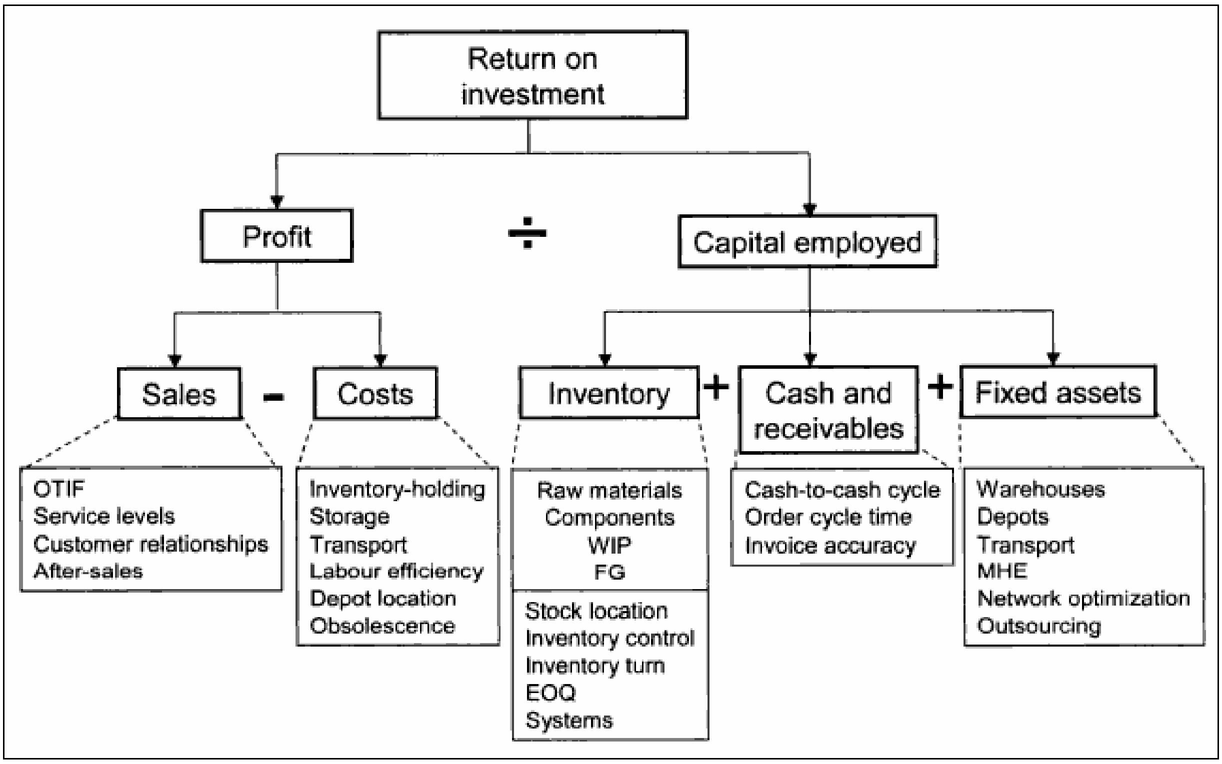

Figure 10: Impact of logistics on the return on investment[34]

[33] Rushton / Croucher / Baker (2006), p. 14
[34] Rushton / Croucher / Baker (2006), p. 23

2.6 Material flow analysis

Material flow is well defined in the literature and the goals are very clear. Contrary to the classic definition and goals of material flow analysis, this project has to deal with some constraints that are described in this chapter.

2.6.1 Definition

Objects that move in regular or irregular timeframe over a certain distance are defined as a flow of material.[35]

By evaluating the amount and the speed of one material unit, the flow rate can be calculated. To be aware of the flow rate is essential for every transportation process, because the bottlenecks that occur in these systems can only be evaluated with the use of this figure.[36]

2.6.2 Objective

The objective of material flow analysis is to quantify and to track the flow of certain materials and energy in a defined area over a certain time period.[37]

An essential feature of material flow analysis is to build an adequate model of reality. It is very difficult to simplify reality to a scientific correct model. For building up a model, the usage of flow sheets, graphs and tables is essential.[38]

Normally the aim is to have the shortest possible lead times with the least possible storage. This principle can be seen as valid, when the main goal of transportation is an adequate supply of commodity to a production unit.[39]

Due to the fact that the main goal of this project is not to supply a certain production site with sufficient raw material, but to guarantee the material flow of excavated material the logistic aims differ to that in the literature. In this project the logistic efforts have to be applied to the excavated material of the project "Energiespeicher Bernegger", because the material flow is determined by the time schedule of the project.

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[35] Cf. Arnold / Furmans (2009), p. 1
[36] Cf. Arnold / Furmans (2009), pp. 2
[37] Cf. Atkinson / Dietz / Neumayer (2007), p. 326
[38] Cf. Atkinson / Dietz / Neumayer (2007), p. 326
[39] Cf. Atkinson / Dietz / Neumayer (2007), p. 326

An optimized material flow can be compiled by defining the storage spaces and optimizing the transportation between the single storage spaces.

2.6.3 Methodology

There are some different tools for displaying the material flow of a specific process or project. The use of these tools is essential to build an abstract model of the reality. With this visualization it is easy to point out the important figures of a model.[40]

Circle diagrams:

The transportation can be visualized by the usage of these type of diagrams. By displaying the capacity with different thicknesses of the arrows, this type of diagram can also be interpreted at the first sight.[41]. An example for a circle diagram is displayed in the figure below.

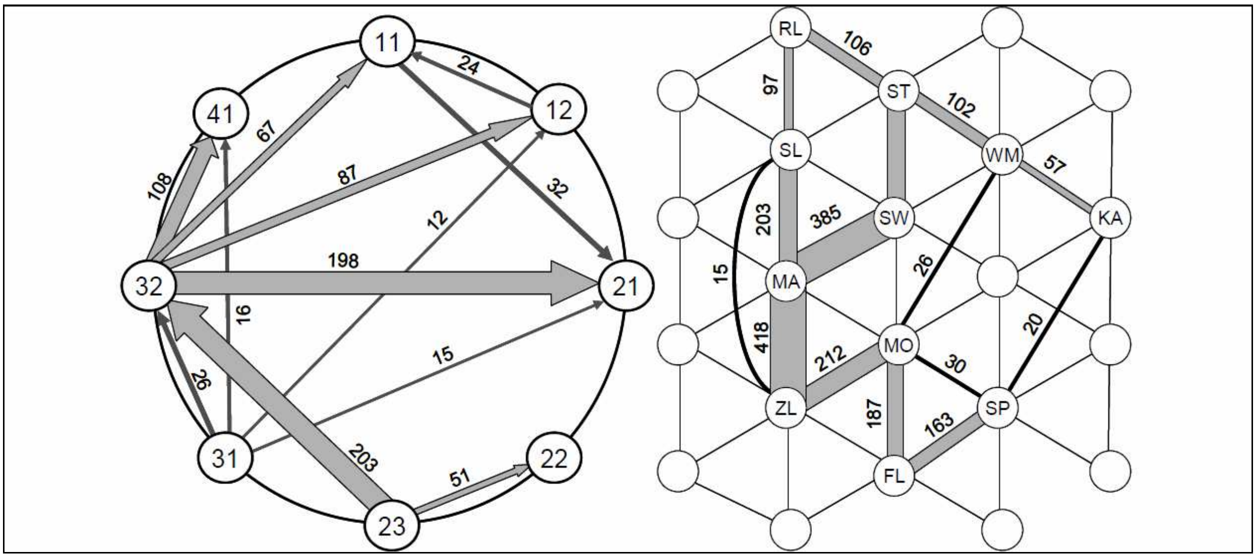

Figure 11: Circle diagram and triangular scheme[42]

Process flow diagrams:

A process flow diagram is a way of displaying a model of a complex process, so that it is easy to understand and to follow. For building the model, the reality has to be

[40] Cf. Atkinson / Dietz / Neumayer (2007), p. 328
[41] Aggteleky (2006), pp. 547
[42] Aggteleky (2006), pp. 547

evaluated and then be simplified. It has to be defined how material flow or other figures look. Generally this type of diagram shows the flow of material or service through a specific process.[43]

An example for a process flow diagram can be found in “Appendix D: Flow sheet”

Relationship chart:

Relationship charts can be used for analyzing the material flow of different materials on different ways. Neither information about the material groups, nor the distances can be extracted from this type of chart. But the big advantage of this type of chart is that the attention is projected to those fields, which require the most subsidies.[44]

Nach / Von	Rohstofflager	Fertigung	Montage	Fertigwarenlager	Abfälle, Verschnitt	Versand	Schrott	**Summe**
Wareneingang	100							**100**
Rohstofflager		72	20	10				**102**
Fertigung			52	16	8			**76**
Montage				65	3			**72**
Fertigwarenlager						91		**91**
Abfälle, Verschnitt	2						9	**11**
Summe	**102**	**76**	**72**	**91**	**11**	**91**	**9**	

Figure 12: Circle diagram and triangular scheme[45]

[43] Cf. Besterfield et al. (2011), p. 391
[44] Kettner / Schmidt / Greim (1984), p. 173
[45] Kettner / Schmidt / Greim (1984), p. 173

Sankey diagrams:

With the use of sankey diagrams quantity flows can be displayed in a graphical way. In opposite to process flow diagrams these quantity flows are displayed by arrows that have a proportional thickness to the transferred amount. For that reason one can see the transferred amount at first sight. The direction of the arrow describes the direction of the material flow. Also loops can easily be displayed with the use of a sankey diagram. The flows that are displayed in this way can be of any kind, like mass, volume, energy, money and so on[46]. In Figure 36 an example of a sankey diagram is displayed.

[46] Cf. Rudolph / Wagner (2008), p. 325

3 Energiespeicher Bernegger

This chapter gives background knowledge about specific methods that are applied in the construction of the Energiespeicher Bernegger. Also the broader limits of the project are displayed.

A general overview of this project can be found in Appendix A: Overview of the project area.

3.1 General information and background knowledge

The background knowledge on some mining methods is essential to understand the logistical effort for handling the excavated material of this project.

3.1.1 Drilling and blasting

All of the information that is given in this chapter is the result of years of experience and field application. KOLYMBAS gives a good overview to explain the process in detail.

In tunnel construction the method of drilling and blasting is one of the oldest procedures of driving a horizontal tunnel of any cross sectional area into the mountain. The process of drilling and blasting is a cyclical method, which can be differentiated into several steps. First of all there are several holes which are drilled into the rock. These holes are then filled with explosives. The amount of explosive which is needed to create a certain surface is calculated exactly. Also the timeframe in which the explosive in the single holes explode is essential for creating the cross sectional surface that is required. Therefore the explosives are connected with an ignition line to keep the blasting scheme in a certain way.[47]

As everything is set up the explosives can then be ignited and the detonation causes the rock to collapse. The solid rock is split up into big gravel, which than have to be removed. In most cases the gravel is removed by the usage of belt conveyors or of dumpers. The timeframe of removing the material and transporting it to the surface should be kept very short, because while transporting, no other work can be done in the tunnel. When all the excavated material is brought to the surface the next step is to reinforce the new tunnel surface. The procedure of reinforcement also includes different

[47] Cf. Kolymbas (2008), pp. 80

steps that have to be done. Starting with a layer of shotcrete a layer of steel meshes follows and then another layer of shotcrete is applied. After this first stabilization of the tunnel surface steel anchors can be applied to guarantee that the tunnel surface is stable and the further work steps can be done without harming any people. When all these steps are completed the cycle can start from its beginning.[48]

According to these steps that have to be followed in tunnel construction, the excavated material is also transported to the surface in a discontinuous timeframe. Therefore it is essential to have storage space in the near of every tunnel mouth to compensate for these fluctuations in excavation.

Normally a tunnel is driven from two directions to save time in building the tunnel. As all the tunnels which are built in the project of Energeispeicher Bernegger have only one exit to the surface, these tunnels are driven from one end.

3.1.2 Raise boring

The procedure of raise boring was invented in the 1960's. This process is set up for producing vertical shafts. The raise boring process can be differentiated into several steps as seen in Figure 13. [49]

First of all the raise boring machine has to be set up in a chamber which is situated above the location where the vertical shaft should be built. Then the machine drills a vertical pilot hole with an approximately diameter of 30 cm into the rock. Later at this stage of construction a second chamber should be driven into the mountain where the reamer can be transported. When the pilot hole has reached this chamber which is located underneath the drilling machine, the reamer can be attached to the drill bit, and the machine pulls the reamer up. The diameter which is produced in this process can reach widths of up to 7 m and the longest holes reach a length of up to 1200 m. During this boring process the excavated material falls down into the lower chamber and has to be removed from there. The removing of the material also happens with the usage of dumpers. [50]

The decision for picking this method for mining the shafts can be found in the reason, that it is the cheapest way to produce a shaft of this dimensions.

[48] Cf. Kolymbas (2008), pp. 80
[49] Cf. Infomine INC. (2011), access date 15.05.2011
[50] Cf. Infomine INC. (2011), access date 15.05.2011

The way that the procedure of raise boring works influences the time schedule of Energiespeicher Bernegger a lot, because the tunnels which are needed for transportation of the raise boring machine and for transportation of the excavated material have to be built at the right time to guarantee that the upper and the lower chamber of the vertical shafts are accessible for the raise boring process.

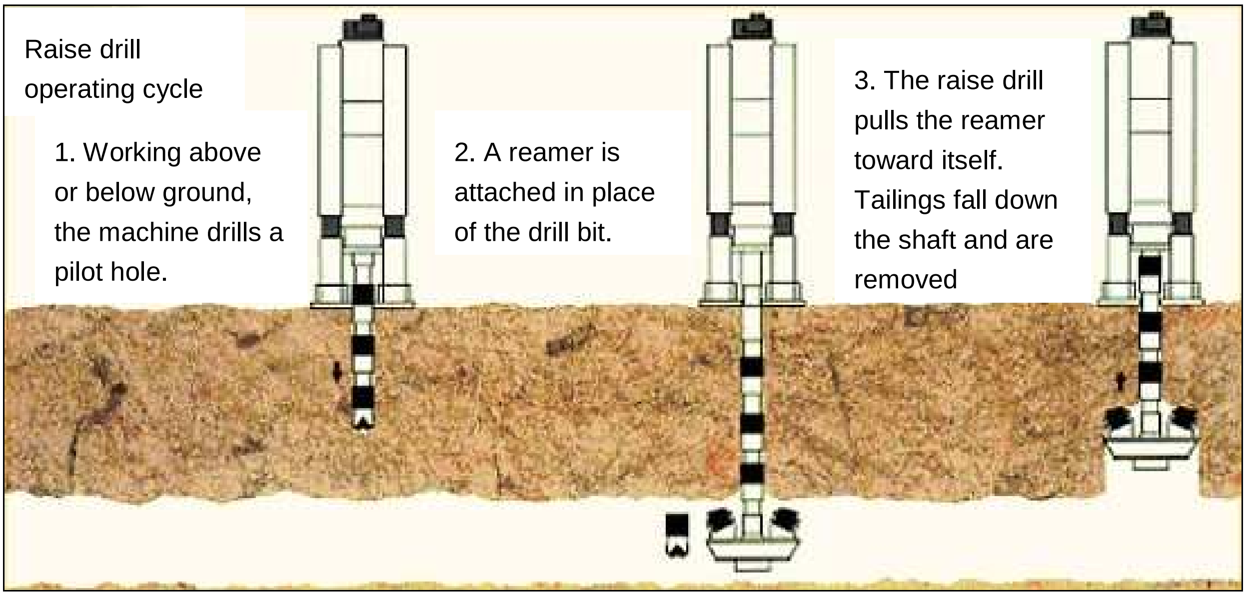

Figure 13: Operating cycle of raise boring[51]

3.1.3 Digital terrain models

The information about digital terrain models, which is given in this chapter can be found in GOMARASCA.

Digital terrain models are a very important feature to display the area surface in a 3D model. The digital terrain models can be differentiated into

- Digital surface model, DSM
- Digital terrain model, DTM
- Digital elevation model

While the digital surface model also includes the buildings which are located on the surface, the digital terrain model and the digital elevation model only describe the surface of the ground level.[52]

[51] Infomine INC. (2011), access date 15.05.2011

A digital terrain model of an area is modeled by taking the location of several surface points that have been measured and connecting them to a triangular mesh. A high accuracy of the digital terrain model can be reached by a fine meshing of the points that are measured.[53]

For the calculation of volume you need two digital terrain models which have to be superimposed. For example the volume of a heap can be calculated by taking the terrain model of the original state and superimposing it with the digital terrain model which contains the data of the heap.[54]

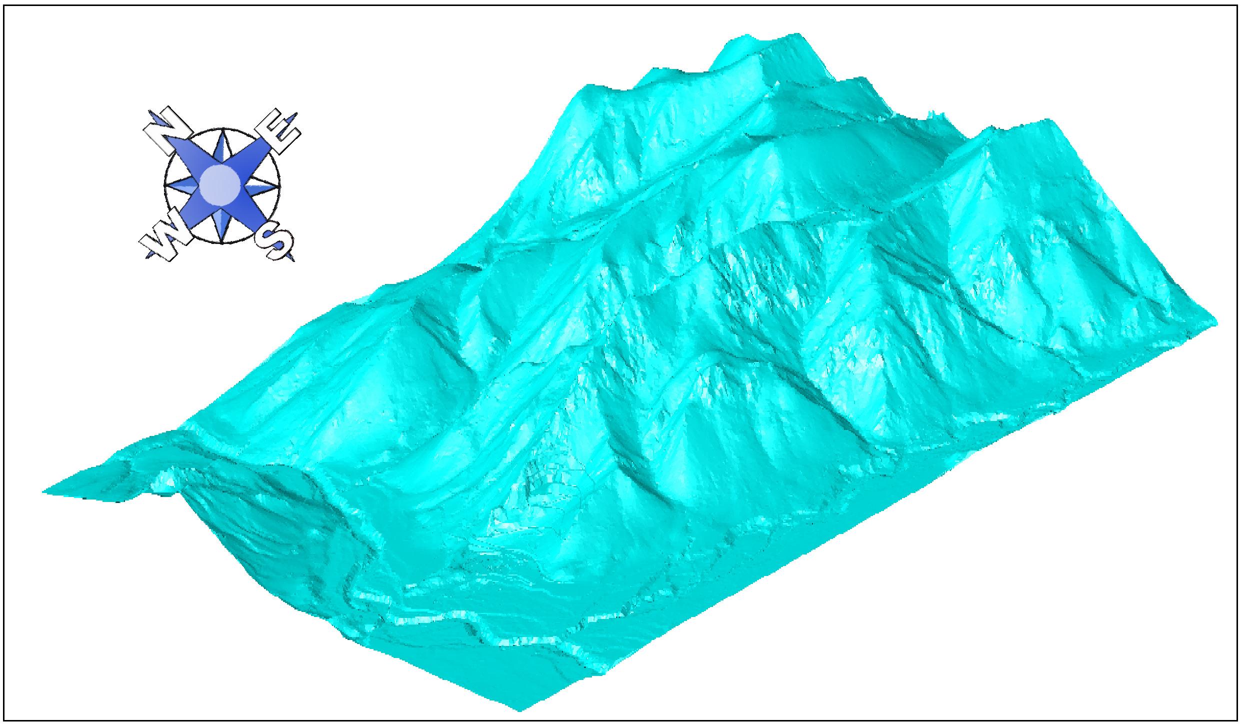

Figure 14: Digital terrain model of the project area in Molln

The terrain models which are superimposed don't have to be the result of measurements. It is also possible to measure the original surface and to model a virtual project and then measure the volume that has to be removed or heaped up.[55]

In case of the project ESB the volume of the lower reservoir and the volume of the storage areas are calculated by the usage of digital terrain models.

For achieving accurate results the terrain model of the original surface has to be detailed in a high degree. In the digital terrain model of the company grounds of

[52] Cf. Gomarasca (2004), p. 506
[53] Cf. Gomarasca (2004), p. 507
[54] Cf. Gomarasca (2004), p. 507
[55] Cf. Gomarasca (2004), p. 508

Bernegger GmbH the mesh is very fine in some locations because the terrain has been surveyed a lot due to the gravel pits that belong to the company. Other areas were not exactly surveyed over the years, therefore a 3D-Laser scan was made by the usage of a plane to increase the accuracy of the digital terrain model of the location where the Energiespeicher Bernegger is planned to be built.

This very good model of the surface is a prerequisite for exactly planning the project.

3.2 Production sites of the company Bernegger GmbH

The production sites of Bernegger GmbH, where the excavated material could be of use are described in detail. It is planned, that the material should serve as high value raw material in these sites of Bernegger GmbH.

The information about the production sites of Bernegger GmbH was gained in various interviews with employees of the company. An overview on the different production sites and the different storage areas is given in Table 3.

Production site	**Material consumption / year**	**Storage area**	**Max. storage capacity**
Molln	450.000 [t/a]	Storage area 1 Elfi-tunnel	640.000 [t]
		Storage area 2 Pfaffenboden	2.297.000 [t]
		Storage area 3 Priethal	1.230.000 [t]
Klaus	83.000 [t/a]	Storage area Klaus	947.000 [t]
Sierninghofen	150.000 [t/a]	Storage area Sierninghofen	2.500.000 [t]

Table 3: Overview of production sites and storage areas

Molln:

In Molln, Bernegger GmbH has it's headquarter and also the biggest production site. The main commodity that is mined in Molln is limestone, which is transported via a belt conveyor from the gravel pit "Pfaffenboden" to the production site. Once transported down the mountain, the stones which have a maximum diameter of 150 [mm] are separated into the following grain sizes:

- 0-8 [mm]
- 8-16 [mm]
- 16-32 [mm]
- 32-64 [mm]
- 64-150 [mm]

In addition to limestone Bernegger produces sand, gravel and split, which is used for many different applications like tunneling, for bridges or for buildings. These products are gained by processing the raw material in further production steps like crushing, washing and separating.

The material which is gained in Molln is either transported to the asphalt mixing plant in Linz and to other construction sites of Bernegger, or can be collected by the customers directly in Molln.

The total amount of commodity which is produced in Molln can be numbered with about 450.000 tons a year.

Klaus

In Klaus Bernegger also has a gravel pit for its asphalt and concrete mixing plant. The total amount of gravel which is needed every year for production can be numbered with 250.000 tons. This amount is gained on the following gravel pits:

- 1/3 of the material: Gravel pit in Klaus
- 1/3 of the material: Neighbored gravel pit where the material is transported to Klaus
- 1/3 of the material: Transported from the gravel pit in Molln

That means the amount of material which could be used for production in Klaus is about 83.000 tons a year.

Sierninghofen

In Sierninghofen there used to be a gravel pit, where mining stopped in 2009. Since that time it serves as a temporarily storage space for the material that is excavated at the gravel pit "Pfaffenboden". This excavated material is transported to Sierninghofen and can then be distributed all over upper Austria.

The amount of material that is transported to Sierninghofen and distributed from there can be numbered with 150.000 tons a year.

3.3 Storage areas for the excavated material

The big amounts of excavated material of course need sufficient storage space. Therefore in this chapter, the storage areas, which are possible for storing the material, are described by means of maximal storage volume and some other data. Figure 15 shows a map of the different storage areas.

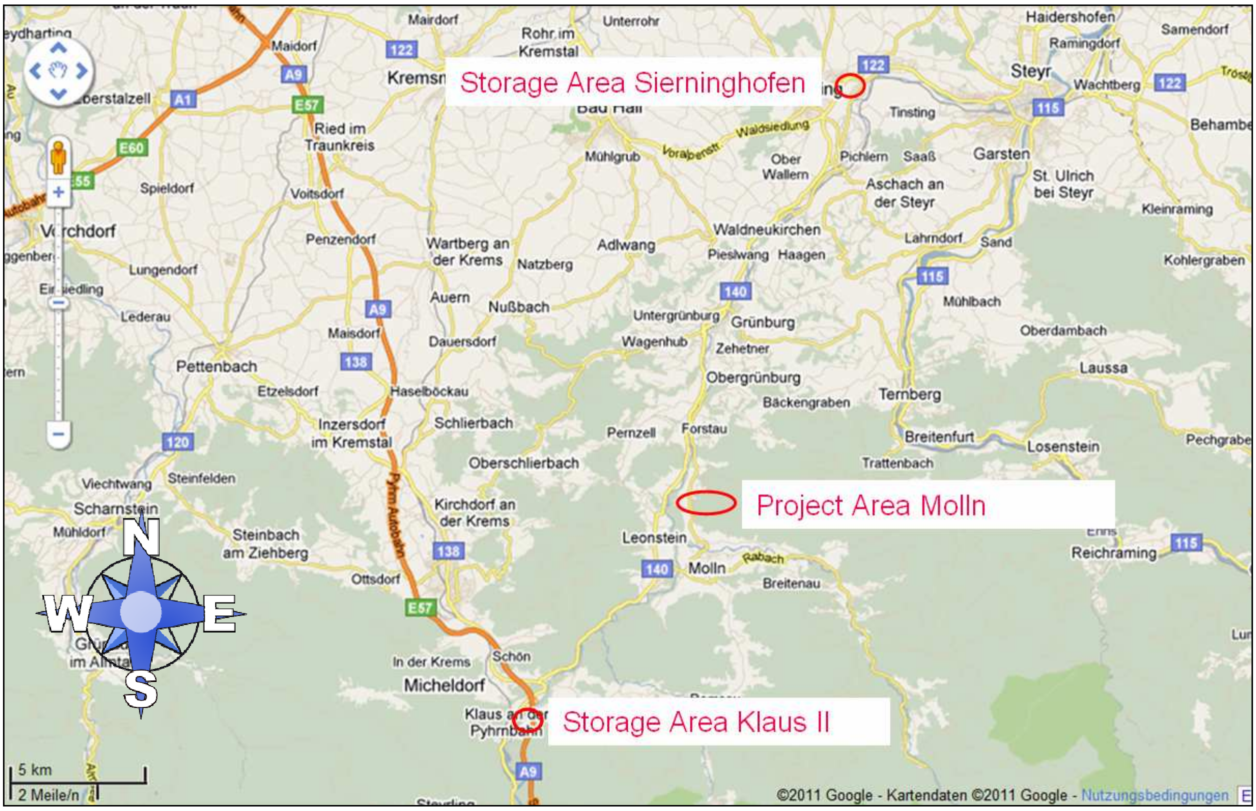

Figure 15: General overview of the storage areas[56]

[56] Google Maps (2011), access date 13.04.2011

3.3.1 Storage areas 1 and 2

Storage area 1 is located directly at the tunnel mouth of the access tunnel of the upper reservoir at an elevation of about 1017 [m.a.s.l.] This storage area would be preferred for the excavated material that is transported out of the unit Pfaffenboden, which is described in 4.1.1, because it is the shortest way for transportation of the material via the access tunnel.

The second advantage of this storage area is, that it is easily accessible for removing the material again from the storage area and transporting it to the belt conveyor, which is integrated in the "Elfi-tunnel".

Storage area 2 is located at the existing gravel pit Pfaffenboden at an average elevation of 1100 [m.a.s.l.] The transportation to this storage area can either happen via the transportation tunnel of the upper reservoir, or via the access tunnel and then over the existing road to the gravel pit Pfaffenboden.

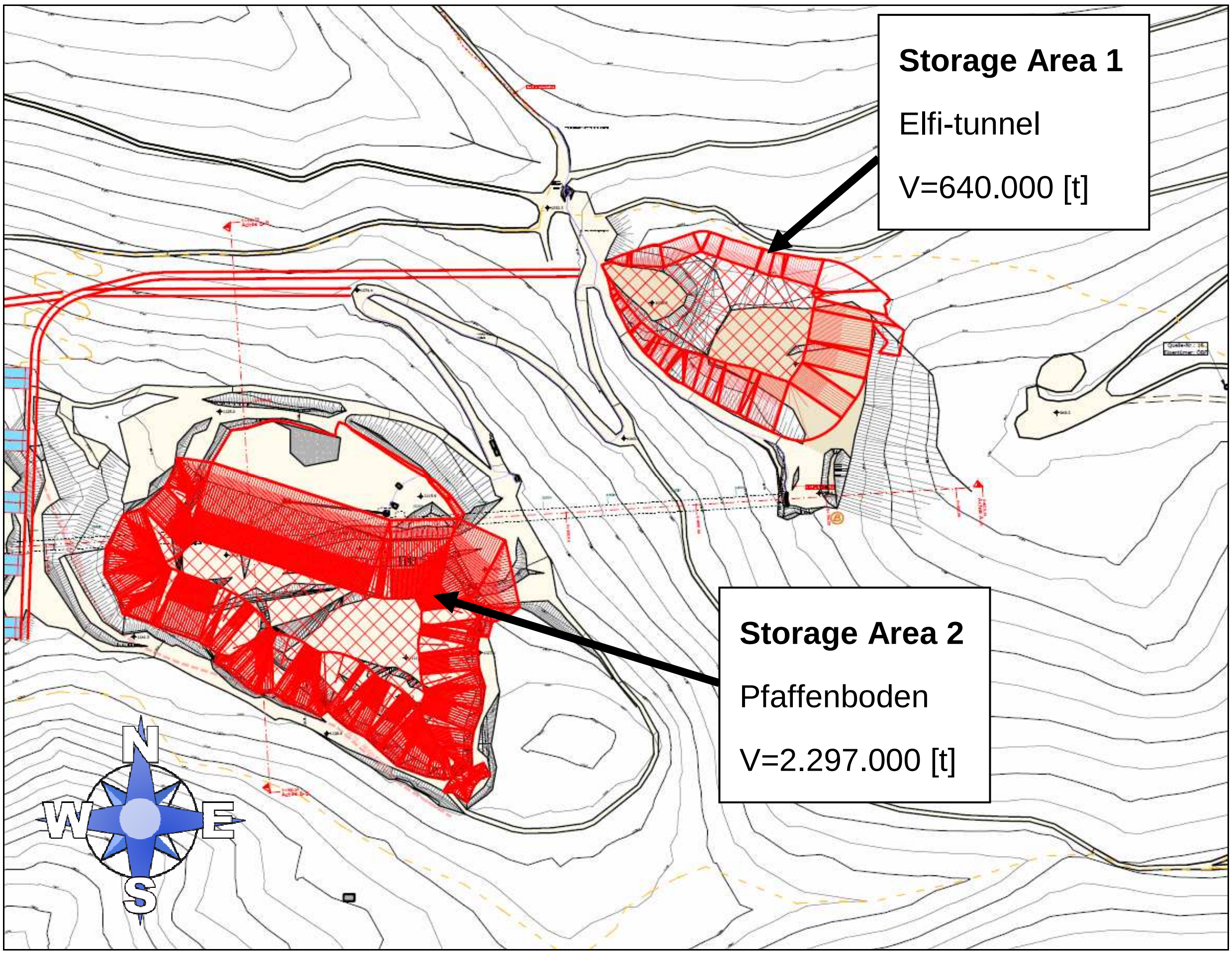

Figure 16: Storage areas 1 and 2

3.3.2 Storage areas on the company grounds

On the company grounds there are several possibilities for storing the excavated material of the unit lower reservoir. All of these storage areas are displayed in Figure 2 in terms of location and main data.

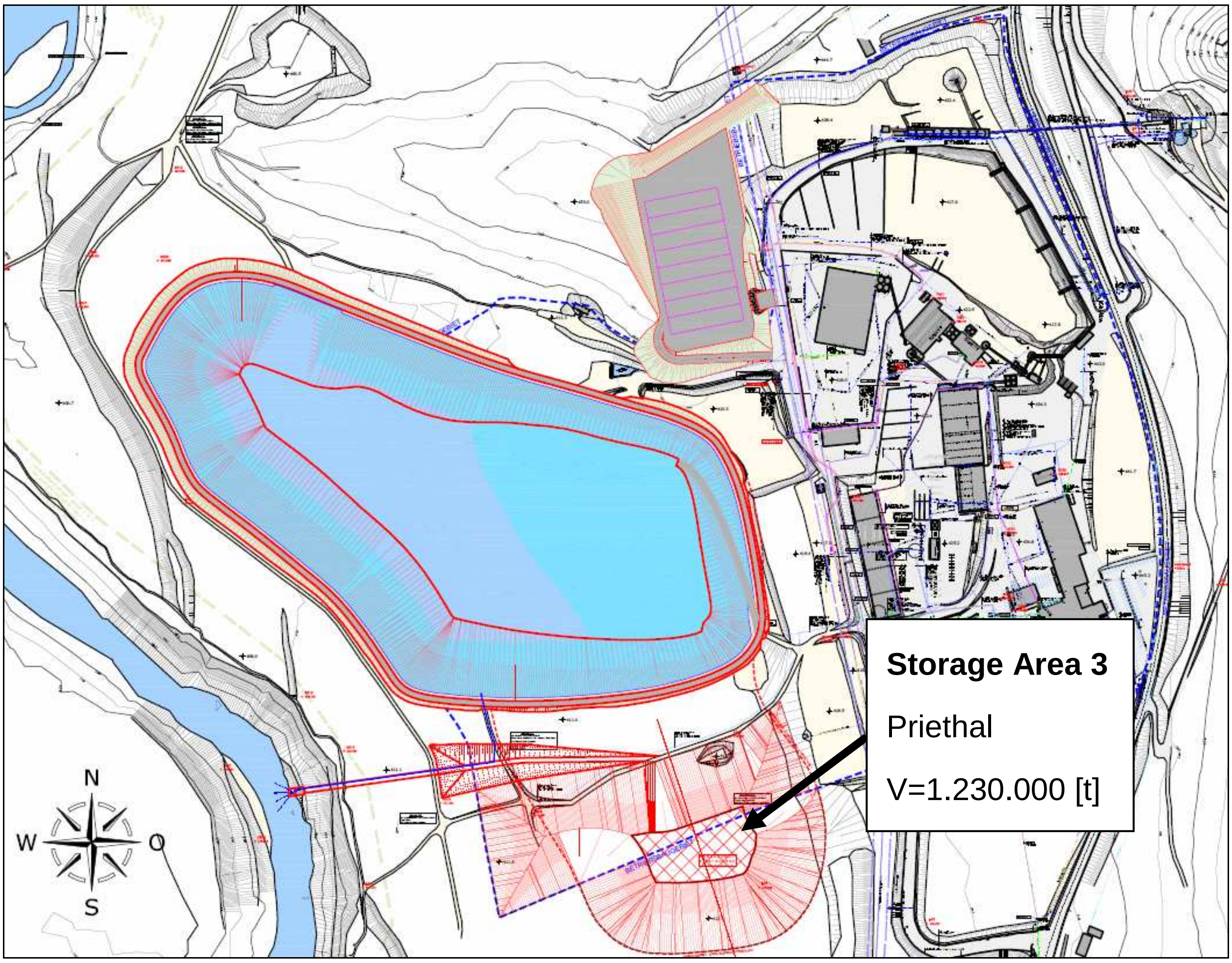

Figure 17: Storage areas on the company grounds

Storage area 3 would be preferred for storing the excavated material, because it is located directly beneath the lower reservoir. It also has big dimensions to ensure that most of the material can be stored on this storage area. Another advantage is that the material is easy reachable after the storing time and no residents are influenced by the transportation.

The dimensions of storage area 4 would also be sufficient to store the material that is mined in the lower reservoir and the surrounding regions. Also the reachability for depositing of the material would be good, but the reachability of the storage space for taking the material after storage is very bad. There are also residents that would not be happy with this storage area. Therefore the storage area is not the best choice for deposition of the material.

Storage areas 5 and 6 are smaller storage areas that could be used for the short term storage of material, because they are situated near the plant in Molln. The dimensions of these storage areas are far smaller than the other storage areas.

3.3.3 Storage area Sierninghofen

The storage area in Sierninghofen is very large in its dimensions. The reachebility of the storage area is a little problematic because it is about 20 [km] away from the construction site. But the old gravel pit in Sierninghofen serves as storage space for the material that is mined in the quarry Pfaffenboden anyway. For that reason the transport to this storage space would not represent an extra effort.

In Figure 18 the main data of the storage space Sierninghofen is displayed.

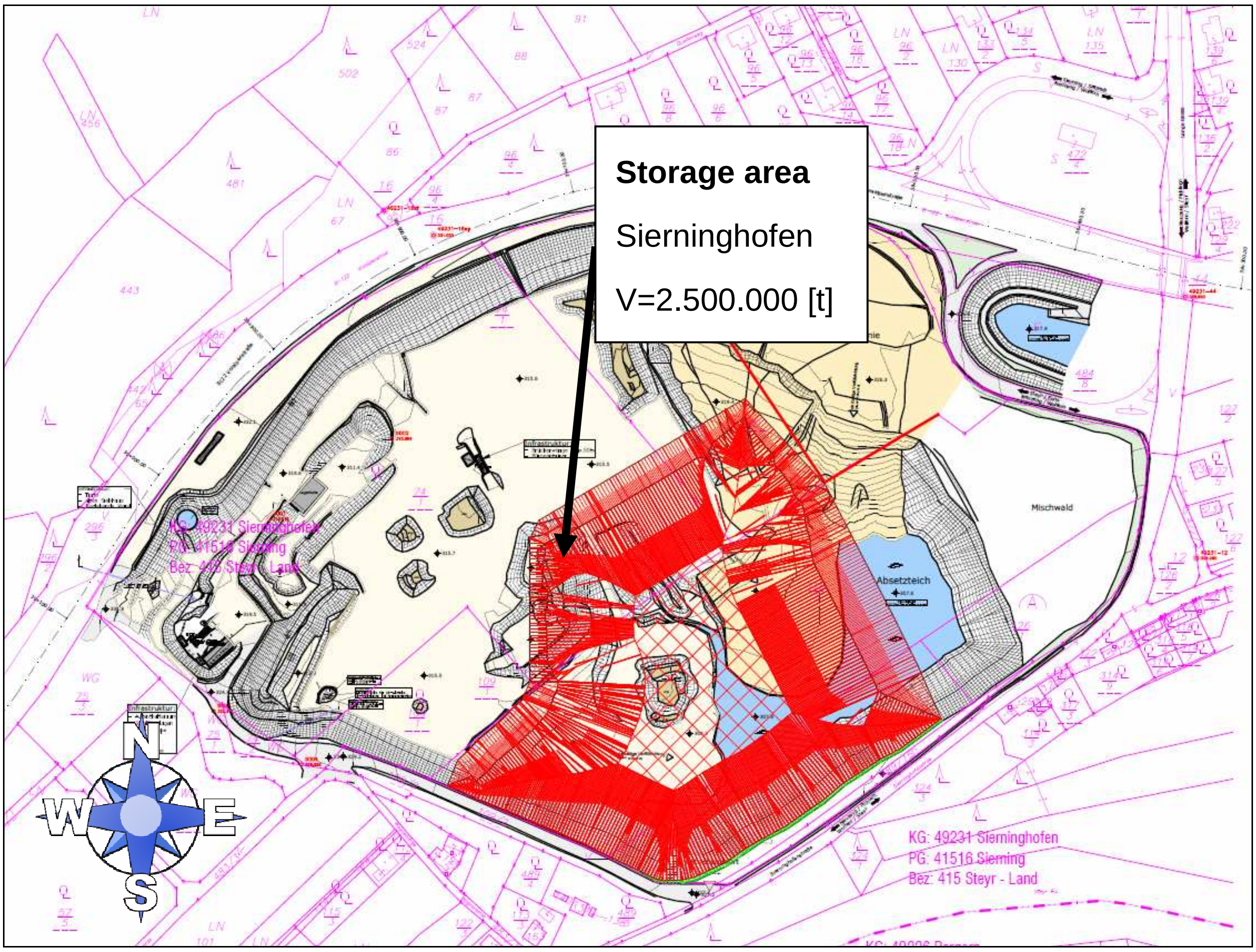

Figure 18: Storage area Sierninghofen

3.3.4 Storage area Klaus

The storage area in Klaus is located on the plant grounds in Klaus. The distance to the construction location of Energiespeicher Bernegger is about 13 [km]. Just like the situation is in Sierninghofen, the material in Klaus is needed for daily business. Therefore the higher distance for transportation would not be a problem.

In Figure 19 the location of KlausII and the main data of the storage spaces is displayed.

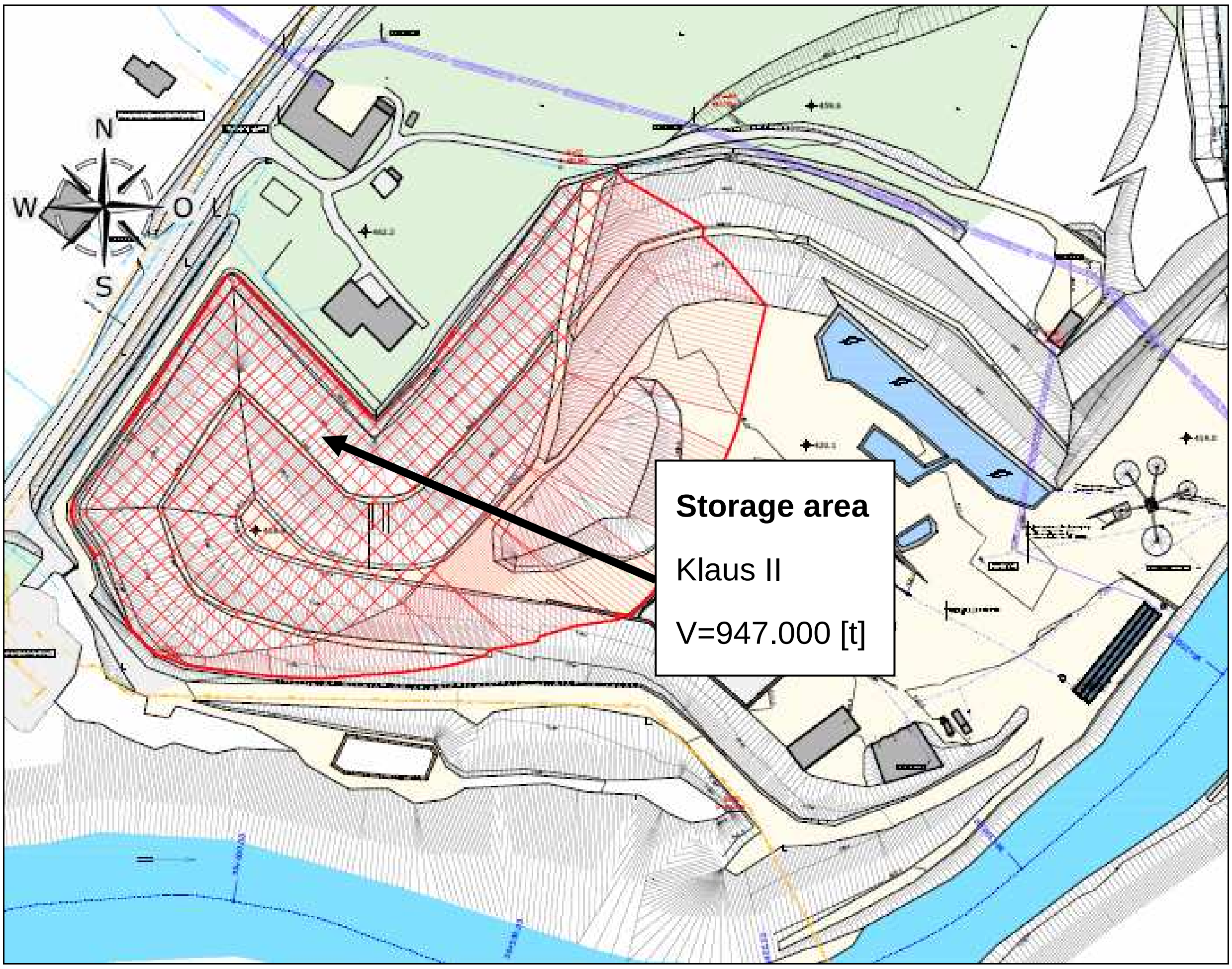

Figure 19: Storage area Klaus II

3.4 Manipulation process

This chapter can be split up into the distances that have to be overcome within the company grounds and the distances to external production sites of Bernegger. There are several possible means of transportation, which are also displayed in this chapter.

Within the company grounds

The routes that have to be overcome within the company grounds do not follow any public road and have a relatively short distance. For that reasons these routes can be covered with dumpers. The distances that are essential for the elaboration of a logistic concept and the involved prices are displayed in Chapter 6 - Concepts for the disposition of the excavated material.

External production sites

There are two external production sites where the material could be transported. These external production sites can only be reached via public roads, therefore the transportation equipment has to be licensed for public transportation. The distance to Sierninghofen is 20 [km] and the distance to Klaus II is 12 [km].

Machinery for manipulation

For transportation there are several different machines that can be used for transportation of the material. The machines are described in detail and a overview is given in Table 4.

- **Wheel loader**

A wheel loader is needed at every storage area. On the one hand it has the task to load the lorries and dumpers. On the other hand it is needed for shaping the mould where the material is dumped. In the machine park of Bernegger there are about 70 wheel loaders which could be used for the construction of the project Energiespeicher Bernegger.

Figure 20: Wheel loader

- **Articulated lorry**

These lorries are licensed for driving on public roads. The articulated lorry consists of a prime mover and a trailer. For this combination there are two variants available. On the one hand the prime mover could have two axles and the trailer three axels. On the other hand the prime mover could have three axles and the trailer only two axels. The field of application drives the decision, which variant is chosen. within the special combinations Bernegger has about 30 articulated lorries.

Figure 21: Articulated lorry

- **Dump truck**

The dump trucks are also licensed for public roads. There are some possible variants concerning the axles. There are dump trucks which have three, four, or even five axles. The fleet of Bernegger contains about 80 of these trucks in all variations and sizes.

Figure 22: Dump truck

- **Dumper**

The dumpers can be used for the transportation on the construction site and on company grounds. These machines are not licensed for driving on public roads. Bernegger has about 40 dumpers that are available for transportation within the company grounds.

Figure 23: Dumper Volvo A30

Overview and price list

In Table 4 an overview for the load capacity and a price list is given. These prices are needed for calculating the cost to the different storage area.

Designation	Dead weight [kg]	Gross vehicle weight [kg]	Load capacity [kg]	Cost [€/h]
Wheel loader	23.790	-	-	75,2
Articulated Lorry 5-A	6.100	33.000	26.900	82
Articulated Lorry 5-A	6.550	31.000	24.450	77
Dump truck 4-A	14.280	32.000	17.720	70
Dumper	20.900	47.900	27.000	100

Table 4: Machinery for manipulation

These prices are the cost per hour for the machinery which are taken for internal calculation of transportation processes.

3.5 Elfi-tunnel

The existing transportation tunnel which is called "Elfi-tunnel" is an essential transportation route for the project Energiespeicher Bernegger. For that reason it is explained in detail within this paper.

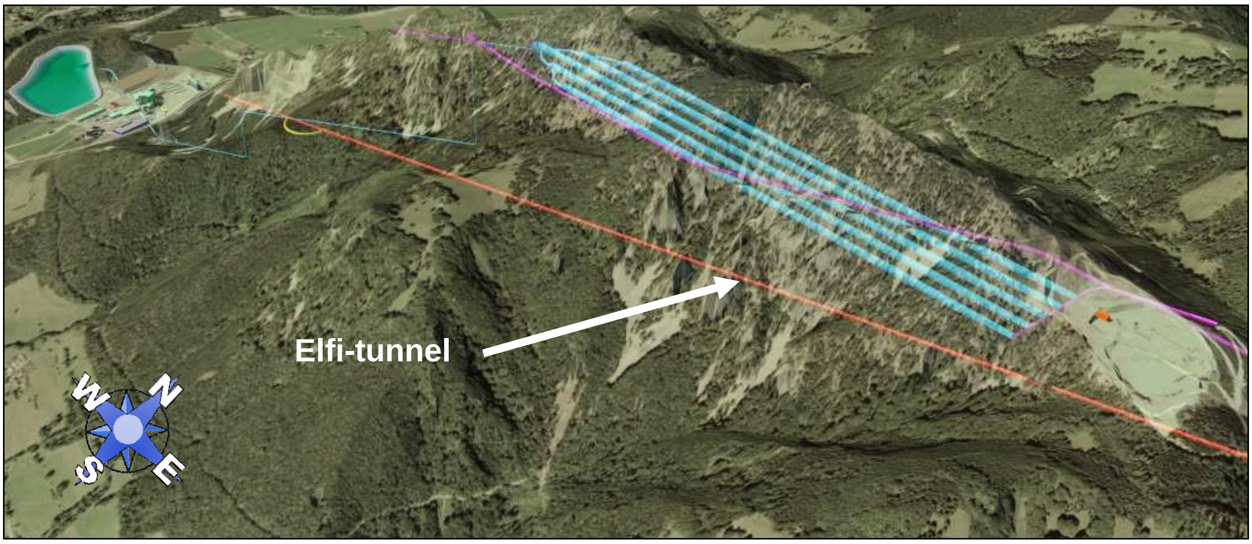

Figure 24: Elfi-tunnel

The reason for building this tunnel in the year 2001 was to make the gravel pit Pfaffenboden easy assessable. For transportation of the material that is gained at the gravel pit, a belt conveyor was installed.

The tunnel has a total length of 3,5 km and a constant slope of 15 [%]. The tunnel portal that points to the company grounds has an elevation of 476 [m.a.s.l] and the tunnel portal that lies on the area Pfaffenboden has an elevation of 996 [m.a.s.l].

Due to the big difference in elevation the belt conveyor can also be used for generating electricity. At a maximum material flow of 500 [t/h] the power output of the belt conveyor is about 400 [kW]. When the material flow goes down to 200 [t/h], due to the friction of the belt, the power output is zero.

In Figure 25 the cross section of the tunnel is displayed. The belt conveyor is situated on the left site of the tunnel when looking from the lower tunnel mouth to the upper tunnel mouth. As one can also see it is very difficult for two lorries to pass each other in the tunnel, therefore the tunnel can be seen as bottleneck for the whole project.

Everything that is needed for the construction process of Energiespeicher Bernegger has to be transported through this tunnel. A lot of machinery, steel pipes, steel mats, and equipment that has to be transported up to the upper basin, machine chamber, and all the tunnels that are situated in this area. Therefore the tunnel is frequented very much during the construction phase.

This tunnel not only plays a big role in making the area Pfaffenboden accessible, but also to transport the excavated material down to the company grounds. The material is transported down the mountain by the use of a belt conveyor, which is situated in the transportation tunnel.

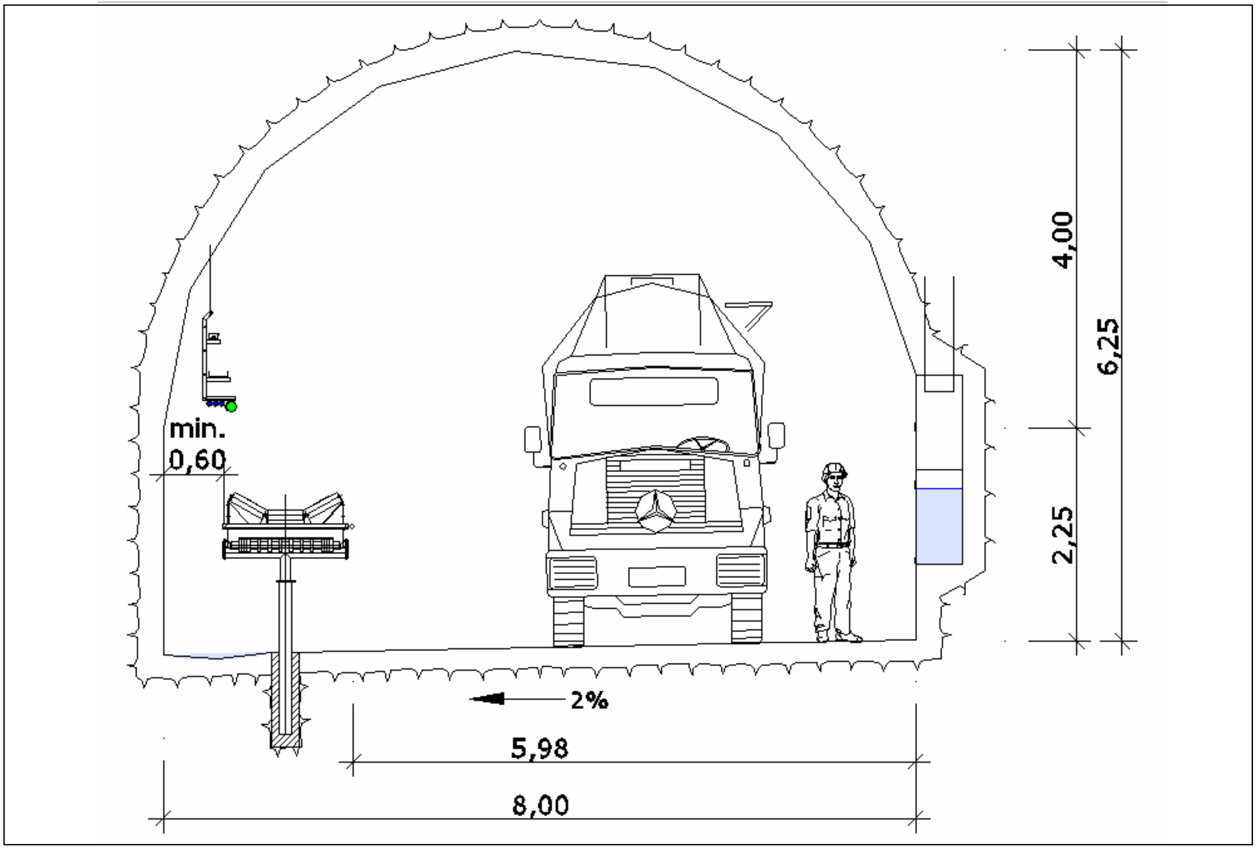

Figure 25: Cross section of "Elfi-tunnel"

3.6 Construction stages of Energiespeicher Bernegger

For calculating the amount of excavated material and for setting up the timetable, this project is differentiated into smaller sections. In this chapter the different parts of the project "Energiespeicher Bernegger" are described and the amount of material which has to be excavated during the construction process is displayed. In Appendix A: Overview of the project area.

The amount of excavated material is displayed in detail for every single construction stage. This spreadsheet can be found in Appendix B: Calculation of excavated material.

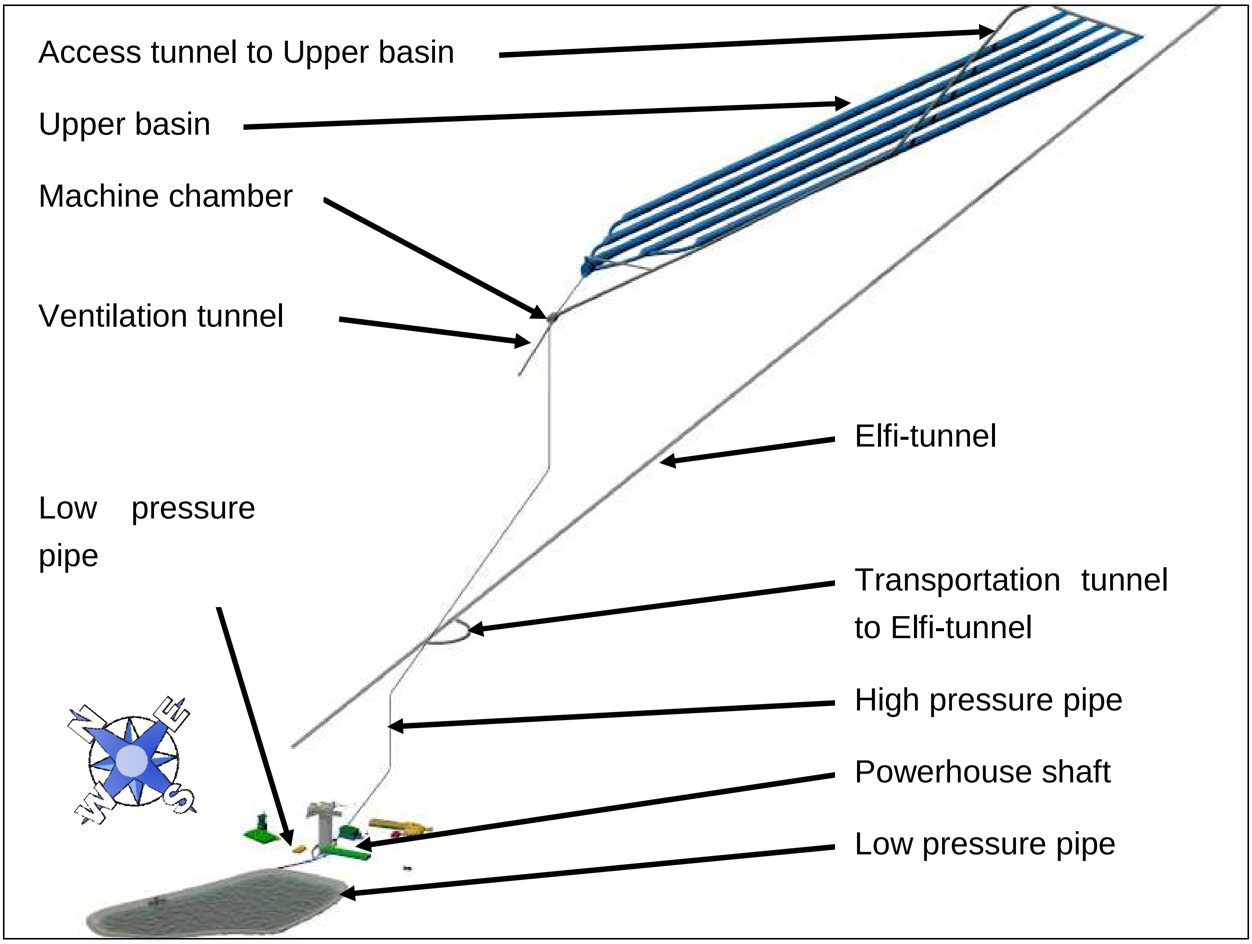

Figure 26: Cross section of "Elfi-tunnel"

3.6.1 Access tunnel to upper basin

For transportation purposes during the construction phase, and also to ensure the access to the machine chamber during the operational phase, this tunnel can be seen as the main access road to the upper basin. The entrance of the tunnel is located near the main site area of the construction unit "Pfaffenboden". Following the tunnel into the mountain it first goes up with a slope of about 3,5 [%] to an junction which is located in the mountain. It then falls with a slope of about 9 [%] down to the first water-tunnel of the upper basin. On its way further it is the connection tunnel for the five water-tunnels of the upper basin. The extents of the tunnel reach a width of 5,5 [m] and a height of 6,5 [m] and a total length of 665 [m].

For calculating the excavated material in the construction process of the tunnel it can be split up into two parts. The first part of the tunnel is a valley to the tunnel mouth, whose volume is calculated with a digital terrain model. The volume of the rest of the tunnel can easily be calculated by multiplying the length of the tunnel with the cross-sectional surface area. The cross section of the tunnel is displayed in Figure 27.

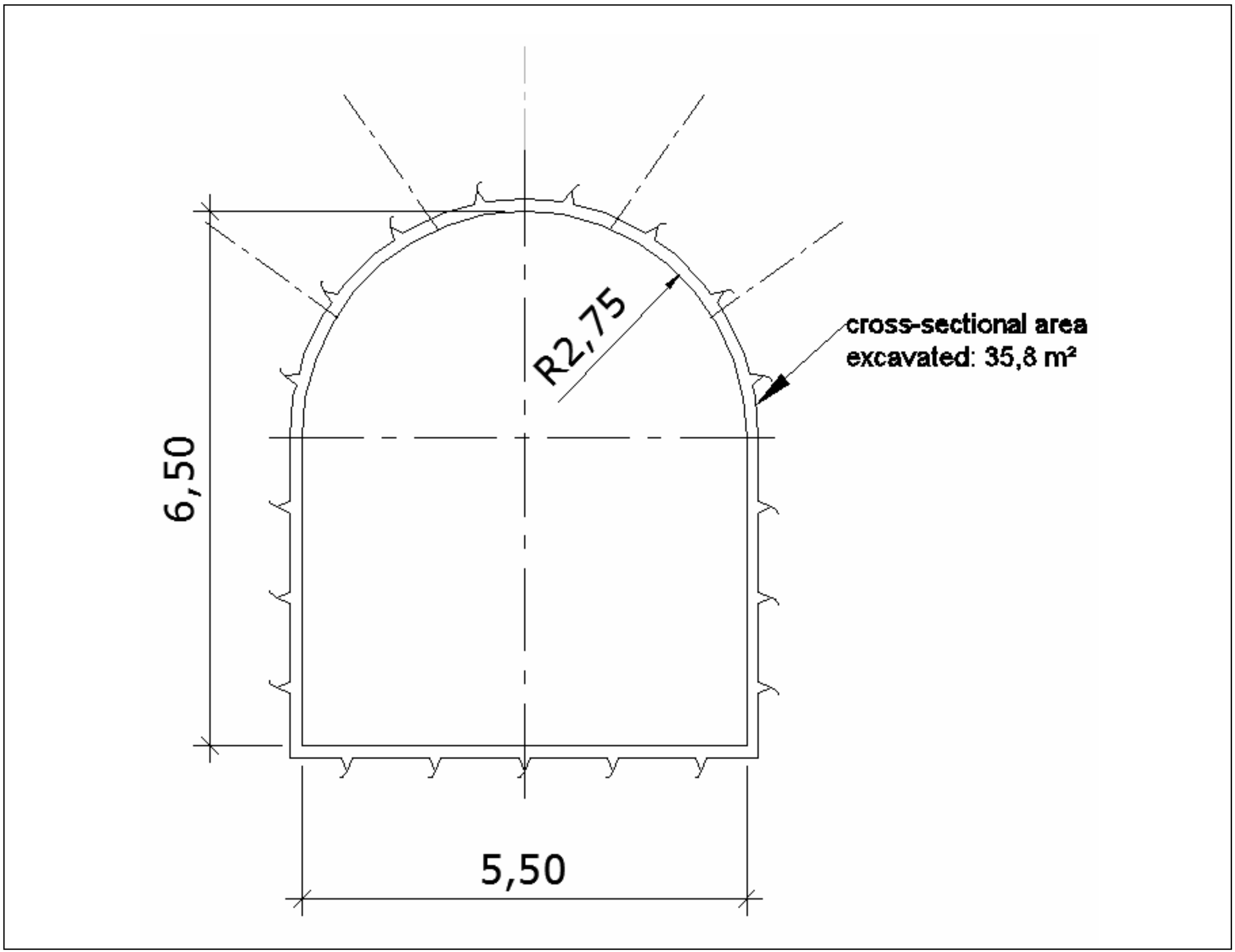

Figure 27: Tunnel cross section of the access tunnel to the machine chamber

Like all the other tunnels which are build in the project "Energiespeicher Bernegger", this tunnel is built by drilling and blasting. Therefore the excavated material comes to the surface in a discontinuous flow as displayed and explained in chapter 3.1.1.

3.6.2 Transportation tunnel to upper basin

The transportation tunnel to the upper basin is a second access tunnel to the upper basin. The reason for building this tunnel lies in the fact that it shortens the route to the "storage area 2" about 550 [m]. It is also part of this thesis to evaluate if the costs for building this tunnel are economical. The upper end of tunnel lies on a hairpin bend of the road which leads up to the quarry "Pfaffenboden". The tunnel then goes down with a slope of 15 [%] to the inner junction in the mountain and has a total length of 207 [m].

Identical to the access tunnel, the first part of the tunnel is a valley which reaches to the tunnel mouth. The volume of the valley is calculated with a digital terrain model. The volume of the rest of the tunnel can easily be calculated by multiplying the length of the tunnel with the cross-sectional surface area of the tunnel.

The cross section of the tunnel is equal to the cross section of the access tunnel to the upper basin.

3.6.3 Upper basin

The upper basin is one of the main parts of the project ESB. The upper basin is a tunnel system of five tunnels, which unite near the machine chamber. It therefore reaches from the connection tunnel to the machine chamber. The volume of the tunnel system should reach a maximum, because it defines the operational data of the whole pumped storage hydro power plant.

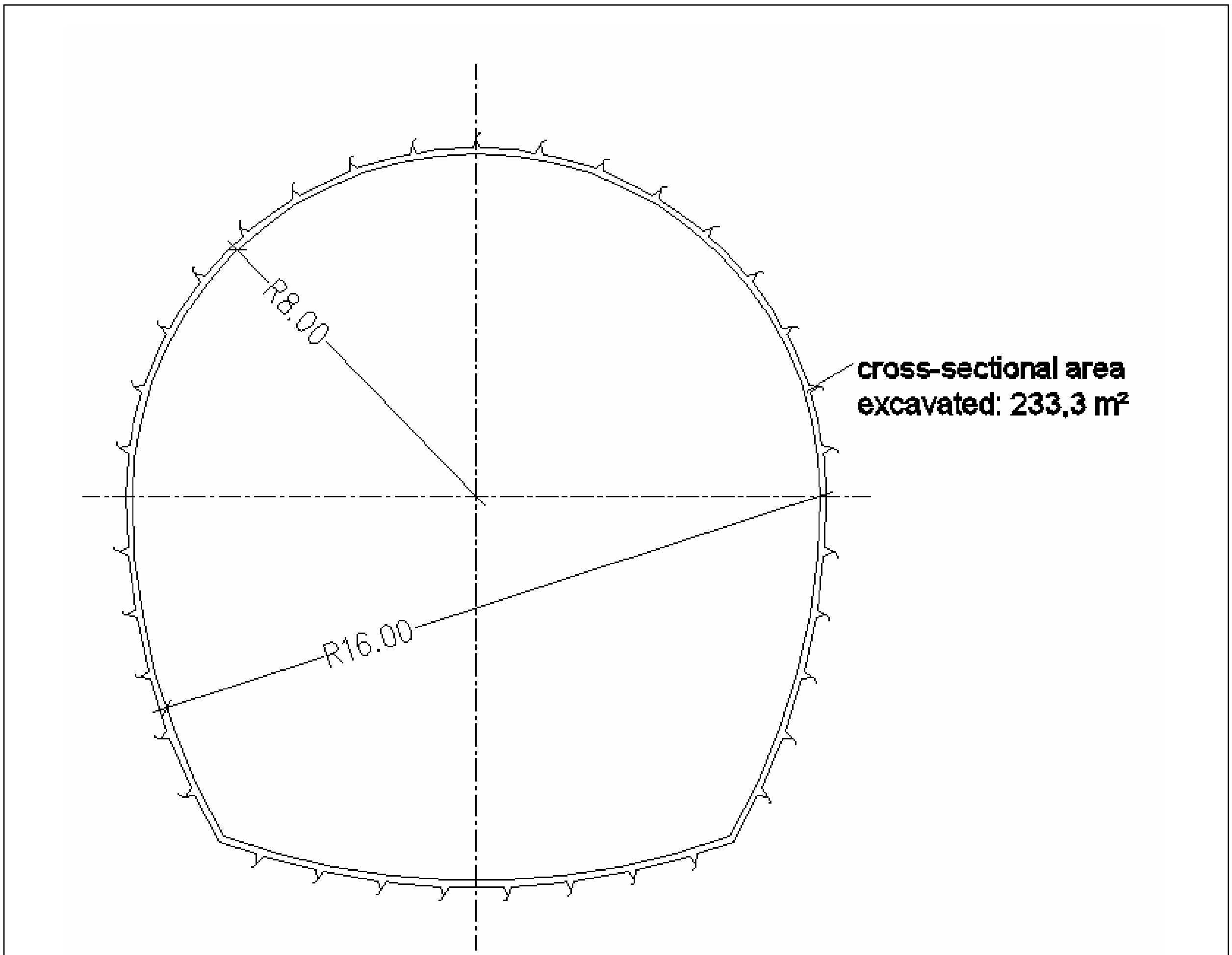

Figure 28: Tunnel cross section of the upper basin

For maximizing the volume, each of the five tunnels has a diameter of about 16 [m] and a length of about 1,55 [km]. Due to the complex geometry of the sector where the tunnels join, the amount of excavated material in the upper basin is calculated with a 3D-model for every single tunnel. By adding up these single tunnels to one unit, the total volume can easily be calculated. Although the volume of the tunnel system is enormous, the daily excavation rate is quite moderate, because the construction phase lasts for a very long time and because one tunnel is built after another. Like in every other tunnel, the duration of the construction phase is given by the time schedule of the drilling and blasting process, and therefore in the rate of daily construction is given in meters per day.

3.6.4 Access tunnel to the machine chamber

The access tunnel to the machine chamber leads from the junction point directly to the machine chamber. It first rises with a slope of 12,5 [%], then falls with a slope of 0,5 [%] and finally falls with a slope of 3,6 [%]. The total length of the tunnel can be declared as 1860 [m].

The volume of the excavated material can be calculated by multiplying the length of the tunnel with the cross-sectional surface area. During the construction phase the purpose of the tunnel serves as transportation tunnel for the construction of the machine chamber and the ventilation tunnels. Later on during the operation phase, the tunnel serves as access tunnel for the machine chamber.

3.6.5 Machine chamber

The machine chamber is a cavern, which is located at the head of the high pressure pipe. Its dimensions are 21,4 [m] in the length, 16,65 [m] in the width and it has a height of 15 [m].

The machine chamber, which is excavated by drilling and blasting, serves as the site for the raise-boring machine during the construction phase and it is also planned to integrate an indoor crane into the machine chamber, which is used for installation of the high pressure steel-pipes and machinery during the construction time. In the operating phase the indoor crane is used for maintenance purposes. The volume of the excavated material in the machine chamber is calculated by multiplying the extents of the camber. The excavated material has to be brought either to the transportation tunnel Pfaffenboden or to the access tunnel of the upper basin.

3.6.6 Ventilation tunnel to machine chamber

The purpose of the ventilation tunnel is to supply the tunnel system and the machine chamber with sufficient fresh air during the construction process. Although the position of the tunnel is at the other side of the mountain "Gaisberg" and it is an access point to the surface, all the excavated material of the tunnel has to be brought either to the transportation tunnel Pfaffenboden or to the access tunnel of the upper basin.

The tunnel has a length of 236 [m] and a constant falling slope of 8 [%]. The volume of the tunnel can be calculated by multiplying the length of the tunnel with the cross-sectional surface area of the tunnel.

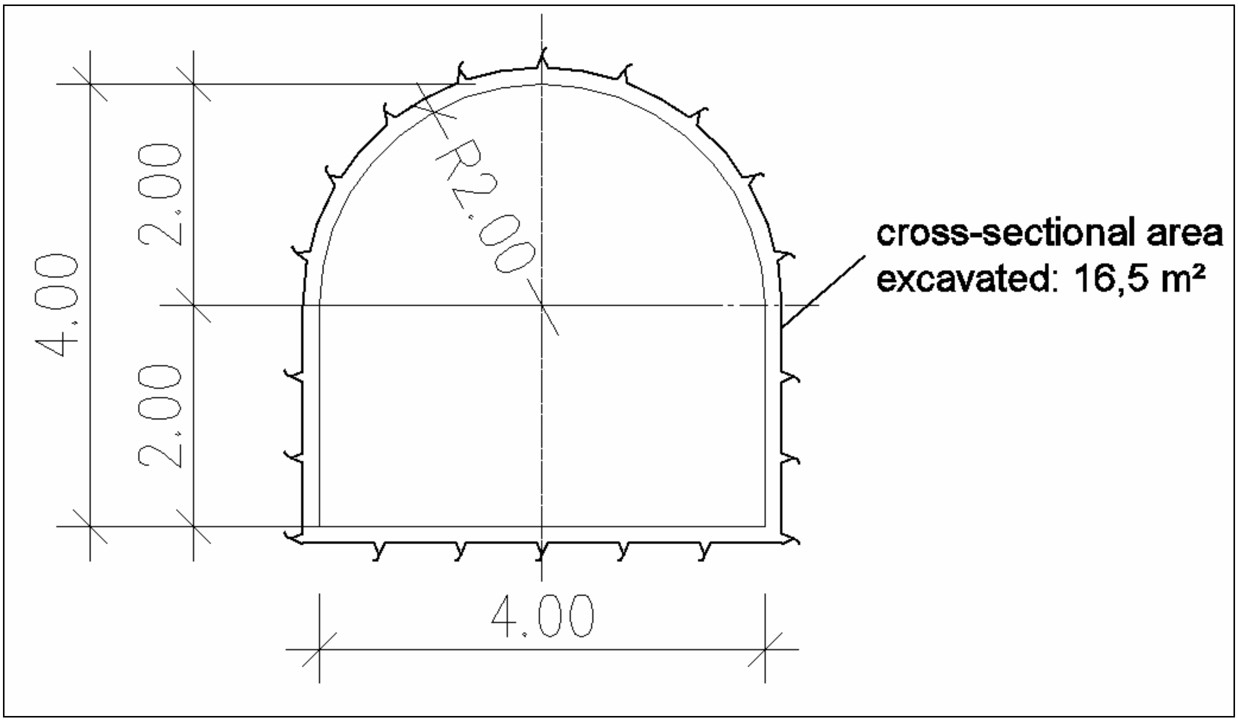

Figure 29: Tunnel cross section of the ventilation tunnel to the machine chamber

3.6.7 Ventilation tunnel for the surge tank

The ventilation tunnel for the surge tank is for maintainance purposes and for ventilation purposes during the operational phase. The tunnel has a length of 133 [m] and a falling slope of 14,7 [%]. The amount of excavated material can also easily be calculated with the length and the cross-sectional area. The cross section of the ventilation tunnel surge tank is the same as the cross section of the ventilation tunnel to the machine chamber.

3.6.8 High pressure pipe

In the operational phase the high pressure pipe serves as connection of the upper basin and the power house. It is a steel pipe which is imbedded into a concrete backfill in the tunnel of the excavated tunnel section in the construction phase. Due to the big diameter Ø 3,1 [m] of the steel pipe, the dimensions of the tunnel which serves as housing for the tunnel have to be very large. Therefore all the tunnels are navigable with big construction machines for transportation of the excavated material. The high pressure pipe has a total length of 1863 [m], consists of various standard sections, and is built with various manufacturing processes. For calculating the excavated material it has therefore to be divided into different sections. During the construction process there are also different sites to which the material has to be transported.

Tunnel 1

This tunnel connects the upper reservoir with the machine chamber. It has a total length of 165 [m] and a constant cross section over the whole length of the tunnel. Therefore the volume that has to be excavated can easily be calculated by multiplying the length of the tunnel with the cross sectional area.

Shaft 1

This shaft with a length of 322 [m] starts in the machine chamber and goes down to tunnel 1 of the high pressure pipe.

The shaft is built with the procedure of raise boring. The raise boring machine is situated in the machine chamber.

Because of the raise boring process the excavated material has to be manipulated through tunnel 1, which is connected to shaft 1 and then through the transportation tunnel Elfi.

The standard section of the shaft is a circle with a diameter of Ø 3,9 [m] and therefore the volume of the excavated material can easily be calculated by multiplying the cross-sectional area with the length of the tunnel.

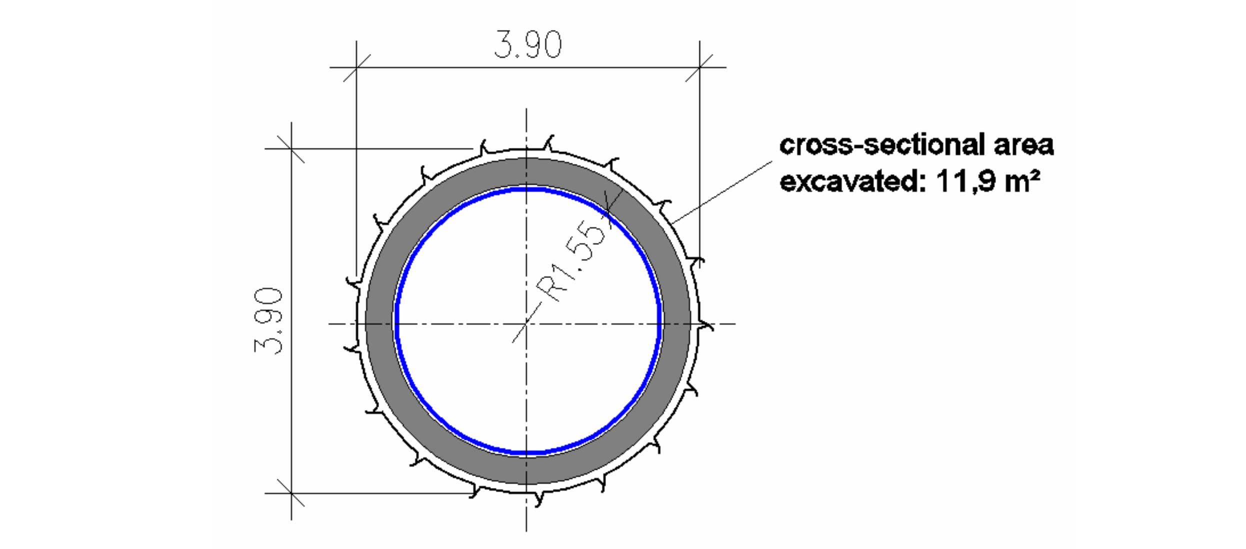

Figure 30: Cross section of the shaft in the high pressure pipe

Tunnel 2

This tunnel has a total length of 898 [m] and a slope of 15 [%]. It can be reached through the transportation tunnel "Elfi".

The volume of the tunnel can also be calculated with cross sectional area multiplied by tunnel length.

During the construction phase the tunnel also serves as transportation tunnel and in the operational phase it can only be accessed via a small hole in the transportation tunnel which leads to the "Elfi-tunnel".

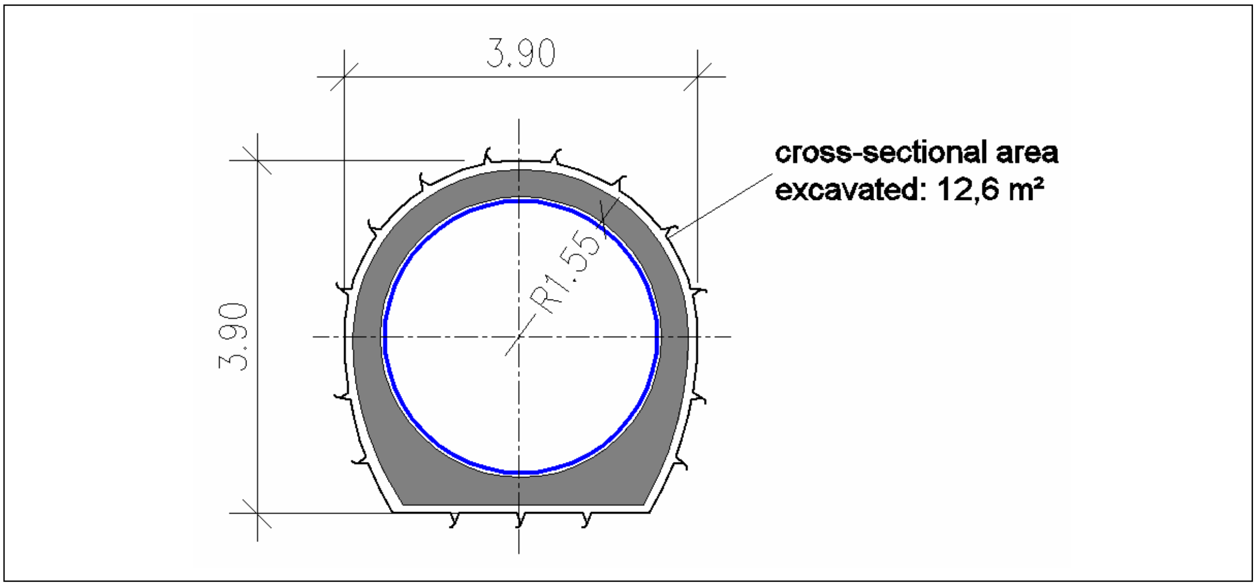

Figure 31: Cross section of the tunnel 1 in high pressure pipe

Shaft 2

This shaft is connected to tunnel 1 of the high pressure pipe. It has a length of 160 [m] but all the other dimensions are equal to shaft 1.

Due to the fact that this shaft is also excavated with the process of raise boring, a small chamber has to be built at the end of tunnel 1 where the raise boring machine can be situated. Like in shaft 1 the material has to be transported away from underneath the shaft, which is tunnel 2 in this case.

Tunnel 3

The tunnel is the connection between the powerhouse shaft and shaft 1. It has a length of 296 [m] and a constant slope of 10,8 [%].

The cross sectional area is exactly the same as in tunnel 1.

3.6.9 Transportation tunnel to “Elfi tunnel”

The transportation tunnel to "Elfi tunnel" is essential to guarantee the reachability of the inner parts of the high pressure pipe. The tunnel has a length of 189 [m] and a constant slope of 2 [%].

This tunnel serves as transportation tunnel during the construction process and as access tunnel to the high pressure pipe during the operational phase.

The volume of the tunnel can also be calculated with the cross sectional area and the length of the tunnel.

3.6.10 Powerhouse shaft

The powerhouse shaft is the main part of the project "Energiespeicher Bernegger". It is located on the company grounds of Bernegger GmbH. All the machinery starting from the turbine up to the transformers are located on different levels in the powerhouse shaft. It can be seen as a high-rise that is built into a big hole and where only the top level is visible from outside.

The excavation diameter of the shaft is 28,1 [m] and it has a total depth of 101 [m]. Due to the big diameter this shaft cannot be excavated with the method of raise-boring like all the other shafts.

Instead it has to be excavated by drilling and blasting in layers starting from top down. The material that is excavated with this method has to be transported up to the surface by the use of a big container and a crane. Therefore a day storage has to be provided in the near of the powerhouse shaft.

3.6.11 Low pressure pipe

This tunnel houses the low pressure pipe during the operational phase, but it is also essential during the construction phase, because it is the only access point to tunnel 2 of the high pressure pipe.

It first rises with a slope of 10,4 [%] on a length of 457 [m] and then has a flat section with a length of 50 [m]. After this flat section it merges into the lower reservoir.

The tunnel has a constant cross section over its whole length, therefore the volume can also be calculated by multiplying the total length with the cross sectional area.

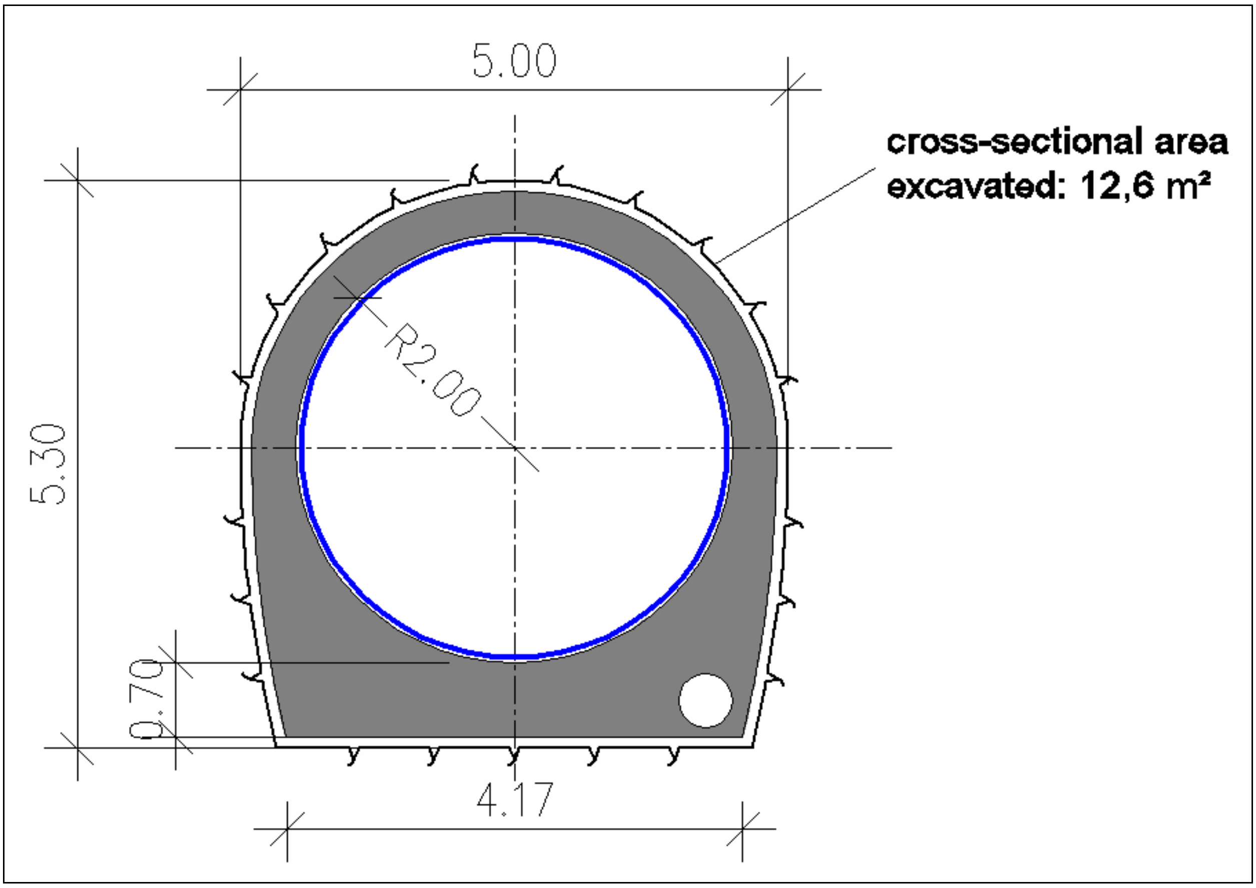

Figure 32: Cross section of the low pressure pipe

3.6.12 Lower reservoir

The lower reservoir is also located on the company grounds of Bernegger. It is built out of an old gravel pit which just has to be extended to the dimensions that are necessary for the project. The material that is excavated from this basin is either grit, gravel or conglomerate. Therefore the mining procedure can vary from blasting to just loading the material with a wheel loader.

The amount of excavated material can be calculated by creating a digital terrain model of the basin and comparing it with the digital terrain model of the company grounds. Due to the continuous surveying of the company ground for various projects, the terrain model is very accurate and extensive.

The total volume of the lower reservoir can be numbered at 1.770.000 [m³]. As already mentioned the basin is just an extension of an existing gravel pit and therefore the amount that has to be excavated is only 1.080.000 [m³].

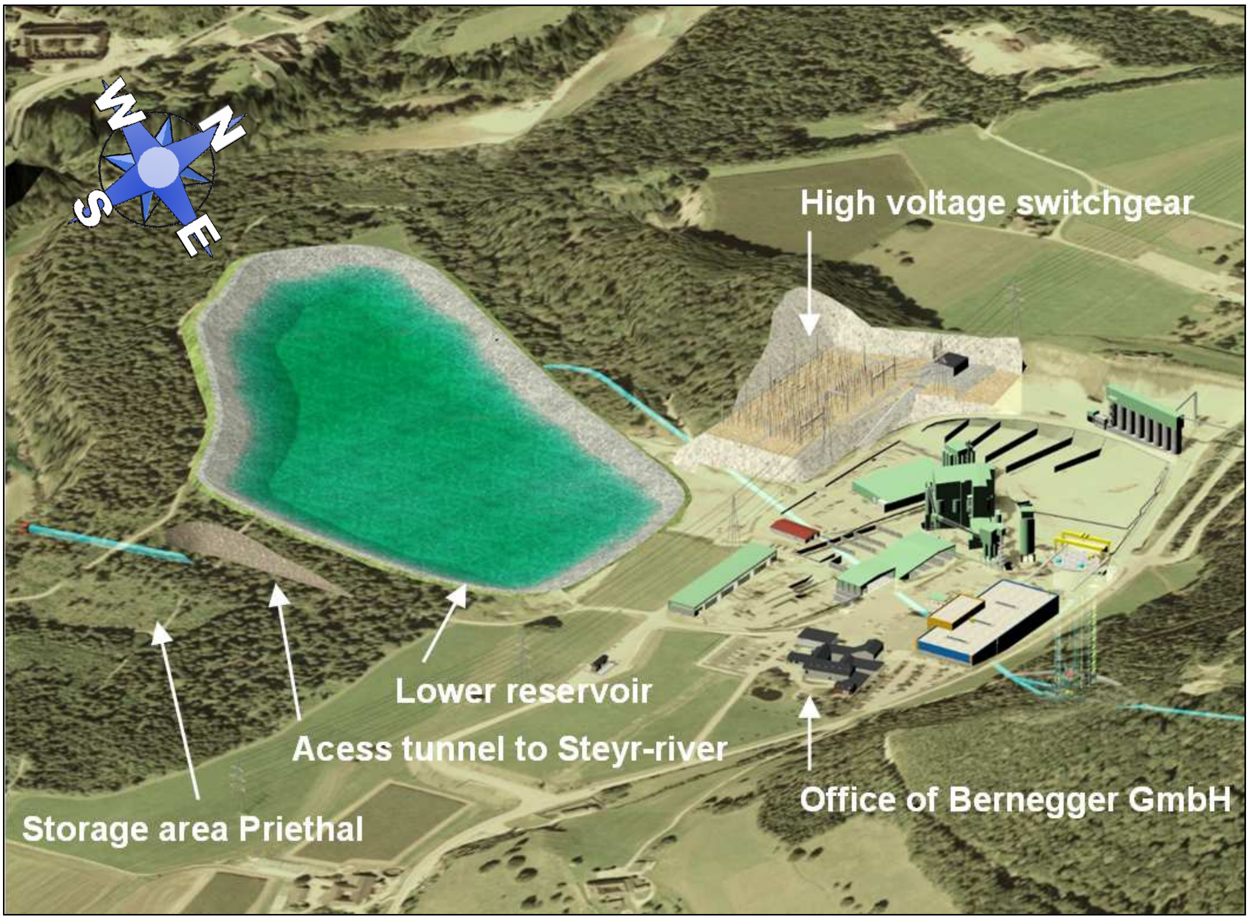

Figure 33: Digital terrain model of the company grounds

3.6.13 Tunnel to the Steyr-river

The tunnel to the Steyr-river is not an essential part for the construction phase of the project. It is needed for the first filling of the lower reservoir with water.

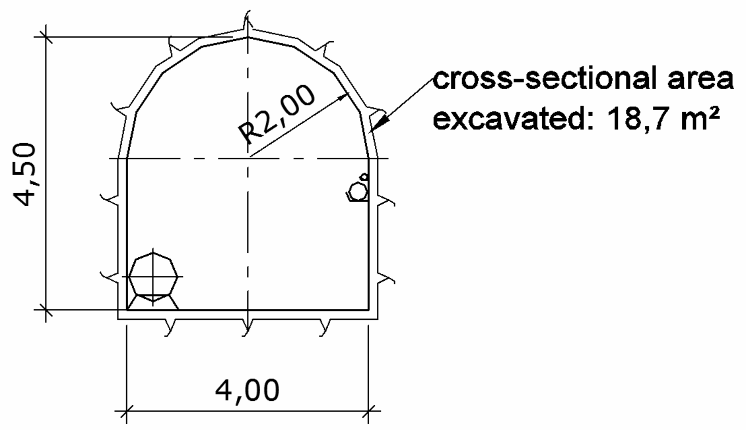

Figure 34: Cross section of the tunnel to the Steyr-river

The length of the tunnel is 280 [m] and the volume can also be easily calculated by multiplication of the length with the cross sectional area.

3.6.14 High voltage switchgear

As the name already implies, the high voltage switchgear is an area on which the high voltage equipment is situated. The area where the equipment is located should be a flat area and should have the dimensions of 155 times 73 [m]. Due to the big dimensions and due to the fact, that this area has to be flat, there are also big amounts of material that have to be excavated to prepare the flat area which is required.

The area is located near the lower reservoir and it was minded, that as much excavated material as possible is refilled into lower points. The amount of excavated material in this area is also calculated by the use of a digital terrain model which you can see in Figure 33.

4 Outcome of excavation analysis

In this chapter the is analysis is summarized and displayed in detail. The gained data serves as basis for the further calculations that are made within this diploma thesis.

4.1 Summarization of excavation works

All of the single construction stages of the project can be connected to units. These units represent tunnel portals where the material is transported to the surface and also where the concrete, shotcrete and steel, which is needed in the different areas, is transported into the mountain.

4.1.1 Unit Pfaffenboden

In this area all the parts of the upper basin are connected to one main area called "Pfaffenboden". This area includes the following parts which are described in Chapter 3.6:

- Access tunnel to upper basin
- Transportation tunnel to upper basin
- Upper basin
- Access tunnel to the machine chamber
- Machine chamber
- Ventilation tunnel to machine chamber
- Ventilation tunnel for the surge tank
- High pressure pipe
- Tunnel 1

All the material of these parts is first either transported to the storage area 2 "Pfaffenboden" or to the storage area 1 "Portal Elfi-Tunnel".

4.1.2 Unit Elfi-Tunnel

This unit includes the following areas:

- High pressure pipe

- Shaft 1
- Tunnel 2
- Transportation tunnel to “Elfi tunnel”
- Powerhouse shaft

All of the excavated material in this area is transported via the transportation tunnel to "Elfi-tunnel". From the mouth of the transportation tunnel the material has to be transported down the Elfi-tunnel.

It is also part of this diploma thesis to evaluate the best solution of how to transport the material from the mouth hole down to the factory.

4.1.3 Unit powerhouse shaft

All of the material that comes out of the shaft can be seen as one unit where the material is transported to the top of the shaft via a mobile crane and stored there in a daily storage area.

4.1.4 Unit lower reservoir

The lower reservoir has one storage area where the material is transported to. The different parts of this unit are:

- High pressure pipe
- Shaft 2
- Tunnel 3
- Lower reservoir

During the construction phase the low pressure pipe serves as transportation tunnel. All the material that is excavated in the high pressure pipe and also the material which is excavated in the low pressure pipe is transported to the mouth of the low pressure pipe, which is situated in the lower reservoir. From that point the material is transported to the storage area, like the material in the lower reservoir.

4.1.5 Unit low pressure pipe

The lower water pipe has its tunnel mouth located directly in the lower reservoir. Therefore the excavated material of the lower water pipe is also transported via the lower reservoir to the storage area 3 "Priethal".

- Low pressure pipe

4.1.6 Unit tunnel to Steyr river

This unit also consists of only one part which is the tunnel to the steyr river. This tunnel is needed for getting water out of the Steyr for the first fill of the lower reservoir. The detailed description of this part can be found in:

- Tunnel to the Steyr-river

4.1.7 Unit high voltage switchgear

The material that is excavated during the construction process of the high voltage switchgear is also brought to the storage area 3 "Priethal". Within this unit there has to be minded, that the material is not the same quality than the other material which is excavated during the construction process of Energiespeicher Bernegger. Therefore the material has to be treaded separately. For this reason this unit is not included into the sum up of the material. The unit consists of only one part which is:

- High voltage switchgear

Time schedule and interconnection of all parts

The time schedule which can be found on the added CD is extremely dependent on the interconnection of the single parts. Also the excavation procedure influences the time schedule to a high degree.

The machine chamber for example can only be excavated after the transportation tunnel to the machine chamber is completed. And shaft 1 of the high pressure pipe can only be excavated when the machine chamber is already excavated and when the transportation tunnel "Elfi" and tunnel 2 of the high pressure pipe are already completed.

4.2 Excavation amounts

The amount of excavated material is summed up and displayed in Table 5. Also the percentage of excavated material within the single units in comparison to the total excavated material is displayed. For better visualization, the single units are colored in a certain way. These specific colors are used in the table for the amounts of excavated material, in the diagram where the excavated material is displayed and also in the sankey diagram. The sum of excavated material can be seen as number that is given through the dimensions of the project.

OUTPUT ESB				
		Excavation [m³]	Percentage [%]	Excavation [t]
4.1.1	PFAFFENBOEN	1.742.250	64,4	4.765.505
4.1.2	ELFI TUNNEL	22.302	0,8	62.444
4.1.3	POWERHOUSE SHAFT	97.586	3,1	229.720
4.1.4	LOWER RESERVOIR	1.017.999	30,3	2.239.598
4.1.5	LOWER WATER PIPE	20.288	0,8	56.807
4.1.6	STEYR TUNNEL	21.601	0,7	48.981
		2.922.026	100	7.403.055

Table 5: Amount of excavated material

In Figure 35 the amount of excavated material in a certain timeframe during the construction phase is displayed for every unit of the project. This diagram is the result of combining the amount of excavated material with the time schedule of the project. The different colors that are used in the diagram represent the different units where the material is excavated. These units are described in this chapter, and the total amount of excavated material is displayed in Table 5.

With the use of the information that is displayed in this diagram, the concepts for the disposition of the material can be elaborated, because the excavated material is given for every single timeframe of the whole project. This fact is essential for the further proceeding, especially for the calculation of the mass balance.

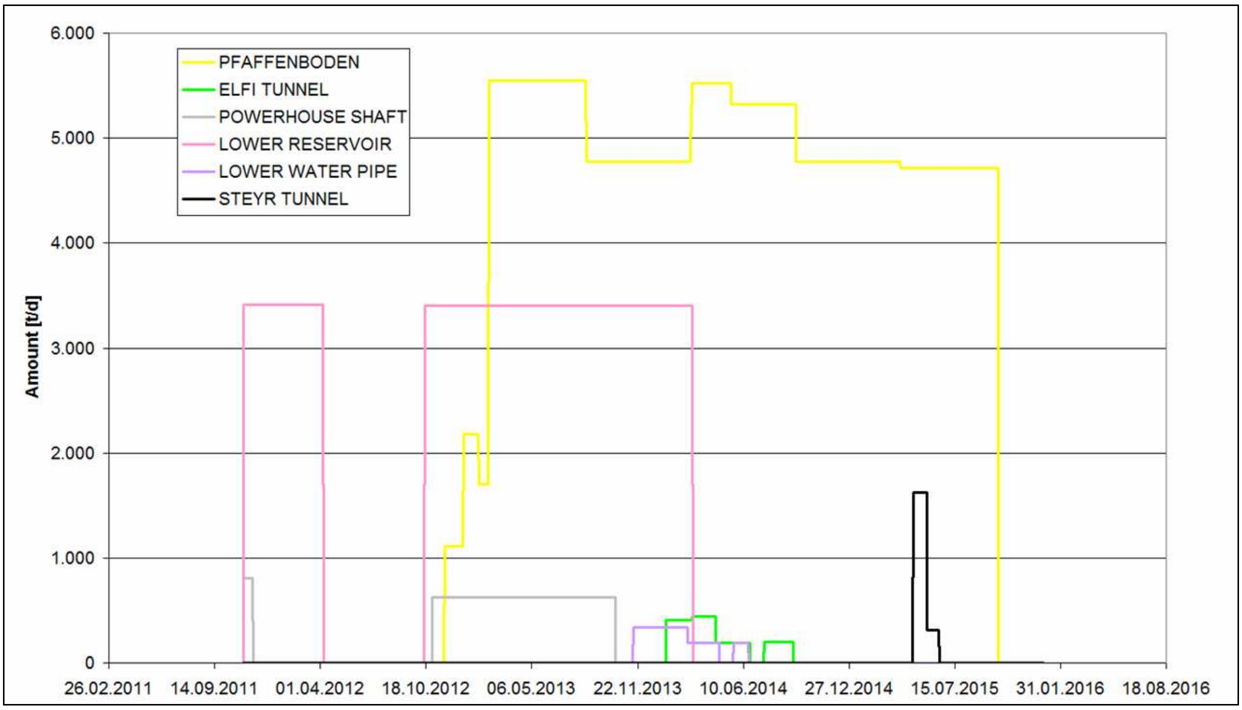

Figure 35: Excavation amounts during the construction phase

4.3 Material flow

The material flow within this project can be displayed with the use of a sankey diagram. The sankey diagram in Figure 36 shows the material flow in the project by making the assumption that all the material is distributed to the different production sites of Bernegger until the whole amount of excavated material is consumed. Like it is done in every sankey diagram the total amount of excavated material is equal to the total amount of consumed material. The total amount is 100 [%] and the incoming material flow is split up in the different units like worked out in the chapter above. The arrows for these units have a proportional size to the transported amount of material. The same procedure is used to display the material consumption of the different production sites of Bernegger.

In the assumption that is made in this case it would take 9,4 years until all the material is consumed and daily business can start again on the production sites. This diagram also represents the minimal time for processing all the resources that are gained during the construction process of Energiespeicher Bernegger.

In later steps of the diploma thesis, the allocation of excavated material will shift due to the optimization of logistic processes.

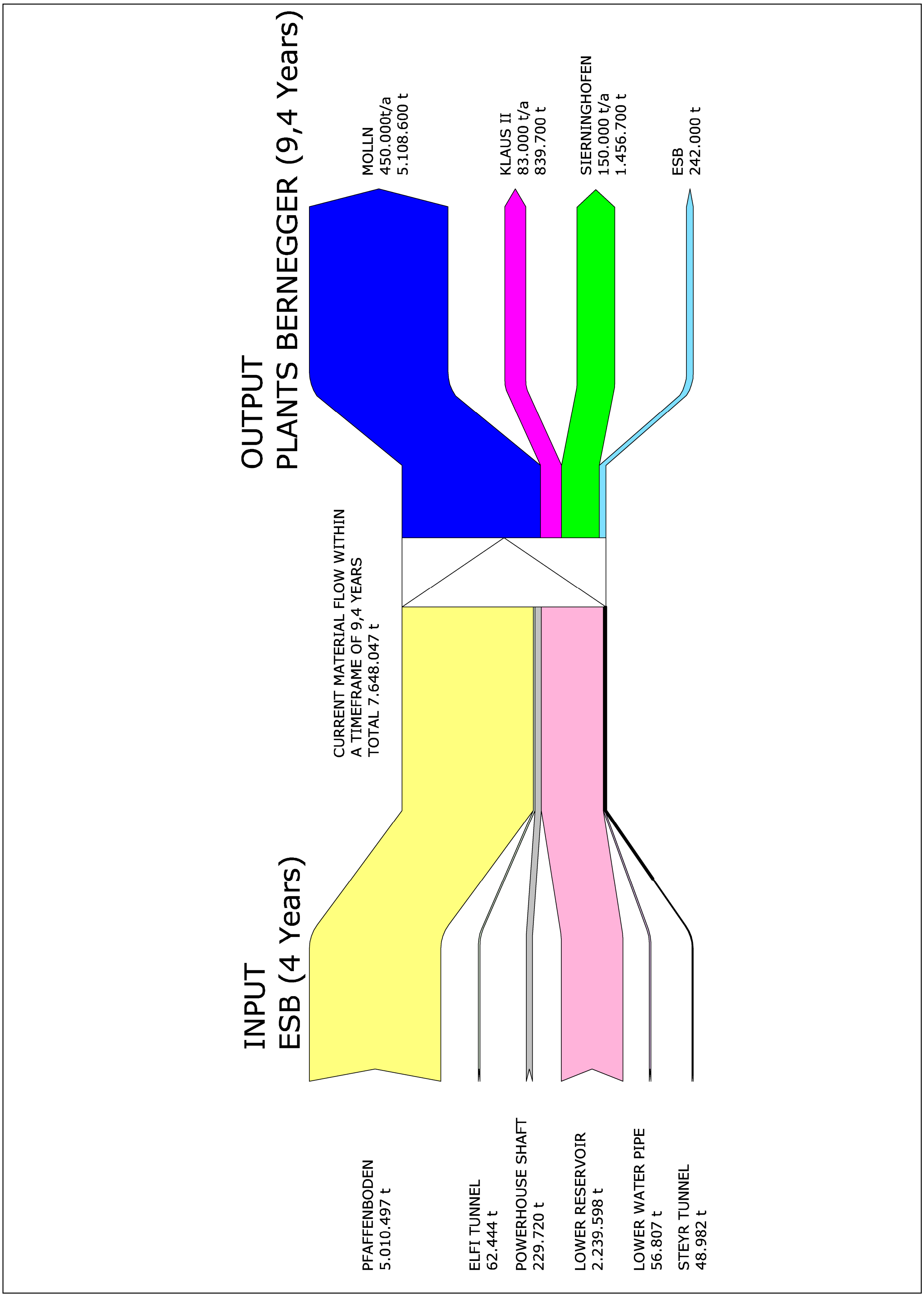

Figure 36: Sankey diagram of the excavated material

5 Mass balance for storage areas

To display the development of the different storage areas it is essential to make a mass balance for every storage area.

The mode for calculating this mass balance is as follows:

$$M_{Store(t)} = M_{Store(t-1)} + M_{Incoming} - M_{Outgoing}$$

$M_{Store(t)}$..........Stored mass of actual day

$M_{Store(t-1)}$........Stored mass of day before

$M_{Incoming}$........Excavated material that is transported to the storage area

$M_{Outgoing}$........Stored material that is transported to another storage area or to a production site

Due to the exact calculation of the amount of excavated material and the time span in which the material is excavated, the period for this calculation can be set to one day. The mode of calculation and the low time period is of high advantage, because the amount of incoming and outgoing material could be changed on a daily basis. It is also imaginable to use this excel spreadsheet during construction works to supervise the development of the single storage areas.

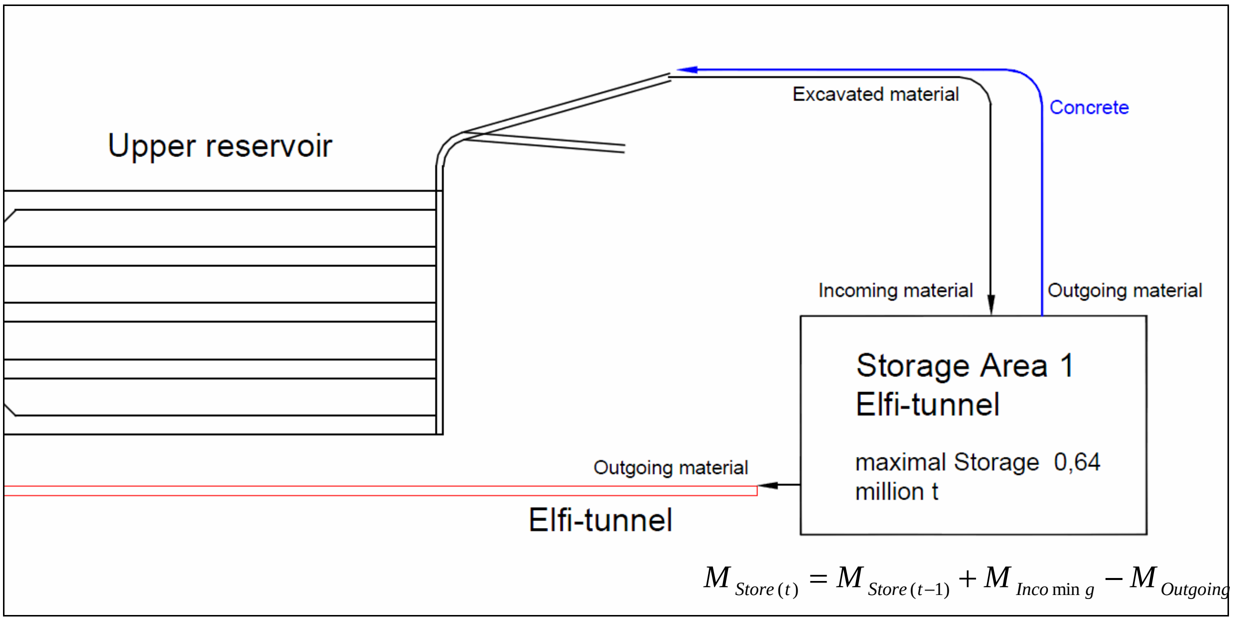

Figure 37: Mass balance for storage area 1

The single storage areas are also interconnected with each other. The own requirements for construction of the project are also observed as are the different production sites and the material consumption of this sites. In "Appendix D: Flow sheet" the interconnections of all the parts and also of all the different storage areas are exactly displayed.

The excel spreadsheet where all of the storage areas and the production sites are connected can easily be adapted to a change in excavated material due to a change of the project size. Also new storage areas can easily be implemented into the spreadsheet.

For entering the amounts and the timeframe in which the material should be transported to the different storage areas, a mask was created for easy handling of the excel spreadsheet. The mask of the excel spreadsheet is displayed in Table 6.

Energiespeicher Bernegger

Variant: All the material is transported immediately to Sierninghofen

Consumption in the plants of Bernegger					
Site	Consumption [t/a]	Consumption/day at 365 days a year [d/a]	Consumption/day at 250 days a year [d/a]	Start	End
Molln	450.000	1.233	1800	22.11.2012	02.03.2017
Klaus II	83.000	227	332	01.04.2012	14.03.2026
Sierninghofen	150.000	411	600	01.03.2013	20.10.2027

Consumption at the construction works Energiespeicher Bernegger					
Area	Total consumption [t]	Consumption/day at 365 days a year [d/a]		Start	End
Pfaffenboden	63.819	57		22.11.2012	25.12.2015
Lower reservoir	62.195	57		30.10.2012	30.10.2015

Transportation				
Transportation	Transportation/day at 365 days a year [d/a]	Transportation/day at 250 days a year [d/a]	Start	End
Priethal --> Klaus	2.360	3.446	01.06.2012	05.10.2013
Pfaffenboden --> Klaus	0	0	05.03.2014	05.10.2015
Priethal --> Sierninghofen	310	453	07.11.2011	05.08.2013
Pfaffenboden --> Sierninghofen	2.110	3.081	01.03.2013	05.10.2015

Storage areas		
Designation	Storage capacity [t]	Maximal stored volume [t]
Storage area 1 Elfi-tunnel	640.812	639.994
Storage area 2 Pfaffenboden	2.297.700	0
Storage area 3 Priethal	1.230.322	1.232.232
Storage area Klaus II	964.982	1.033.237
Storage area Sierninghofen	2.489.138	1.807.851

Table 6: Mask for calculating the mass balance

6 Concepts for the disposition of the excavated material

As seen in Figure 38 the project can roughly be split up into three sub areas. Different logistic concepts are worked out for these different sub areas. The reason for working out the logistic concept for this sub areas can be found in the reason, that the material of the whole project is transported to the surface in this three areas. A cost model is worked out for the sub areas and the involved concepts. The concepts are then evaluated by the use of value benefit analysis. Therefore, a recommendation for action can be given for every sub area. An overall concept can be derived from these partial solutions. For that reason there are no overall concepts which have to be evaluated.

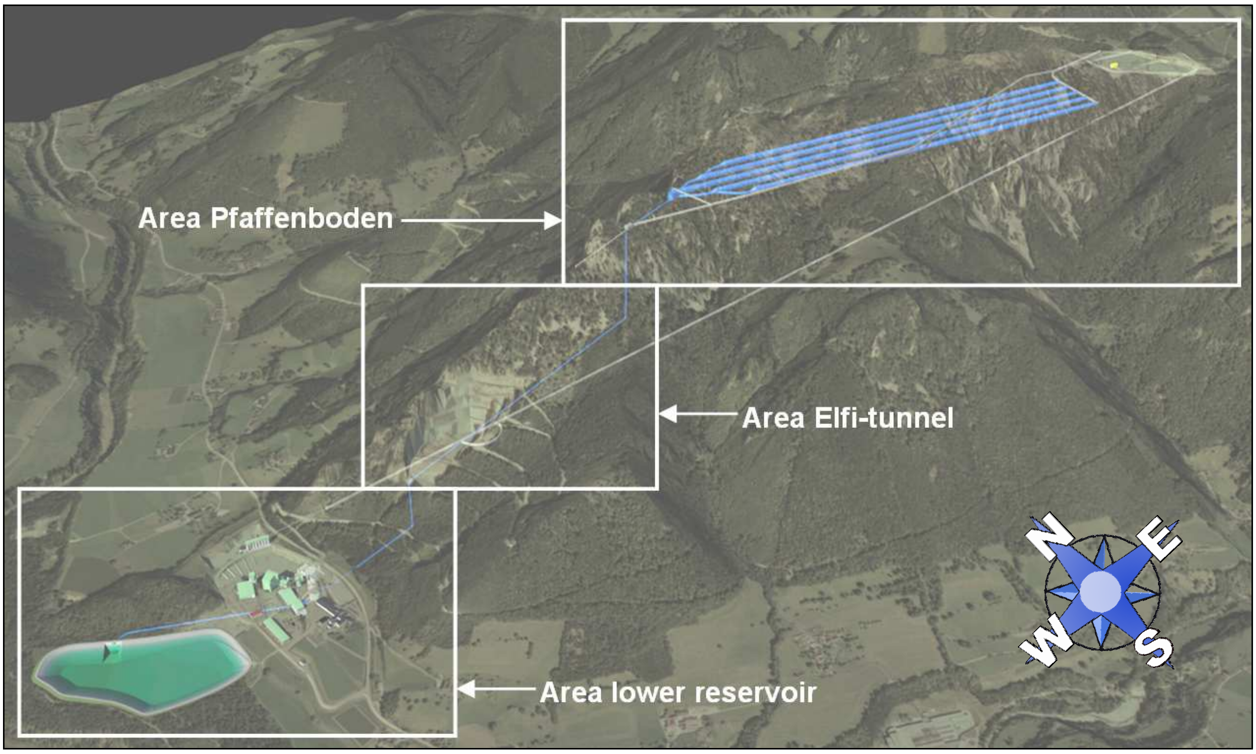

Figure 38: Sub areas of the project

6.1 Theory to value benefit analysis

The procedure of value benefit analysis was invented by Zangemeister. The theoretical part of value benefit analysis follows the rules and instructions of his book.

The procedure of value benefit analysis has the goal of evaluating different variants that cannot be displayed in figures. Therefore this method is a subjective evaluation method that has to be based on different criteria that have to be summed up to a decision. This decision finding process can for example be set up for deciding between various products, various persons, various solution approaches and so on. The value benefit analysis can be separated into the following seven steps.[57]

1) Elaborating of different solution approaches

In this first step some different possibilities for reaching a goal are listed. These different possibilities can be on the one hand an elaboration of different solution approaches for reaching a defined goal. It can also be the picking of different candidates if the value benefit analysis is used for deciding for a candidate for a certain job.

2) Formulating of criterions:

These criterions describe a certain goal that is aimed to be reached.

The criteria for evaluating the different possibilities have to be very detailed to ensure that the evaluating process can be done by every person.

Criteria that belong to one category have to be subordinated to this special category.

The criterions can for example be separated into the following categorys:

- **Sales goals**

  Amount of sold units

  Organisation of sales

  Price

- **Research and development goals**

  Existing know-how

  To be ahead of the competitors

  New patents

- **Production goals**

  Using of existing capacity

[57] Zangemeister (1971), pp. 159

Possibilities for getting raw material

- **Financing goals**

  Necessary assets

  Possibilities of gaining assets

- **Technical project goals**

  Processing speed

  Flexibility of the machine

  Maintenance intervals

  Usability

3) Preselection by the use of knock out criterions:

This preselection is used to knock out all the possible variants which do not fulfill one of the picked criterions.

4) Emphasis of the different criterions:

All the different criterions are not equal important for reaching a the defined goals. Therefore the emphasis of the different criterions has to be evaluated. There are some possibilities for evaluating the emphasis of these criterions like displayed below.

- **Pair-wise comparison**

  This method uses a table where all the different criterions are listed. An example for such a table can be seen in Figure 42. The different criterions are then compared with each other. The procedure for this type of evaluation for the emphasis of the criterions is used in this diploma thesis and is explained in detail in the chapter 6.2.3-Value benefit analysis

- **Directly evaluating the emphasis**

  In this procedure, the importance of the single criterions is defined by the person that creates the value benefit analysis and directly entered into the table of the analysis. The advantage of this procedure is, that the mathematical effort is reduced to a minimum. On the other hand this method is very subjective. Therefore the advice is given to use the method of pair-wise comparison

5) Rating of the different criterions:

Every criterion is rated by means of how much a certain variant or product fulfills this criterion. The rating system could for example be a number from 1 to 10. Giving the number one means, that the product or variant is very weak in fulfilling a certain criterion. If the number 10 is given for a certain criterion means, that the product fulfills the criterion very good.

6) Calculation of the result:

For the calculation of the result for a value benefit analysis a table has to be set up that looks like the example below.

7) Interpreting of the result:

Evaluating how a change of the importance of a criteria could change the whole result.

Procedure for calculating a result of a value benefit analyses

The emphasis of the different criterions can be evaluated with different methods, like displayed in Table 7. The rating of how much a certain product or variant fulfills a criterion can now be defined by the person or group that wants to do the value benefit analysis. The rating of a certain criterion is then multiplied with the emphasis of this criterion. By adding all this numbers, a result for every product or variant can then be calculated. This number gives an overview of why a certain product, person, or variant for a solution should be preferred.

Emphasis of the different criterions

Rating of how much a product fulfills the criterion

Emphasis*Rating

Criteria	Emphasis	Product A	A*E	Product B	B*E
Criterion 1	19	2	38	5	190
Criterion 2	44	5	220	1	44
Criterion 3	31	3	93	2	62
Criterion 4	6	2	12	3	18
Sum	100		**363**		314

Result of the calculation

Table 7: Procedure for calculating a value benefit analysis

6.2 Logistic concepts for the area Elfi tunnel

The material in this area comes out of the transportation tunnel, which has its tunnel mouth in the existing Elfi tunnel.

There are two possibilities for how to process the material. On the one hand the material could be transported down to the company grounds by a dump truck. On the other hand the material could be crushed in the Elfi-tunnel and then be transported down to the company grounds by the use of the existing belt conveyor, which is integrated into the Elfi tunnel.

6.2.1 Transportation via the belt conveyor in the Elfi-tunnel

If the material was transported with the belt conveyor it has to be crushed before it is applied to the conveyor. Therefore a stone crusher is needed for processing the material. A crusher which is available and can easily be set up for these purposes is the

"Rubble Master RM100". It has to be situated on the intersection of the transportation tunnel and the existing Elfi-tunnel.

The material that is transported out of the transportation tunnel could be applied directly to the stone crusher and then to the conveyor. The storage space could be a bit smaller for that reason.

Advantage of this variant:

- Material is applied into the production process of Bernegger and can be separated to different grain sizes
- Temporarily storage space could be smaller
- Saving the cost of transportation
- Generating energy by the transportation via the belt conveyor

Disadvantage of this variant:

- Stone crusher has to be provided by Bernegger GmbH
- "Parking lot" for stone crusher has to be built
- The traffic in the Elfi-tunnel is affected by the stone crusher during the crushing process

Figure 39 gives an overview of how the intersection between the transportation tunnel and the existing Elfi-tunnel could look like. Also the stone crusher and the needed parking lot and its dimensions are displayed in this figure.

The cost for this variant are estimated by an expert of Bernegger GmbH and can be numbered with about 30.000 [€]. These are the costs which are needed for building the parking lot for the stone crusher. The costs for running the stone crusher don’t have to be calculated, because the stone crusher is needed in both variants. The evaluation of the different variant is only a comparison of extra costs for a certain variant. Therefore the costs for the different variants don't have to be calculated in absolute numbers.

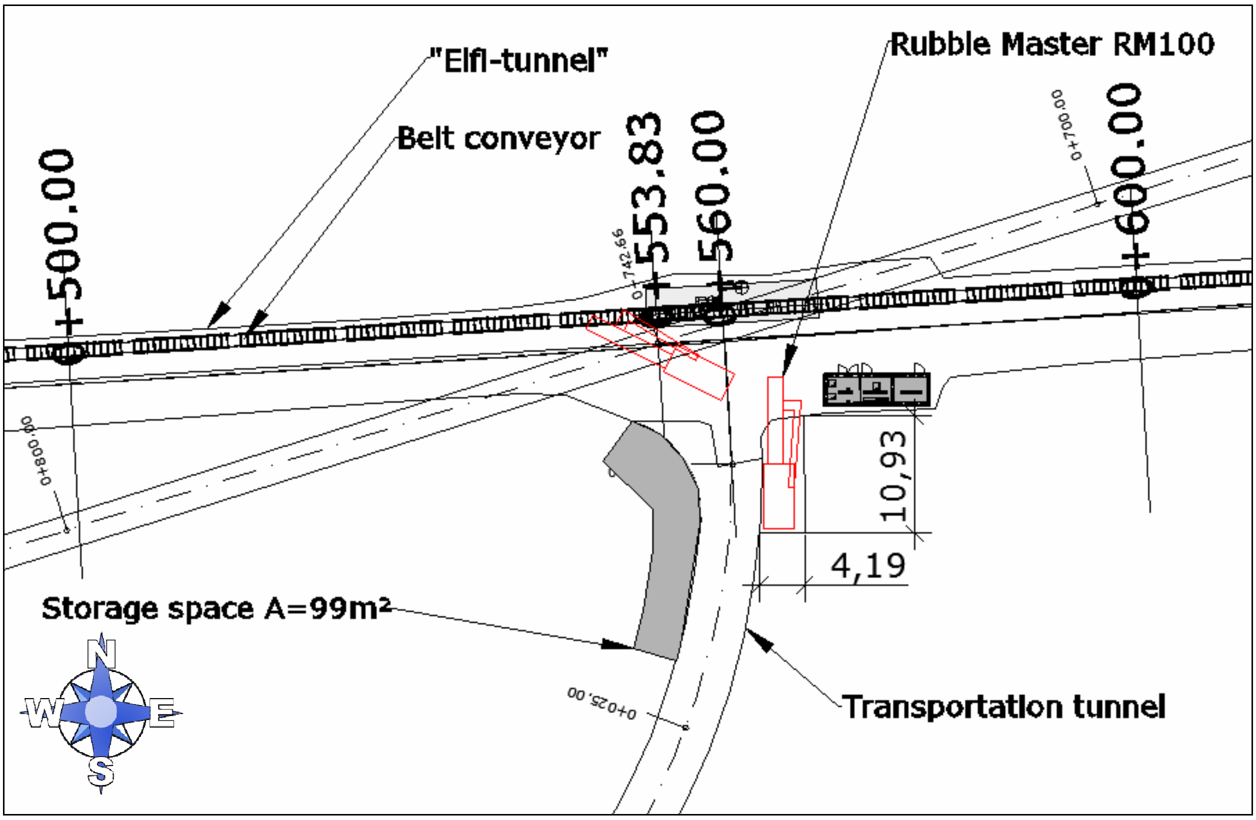

Figure 39: Intersection Elfi-tunnel and transportation tunnel

6.2.2 Transportation with a dumper

For transportation with a dumper, the excavated material has to be transported to the storage space that is displayed in Figure 39 by a wheel loader and temporarily stored there. From there the material has to be loaded to a dumper. The dumper transports the material to the company grounds and unloads it to a daily storage. Down at the company grounds the material has to be picked again and applied to the stone crusher. After crushing the material it can be stored on the company grounds and then sold to the end customers.

With this variant the traffic through the transportation tunnel will be enourmous.

In Figure 40 an overview for the calculation of the cost within this variant is given.

Advantage of this variant:

- No stone crushing machine is needed
- No "parking lot" for stone crushing machine is needed

Disadvantage of this variant:

- Dumper is needed
- Cost for dump truck
- Material has to be manipulated several times
- Material has to be crushed at the company grounds
- Material cannot be separated to different grain diameters

Dump Truck Volvo A30

From: Temporarily storage space
To: Plant grounds in Molln

Listprice:	€ 100,00		
Internal cost:	€ 80,00		
Capacity of a dump truck:	27,00 to		
	Distance	**Speed**	**Time**
Transportation	1.146 m	10,00 km/h	6,88 min
Return	1.146 m	10,00 km/h	6,88 min
Loading/Unloading	15,00 min		
Total timeconsumption:	**28,75 min**		
Cost of the dump truck:	€ 38,34		
Cost per ton:	**€ 1,42**		
Transported amount	62.444 to		
Cost for transportation	**€ 88.661,23**		

Figure 40: Cost calculation for transport Elfi-tunnel to company grounds

6.2.3 Value benefit analysis for the area Elfi-tunnel

The two possible variants can be compared by the use of a value benefit analysis like it is done in Table 8. There are four different criterions as seen in Figure 41 for evaluating the two variants. These criterions are picked for evaluating the advantages and disadvantages of the different project possibilities. The rating of the different criterions is defined in Figure 41. This scale gives an overview of how much the different variants fulfill these criterions. Several different experts of Bernegger GmbH where interviewed to define the certain ratings.

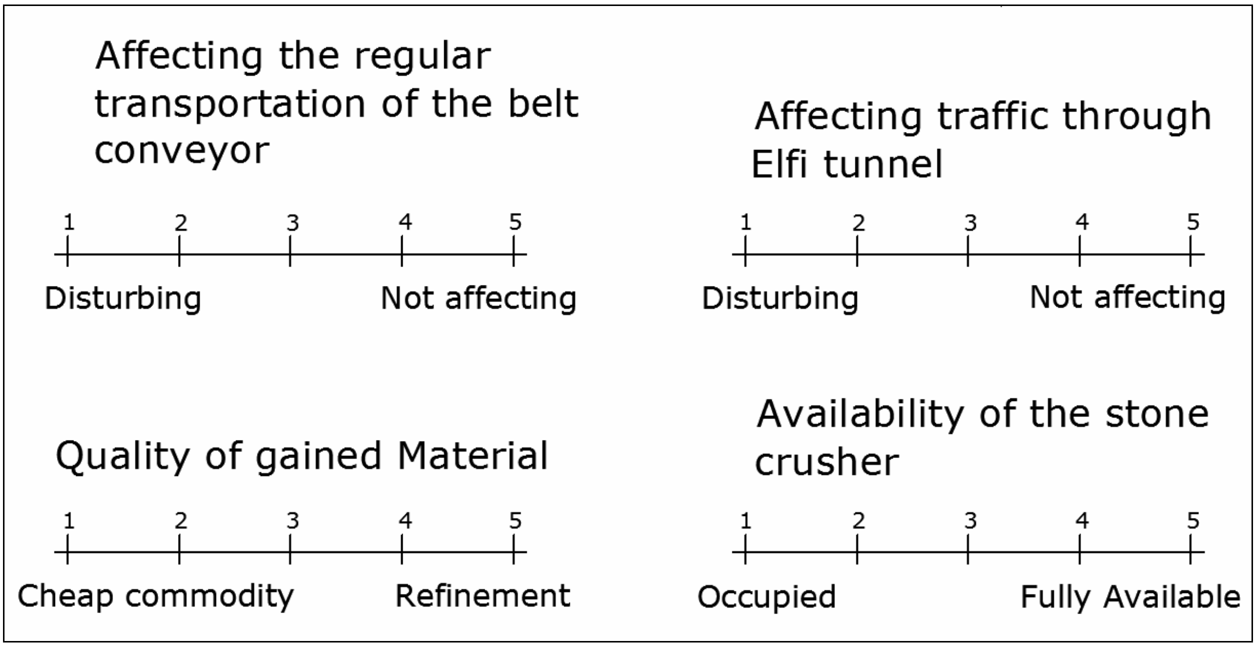

Figure 41: Criterions for value benefit analysis

Affecting the regular transportation of the belt conveyor

When material is applied to the belt conveyor in the middle of the tunnel, it has to be noted, that the amount of material which can be applied on the upper portal of the Elfi-tunnel has to be reduced. Since the application of material in the middle of the tunnel would be very intermittent, this fact can be seen as bad influence.

Quality of gained material

When the material is applied to the belt conveyor, it is transported to the separation plant in Molln. The gained material can then be sold in the sort clean grain sizes and is therefore a high value commodity. When the material is transported via dump trucks, it is crushed on the company grounds, but cannot be separated. Therefore it can only be sold as low quality rubble.

Affecting traffic through Elfi tunnel

It can be seen as fact, that during the construction phase of Energiespeicher Bernegger, there will be a lot of traffic through the Elfi tunnel. Therefore it is very important that this traffic is affected by other activities as little as possible.

	Affecting the regular transportation of the belt conveyor	Quality of gained material	Affecting of traffic through Elfi tunnel	Availability of stone crusher	∑	
Affecting the regular transportation of the belt conveyor	1	0	0	2	3	18,8%
Quality of gained material	2	1	2	2	7	43,8%
Affecting of traffic through Elfi tunnel	2	0	1	2	5	31,3%
Availability of stone crusher	0	0	0	1	1	6,3%
				∑	**16**	**100%**

2 Points: row criterion more important than column criterion
1 Points: row criterion as important as column criterion
0 Points: row criterion less important than column criterion

Figure 42: Pairwise comparison of the criterions

Availability of stone crusher

The stone crusher is needed for crushing the excavated material into processable pieces. The two possible variants for transportation of the material offer two possible variants for setting the stone crusher. On the one hand the stone crusher could be set up on the company grounds. Here it is also available for crushing other material which is excavated somewhere in the project area. On the other hand, by transportation with the belt conveyor, the stone crusher would have to be set up in the Elfi tunnel. In this variant it would not be available for other activities.

For evaluating the emphasis of the different criterions a pair-wise comparison was made. If the row criterion is more important than the column criterion, it gets two points. If the row criterion is as important as the column criterion it gets one point. And if the row criterion is less important than the column criterion, it gets zero points. With this distribution of points it is clear, that the yellow marked diagonal has one point, because the row and the column criterions are equal. Now the right upper corner is filled out by an expert of the company. The left lower corner of the table has then just to be extended.

The numbers of the emphasis and the scaling of the criterions have just to be put into the following table and then be calculated.

Criteria	Emphasis	Variant A Belt conveyor	A*E	Variant B Dump truck	B*E
Affecting the regular transportation of the belt conveyor	19	2	38	5	190
Quality of gained material	44	5	220	1	44
Affecting traffic through Elfi tunnel	31	3	93	2	62
Need for machines	6	2	12	3	18
Sum	100		**363**		314

Table 8: Value benefit analysis for the area "Elfi tunnel"

The result of the value benefit analysis is that it would be of higher value for the company to transport the material with the use of the belt conveyor.

6.2.4 Recommendation for action for the area Elfi-tunnel

To give a recommendation for the procedure of the excavated material, it is necessary to mind the cost of the single variants. The costs for transportation with the dump truck are calculated in Figure 40.

The costs for transportation with the belt conveyor can be estimated with about 30.000€ for building a parking lot for the stone crusher. There are no transportation costs, because the belt conveyor produces energy, and therefore generates money, which can be used for maintenance of the belt conveyor.

The cost for the stone crusher can also be neglected in this comparison, because it is needed in both variants.

In Figure 43 the two variants are opposed in terms of benefit for the company and in terms of cost.

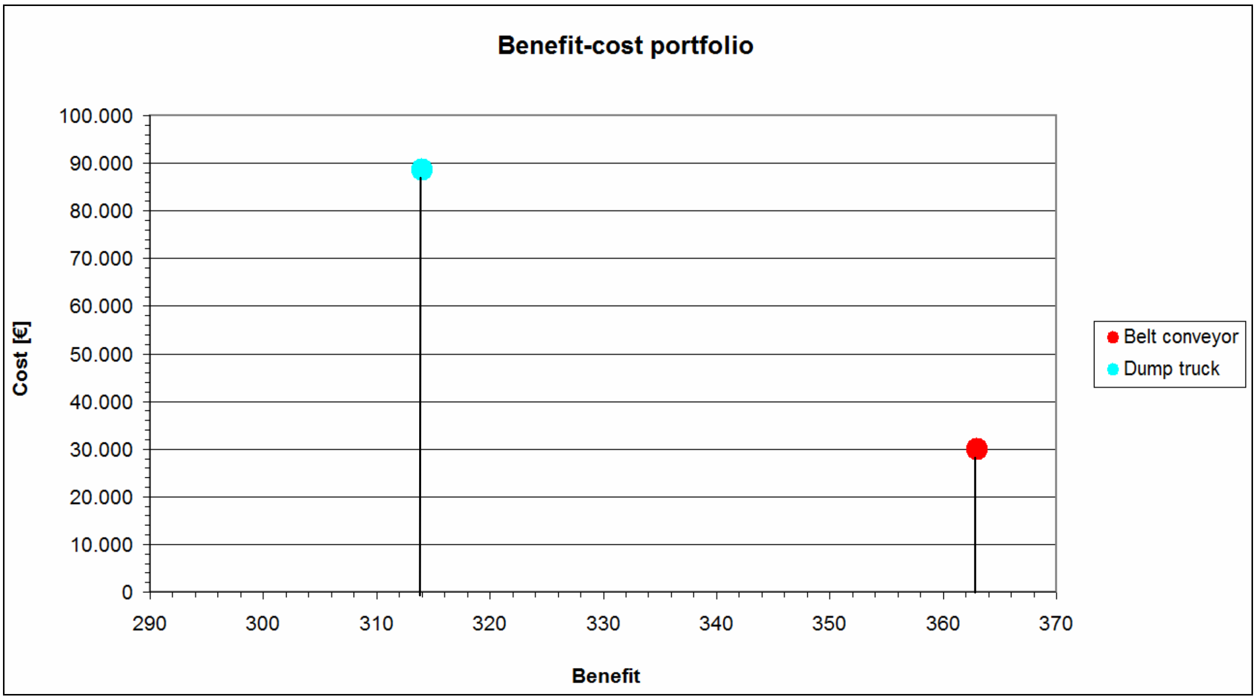

Figure 43: Portfolio of benefit and costs

By including all facts it is clear, that the better variant for proceeding the material would be to transport it via the belt conveyor. This variant has advantage in benefit for the company, and is also cheaper than the transportation with dump trucks.

6.3 Material concept for Pfaffenboden

In the area Pfaffenboden a total amount of 4 million tons is excavated. Due to this big amount of excavated material it is very important to have a logistic concept that is detailed and prepared very well.

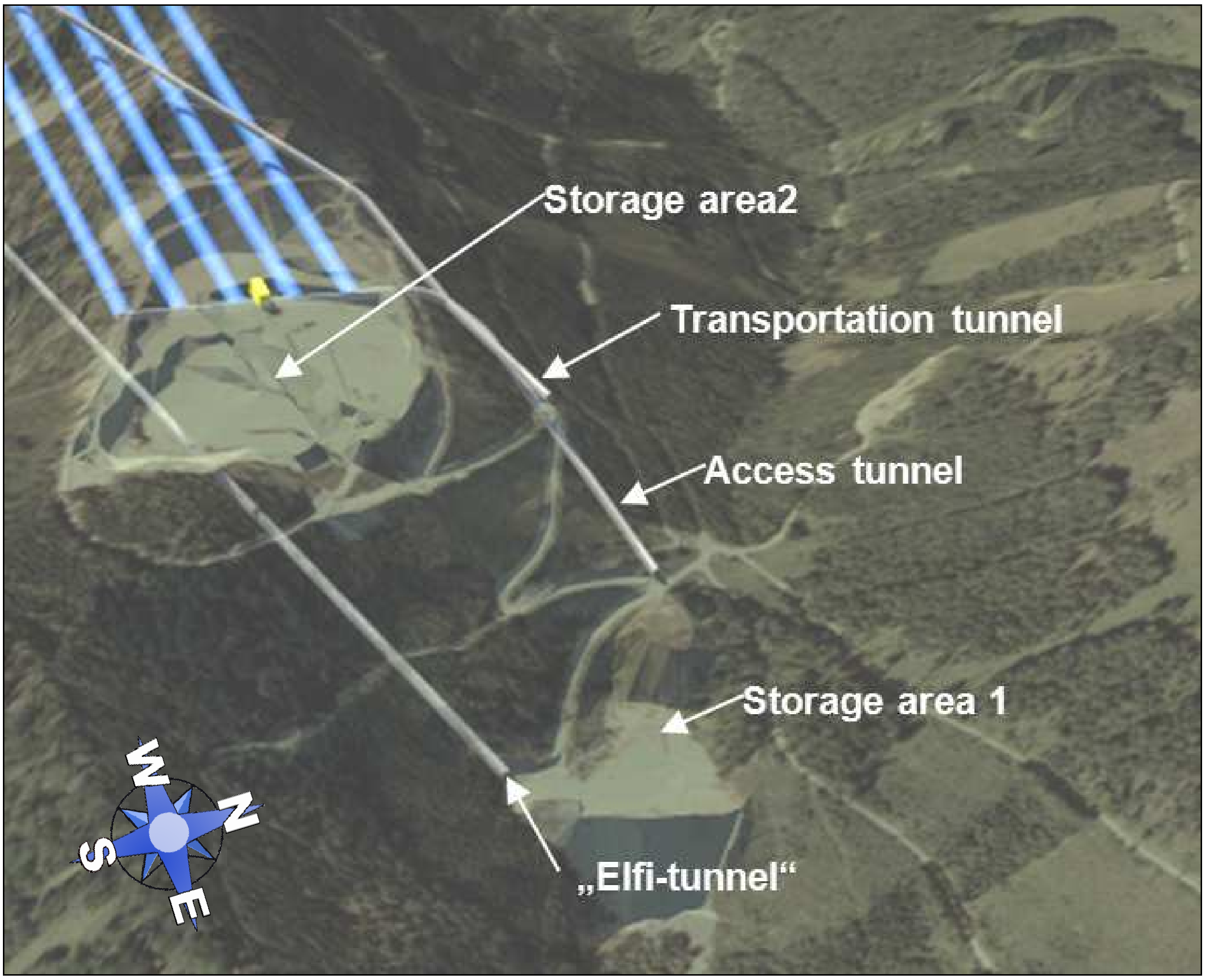

Figure 44: Project area Pfaffenboden

The material that is excavated from the unit Pfaffenboden is transported to the surface via dump trucks. There are some different possibilities for the disposal of the material.

The possible storage areas to deposit the material are storage area 1 and storage area 2 which are located in the area Pfaffenboden. It is also possible to transport the material to the storage area Sierninghofen. The descriptions of the different storage spaces can be found in chapter 3.3 - Storage areas for the excavated material.

The main part of the material should be transported to the surface through the access tunnel of the upper reservoir and then brought to storage space 1. After finishing the construction works at Energiespeicher Bernegger the material could be taken by a wheel loader and be applied to the belt conveyor that transports the material down to the plant in Molln.

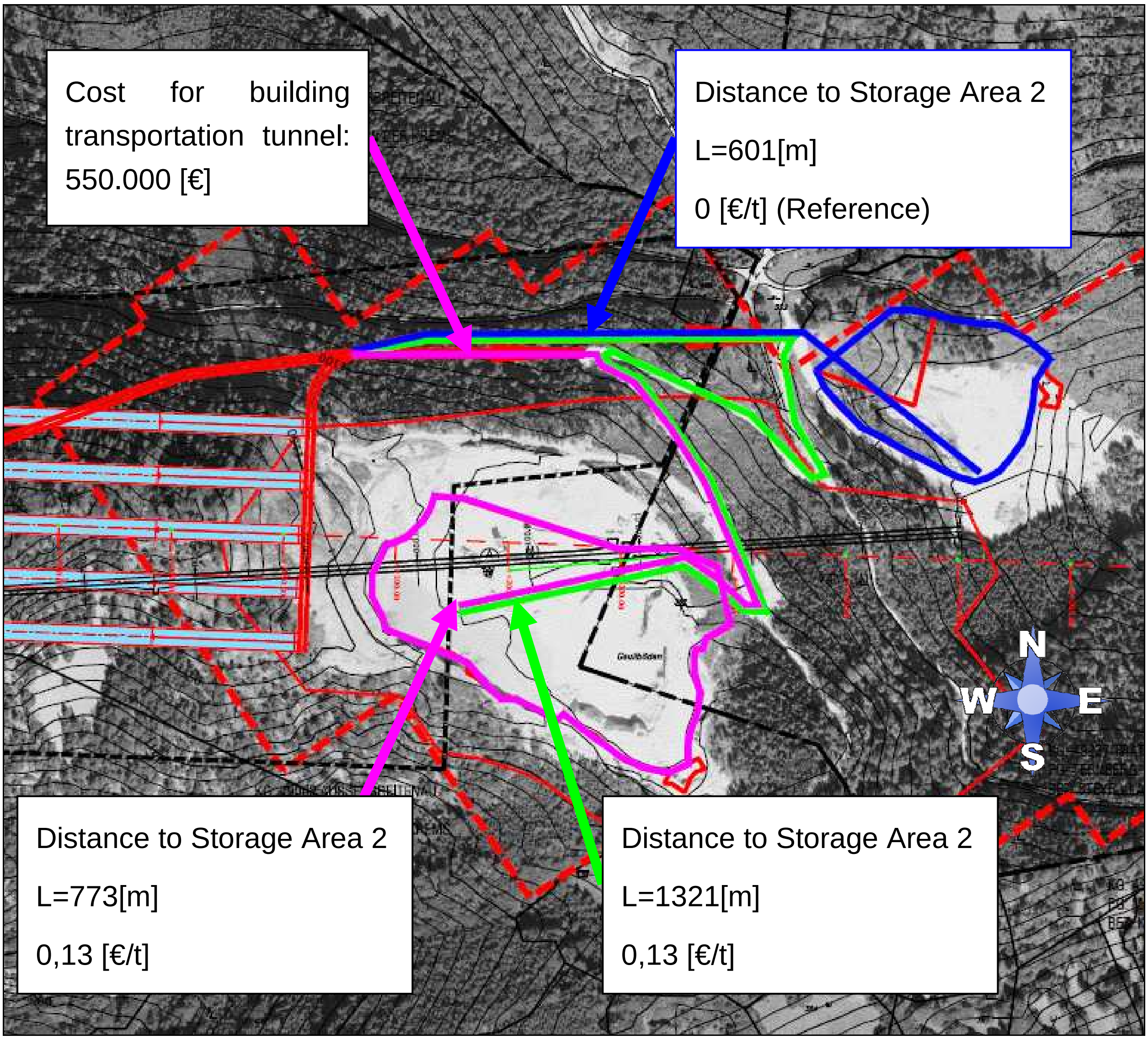

Figure 45: Cost for transportation to storage areas

Also the material that would be needed immediately for the production in Molln could be dumped to the storage area 1 and then be taken by a wheel loader and be applied to the belt conveyor for transportation it to the plant in Molln.

The optimal procedure regarding the excavated material of the area Pfaffenboden would be to fill storage area 1 with excavated material. When the capacity of the storage area is exhausted, the material has to be transported to storage area 2 or storage space Sierninghofen. For transporting the material to storage area 2 there are two possible variants for transportation. The first possibility is to transport the material over the transportation tunnel and then follow the road up to the quarry. The second possibility is to transport the material via the access tunnel and then follow the road up to the quarry.

The possibility of transporting the material through the access tunnel seems more cost intensive at first sight. But when deciding for this variant it has to be minded, that the transportation tunnel, which costs about 550.000€ can be omitted.

The costs for transportation on the possible roads are displayed in Figure 45. For making the costs of transportation comparable, the cost of transportation to storage area 1 are taken as reference and can therefore be set to zero. The real cost for transportation to this storage area are included in the price of the construction company for excavation of material.

6.3.1 Variant A: All material to Sierninghofen

In this variant all the material that cannot be stored in storage area 1 is transported to the storage area Sierninghofen immediately.

The procedure for this variant would be that the material which is excavated in the area Pfaffenboden is transported to the surface via the access tunnel and then transported to storage area 1. The material that exceeds the capacity of storage area 1 is then picked up by a wheel loader and applied to the belt conveyor that is integrated in the Elfi tunnel. The material is then transported to the company grounds and separated into different grain sizes. From there it is loaded to lorries which transport the material to Sierninghofen.

In this variant there is no material transported to the storage area 2, which means the transportation tunnel does not have to be built.

The capacity of the storage area Sierninghofen would nearly be used to its full extent. The material could then be used for selling it all over Austria. Due to the big amounts of material that would be transported to Sierninghofen and due to the low material consumption in this area, the material would be available until July 2026.

After finishing the construction of Energiespeicher Bernegger, and also during construction, the material which is stored on storage area 1 is used as commodity for the plant in Molln. In this variant the material for processing in Molln would be available until March 2017.

The cost for this variant and also the main parameters are displayed in Table 9.

Variant A: All material to Sierninghofen					
Transportation	**Timeframe of transporation**		**Amount [tons/d]**	**Cost [€/t]**	**Total amount of transported material [t]**
	From	To			
Pfaffenboden-->Sierninghofen	01.03.2013	05.10.2015	2110	2,72	2.000.280
Cost					
Total cost	**€ 5.446.501**				

Table 9: Price calculation variant A

6.3.2 Variant B: All material to Pfaffenboden

All the material that cannot be stored in storage area 1 is transported to storage area 2.

The procedure for this variant would be that the material which is excavated in the area Pfaffenboden is transported to the surface via the access tunnel and then transported to storage area 1. The material which exceeds the capacity of storage area 1 is transported to the storage area 2.

This variant of transporting the material to the storage area 2 could be divided into two sub variants. On the one hand the transportation tunnel could be built. On the other hand the transportation tunnel could be left and the material could be transported over the detour. In this case, the cost for building the transportation tunnel could be saved, but the extra cost for the transportation of the material has to be considered.

The material which is needed as commodity in Molln or in Sierninghofen is transported to these locations from storage area 1.

After finishing the construction works at Energiespeicher Bernegger, the material of storage area 1 is included in the production process until this storage area is empty. After this time, the material of storage area 2 would be taken as commodity for Molln and Sierninghofen.

In this variant the material for delivering the plant in Molln and in Sierninghofen would reach until July 2019.

The cost and the main parameters for this variant and the assumption that the transportation tunnel should be built is displayed in Table 10 as well as the numbers for the assumption that the transportation tunnel should not be built.

Variant B: All material to Pfaffenboden; Transportation tunnel should not be built					
Transportation	**Timeframe of transporation**		**Amount [tons/d]**	**Cost [€/t]**	**Total amount of transported material [t]**
	From	To			
WerkMolln-->Sierninghofen	01.03.2013	05.07.2019	411	2,72	952.287
WerkMolln-->Sierninghofen	05.07.2019	28.06.2026	411	2,72	1.048.050
ESB-->storage area 2	01.03.2013	05.10.2015	1.697	0,47	1.609.000
Cost					
Transportation cost to Sierninghofen	€ 5.851.193			**Sum**	**2.000.337**
Transportation cost to Pfaffenboden	€ 764.007				
Total cost	**€ 6.615.200**				

Variant B: All material to Pfaffenboden; Transportation tunnel should be built					
Transportation	**Timeframe of transporation**		**Amount [tons/d]**	**Cost [€/t]**	**Total amount of transported material [t]**
	From	To			
WerkMolln-->Sierninghofen	01.03.2013	05.07.2019	411	2,72	952.287
WerkMolln-->Sierninghofen	05.07.2019	28.06.2026	411	2,72	1.048.050
ESB-->storage area 2	01.03.2013	05.10.2015	1.697	0,13	1.609.000
Cost					
Transportation cost to Sierninghofen	€ 5.851.193			**Sum**	**2.000.337**
Transportation cost to Pfaffenboden	€ 208.018				
Cost for building the transportation tunnel	€ 550.000				
Total cost	**€ 6.609.212**				

Table 10: Price calculation variant B

6.3.3 Variant C: Capacity orientated disposition

This variant is a mixture of variant 1 and 2. That means that a part of the material is transported to storage area Sierninghofen and the other part of the material is transported to the storage area 2. When transporting the material to Sierninghofen and when to storage area 2 does depend on the free capacity of the fleet of Bernegger

GmbH. The experts of Bernegger GmbH assume that about 767.000 tons are transported to storage area 2 within this variant.

This variant can also be divided into the two sub variants that the transportation tunnel is built or not.

The material which is stored on storage area 1 and 2 would reach until November 2019 and the material which is stored on storage area Sierninghofen would reach until August 2022.

The cost and the main parameters for this variant and the assumption that the transportation tunnel should be built is displayed in Table 11 as well as the numbers for the assumption that the transportation tunnel should not be built.

Variant C: Capacity orented dispostion; Transportation tunnel should not be built					
Transportation	**Timeframe of transporation**		**Amount [tons/d]**	**Cost [€/t]**	**Total amount of transported material [t]**
	From	To			
WerkMolln-->Sierninghofen	01.03.2013	05.10.2015	1.300	2,72	1.232.400
WerkMolln-->Sierninghofen	16.05.2021	28.06.2026	411	2,72	768.159
ESB-->storage area 2	01.03.2013	05.10.2015	809	0,47	767.000
Cost					
Transportation cost to Sierninghofen	€ 5.446.174			**Sum**	**2.000.559**
Transportation cost to Pfaffenboden	€ 364.197				
Total cost	**€ 5.810.372**				

Variant C: Capacity orented dispostion; Transportation tunnel should be built					
Transportation	**Timeframe of transporation**		**Amount [tons/d]**	**Cost [€/t]**	**Total amount of transported material [t]**
	From	To			
WerkMolln-->Sierninghofen	01.03.2013	05.10.2015	1.300	2,72	1.232.400
WerkMolln-->Sierninghofen	16.05.2021	28.06.2026	411	2,72	768.159
ESB-->storage area 2	01.03.2013	05.10.2015	809	0,13	767.000
Cost					
Transportation cost to Sierninghofen	€ 5.446.174			**Sum**	**2.000.559**
Transportation cost to Pfaffenboden	€ 99.161				
Cost for building the transportation tunnel	€ 550.000				
Total cost	**€ 6.095.335**				

Table 11: Price calculation variant C

6.3.4 Value benefit analysis for the area Pfaffenboden

Also for this project area a value benefit analysis could ease the decision how to proceed with the excavated material.

In “Appendix E: Price calculation” a calculation is made, where all this cost positions are considered. There are different possibilities that are compared with each other in this scheme.

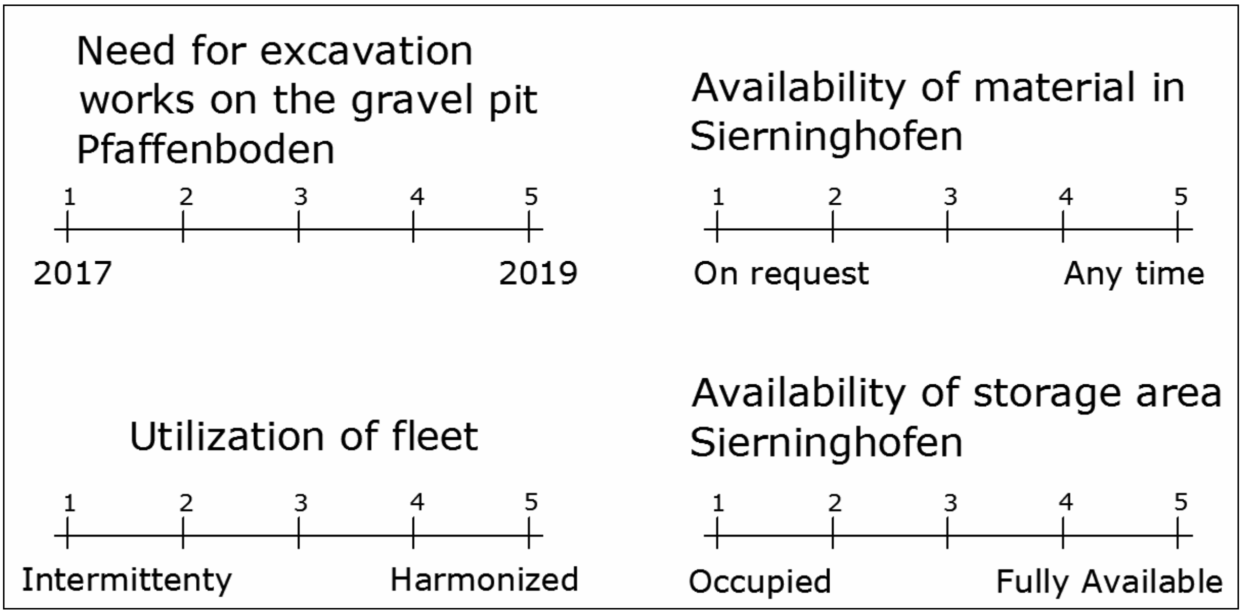

Figure 46: Criterions for value benefit analysis

Need for excavation works on the gravel pit Pfaffenboden

By incorporating the excavated material into the production process of Bernegger GmbH, the quarry Pfaffenboden can be closed for a while. The point in time when the excavation works have to be started again depends on the variant of material deposition. The later the excavation works on Pfaffenboden have to start again, the better it is for Bernegger GmbH.

Utilization of fleet

The construction business is pretty much dependant on seasonal works. Therefore it is very important for Bernegger GmbH to have some extra work in winter time, which is low season for construction works. The optimal utilization could be reached by transportation of the material to Sierninghofen during winter time and using the fleet for daily business during summer time.

The emphasis of the different criterions is again evaluated by pairwise comparison of the single factors.

Availability of material in Sierninghofen

This means the timeframe and the amount of material which is available for distribution in Sierninghofen. It is of high interest for Bernegger GmbH, that sufficient material is stored in Sierninghofen to overcome a peak in material demand.

Availability of storage area in Sierninghofen

The company grounds in Sierninghofen could also be used for other purposes than for storage of material. Therefore it could be of high interest, to have free space in future times.

	Need for excavation works on the gravel pit Pfaffenboden	Optimal utilization of fleet	Availability of material in Sierninghofen	Availability of storage area Sierninghofen	Σ	
No need for excavation works on the gravel pit Pfaffenboden	1	0	0	2	3	18,8%
Optimal utilization of fleet	2	1	1	2	6	37,5%
Availability of material in Sierninghofen	2	1	1	2	6	37,5%
Availability of storage area Sierninghofen	0	0	0	1	1	6,3%
				Σ	16	100%

2 Points: row criterion more important than column criterion
1 Points: row criterion as important as column criterion
0 Points: row criterion less important than column criterion

Figure 47: Pairwise comparison of criterions

The numbers can be entered in the table for value benefit analysis.

Criteria	Emphasis	Variant A Everything to Sierninghofen	A*E	Variant B Everything to Pfaffenboden	B*E	Variant C Capacity oriented disposition	C*E
No need for excavation works on the gravel pit Pfaffenboden	19	1	19	5	95	2	38
Optimal utilization of fleet	38	1	38	1	38	5	190
Availability of material in Sierninghofen	37	5	185	1	37	3	111
Availability of storage area in Sierninghofen	6	1	6	5	5	3	18
Sum	100		248		175		**357**

Table 12: Value benefit analysis for the area Pfaffenboden

6.3.5 Recommendation for action for the area Pfaffenboden

Also in this area the costs have to be included in the process of deciding for a variant. To make the costs for transportation comparable, it is assumed that the material the same amount of material is transported to Sierninghofen in every variant. The only difference is the time of transportation of the material. An overview of the cost for the different possibilities for material disposition is given in "Appendix E: Price calculation for the area Pfaffenboden".

The costs for the different variants are calculated on the basis of transportation costs like they are today. Due to the long timeframe of transportation within this project, it is difficult to forecast the development of the transportation price. Therefore these numbers can change in the future.

In Figure 46 the benefit of the different variants and also the cost are displayed.

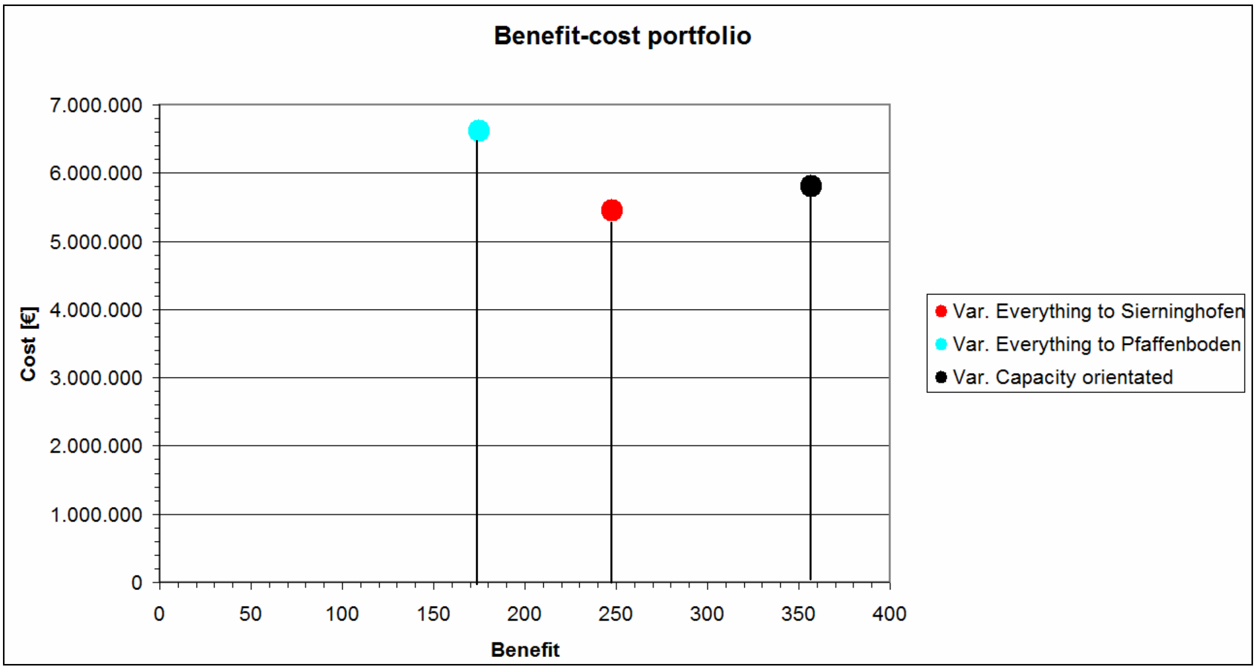

Figure 48: Comparison of benefit and costs

It can be seen that the variant of transporting all the material to Pfaffenboden has the lowest benefit and the highest price. The variant of transporting all the material to Sierninghofen has the lowest price and is moderate in the means of benefit. The capacity orientated variant is slightly higher in costs but is leader in terms of benefit for the company.

Therefore the recommendation to Bernegger GmbH is to transport the material to Sierninghofen whenever possible. Especially during winter time it is of high advantage to transport the material to Sierninghofen, because of the strong winters in Upper Austria it could occur that the material cannot be transported to storage area 2. Also the fleet of Bernegger GmbH has free capacity during winter time.

During summer time when there is high season in construction business it would be best to transport most of the material to the storage area 2.

During the construction phase of Energiespeicher Bernegger, storage area 1 should never be filled up to its maximum capacity because it can serve as buffer when there are bottlenecks in transportation.

6.4 Material concept for the area lower reservoir

The nearest site for storage of the material in this area is storage area 3 "Priethal". As already explained in chapter 4.1.4 - Unit lower reservoir, there are some different construction stages in which the material is transported to this area.

Due to the big amounts of excavated material in this area of about 2,6 million tons, and a relatively small storage volume of only 1,2 million tons, it is clear that not all of the material can be stored on storage area 3.

Today there are about 85 thousand tons per year transported from the existing gravel pit "Schacher" (this gravel pit is extended to serve as lower reservoir) to the plant in Klaus. Therefore it is obvious to increase the transportation capacity during the construction time of Energiespeicher Bernegger and to store some of the material in the storage area Klaus II.

As displayed in “Appendix C: Mask for calculating the mass balance for the storage areas”, the storage area Klaus also reaches the limits of its capacity. The only storage space that could serve as extra storage for this material is the storage area Sierninghofen. Therefore a small amount of material also has to be transported to the storage area of Sierninghofen.

Recommendation for Action

Due to the big amounts of excavated material in this area and the lack of storage spaces, there are no variants of which a concept can be chosen. As seen in Table 6, the material has to be transported to the storage area Klaus from the beginning. There is also a small amount of material which has to be transported to the storage area Sierninghofen.

6.5 Conclusion of variants

Due to the logistic optimization during the diploma thesis, the material distribution was shifted to better usage of the different storage spaces and to cheaper transportation routes. A result of this process is that the material does not last for an equal amount of time in all the production sites.

Also the material input changed during the project. The reason for this change is, that the management of Energiespeicher Bernegger GmbH decided to optimize the volume of the upper and the lower reservoir in means of economic aspects. Therefore these two parts of the project got smaller in size. Since these parts are mainly responsible for the material output it does influence the total excavated amount to a high degree.

The numbers for this sankey diagram are calculated by the use of the excel sheet that was set up for displaying the mass balance of the project.

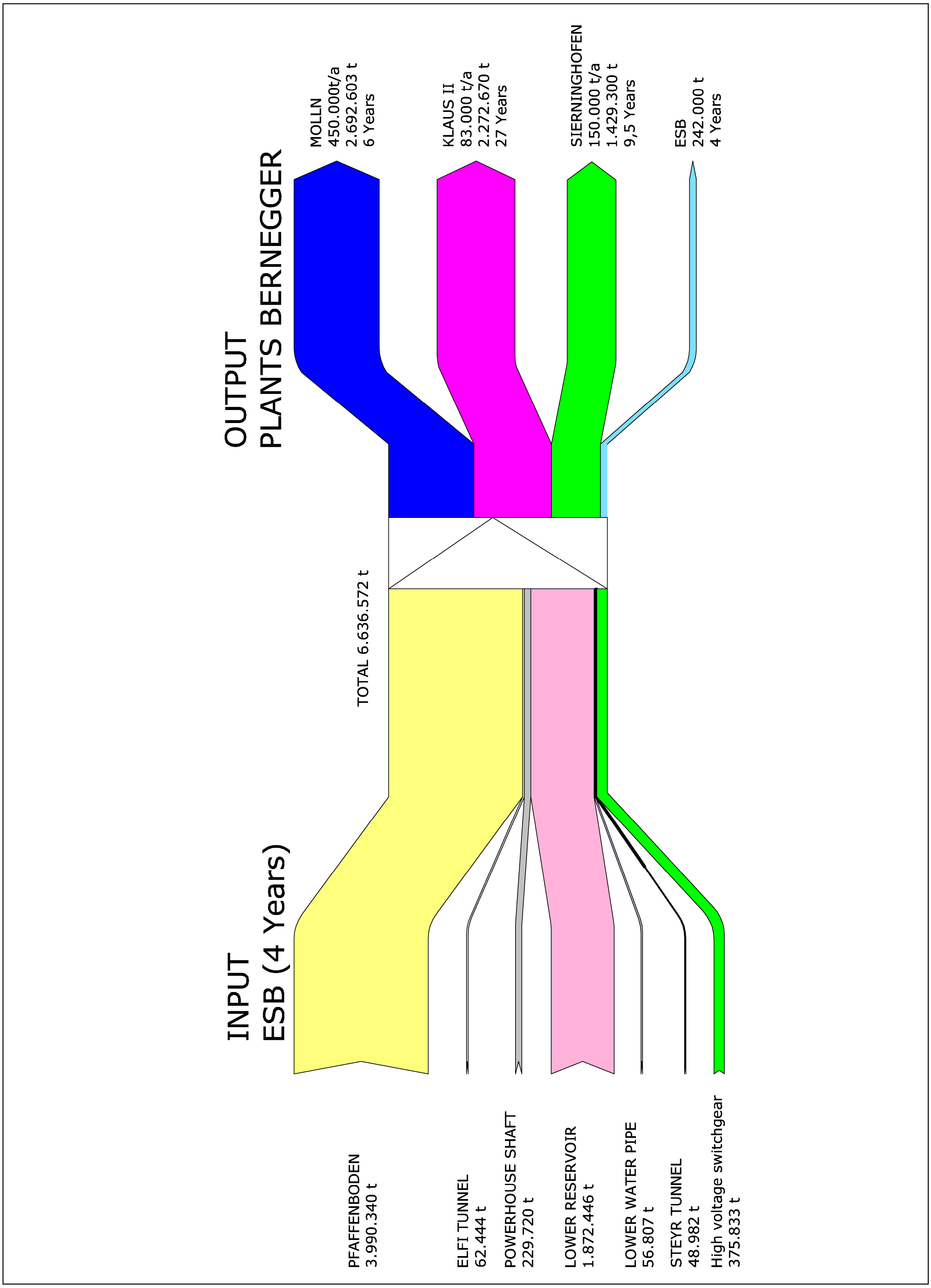

Figure 49: Sankey diagram of final over all concept

7 Conclusion and outlook

The goal of this diploma thesis was to work out a logistic concept for the disposition of the material which is excavated during the construction process of Energiespeicher Bernegger.

In the first stage of the diploma thesis the framework of the project was analyzed. Because of the fact that the system limits are defined by the dimensions and the layout of the whole project, this analysis can be seen as necessary step to set up the various logistic concepts. The main point of this stage was to elaborate the amount of excavated material and also the time in which the excavated material has to be transported. Also, possible storage areas were analyzed and the maximal storage volume of these storage areas was calculated. As the excavated material should be used as commodity for the production process in Bernegger GmbH and for the construction of Energiespeicher Bernegger, also the material consumption of these sites was worked out. The means of transportation were evaluated by transportation capacity and the price. In summary for this stage, the different construction stages of the project were joined to units of which the material flow can be displayed.

The second part was to work out different concepts for the disposal of the material. First of all a mass balance was set up for every storage area to display the usage of these storage areas. For working out different concepts the project was separated into three sub areas. Various concepts were worked out for every sub area and also the cost for every concept were worked out and compared with each other. All of the important factors for these concepts were then evaluated by the use of value benefit analysis. A recommendation for action was then given for every sub area. The sum of these partial solutions then led to an overall concept. The material flow of this overall concept was then displayed by the use of a sankey diagram.

All the information and the data which was gained during the diploma thesis is displayed in Table 13, which can be seen as an overview of the results that were gained during the diploma thesis.

In future times of this project it is very likely, that the dimensions of the whole project and the time schedule will slightly change. Therefore the concept for disposition of the material needs to be adopted. Since the excavated sheets, which were created for this diploma thesis, are easy adoptable, it is very little effort to change some numbers.

This diploma thesis can be seen as bases and a instruction to the logistics of the excavated material. All the changes that are necessary in future times of the project can easily be followed.

Sum of excavated material	6.600.000 tons
Timeframe for excavation	3 years
Possible storage volume of all storage areas	7.600.000 tons
Material consumption of the project Energiespeicher Bernegger	242.000 tons
Material consumption of the production sites of Bernegger GmbH within the timeframe of 3 years	2.000.000 tons
Influence of the storage time on the quality of the material	None
Concepts for the disposition of the material	Divided into three main areas with concepts for the specific area

Table 13: Conclusing facts of the diploma thesis

Due to the long timeframe of transportation, the idea came up to involve the change of the transportation price and the rate of interest into the financial calculation. The cost overview was already prepared to implement the rate of interest and the development of the transportation index. Because of the fact that the development of the transportation index cannot be forecasted for future times, there will definitely be need for a worst-case a best-case and a realistic prognosis.

For this prognosis the existing development of the transportation index has to be extrapolated.

Also the economic development of the whole industry could change the material consumption at the different sites of Bernegger and therefore the concept for transportation would also have to be adopted.

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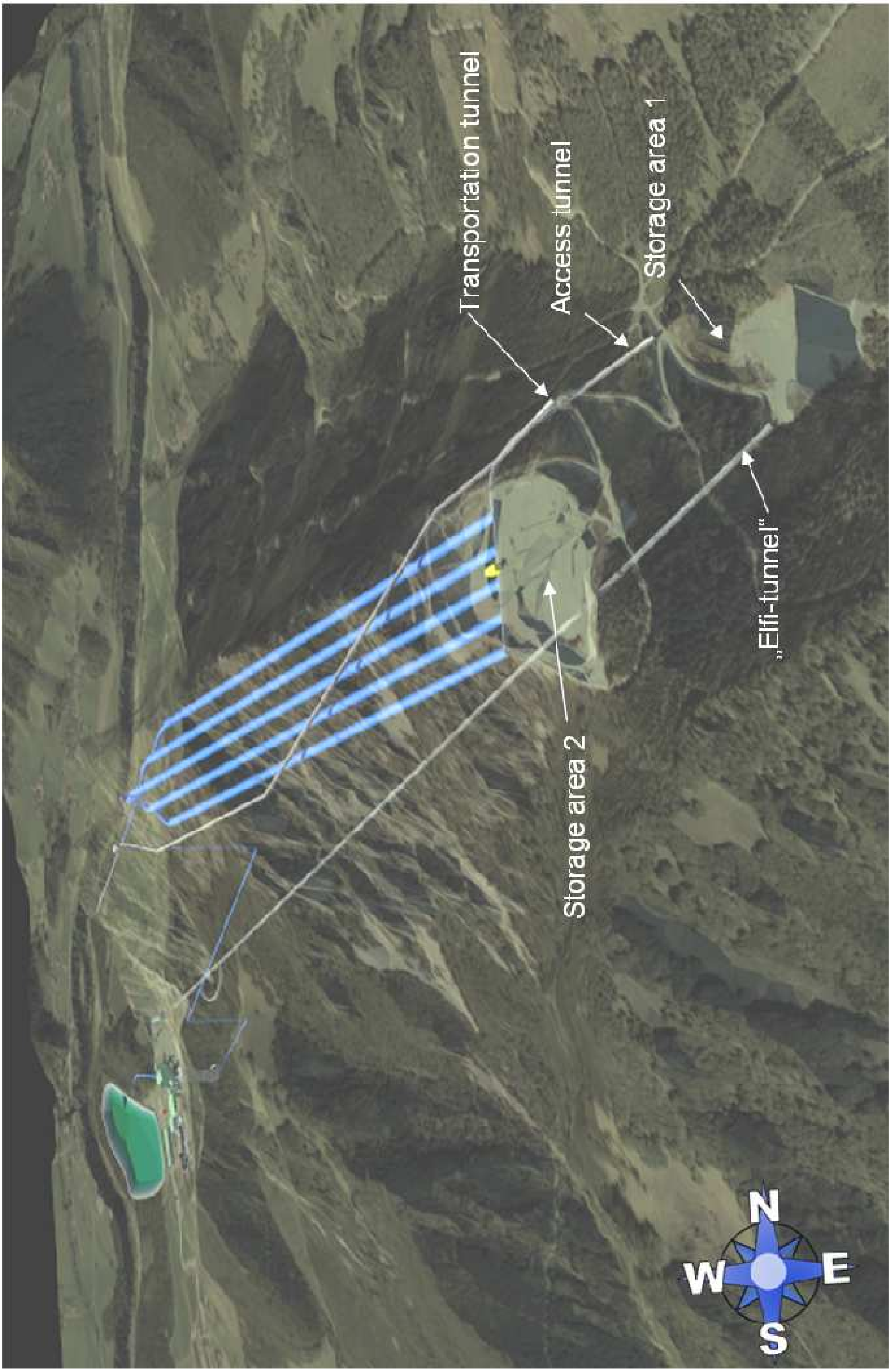
10 List of figures

11 List of tables

Appendix


Transportation tunnel
Access tunnel
Storage area 1
Storage area 2
„Elfi-tunnel"
N
W
E
S

Upper reservoir		Unit	Amount Firm	Factor	Ammount Excavated
1.1	**Reservoir tunnel north (L = 1470m)**				
1.1.1	Excavation (A=233,3m²)	m³	309.748	1,5	464.622
1.1.2	Securing	m²	76.222		
1.1.3	Shotcrete (thickness = 20cm)	m³	15.244		
1.2	**Reservoir tunnel north-mid (L = 1581m)**				
1.2.1	Excavation (A=233,3m²)	m³	336.018	1,5	504.027
1.2.2	Securing	m²	81.829		
1.2.3	Shotcrete (thickness = 20cm)	m³	16.366		
1.3	**Reservoir tunnel mid (L = 1593m)**				
1.3.1	Excavation (A=233,3m²)	m³	334.455	1,5	501.683
1.3.2	Securing	m²	80.058		
1.3.3	Shotcrete (thickness = 20cm)	m³	16.012		
1.4	**Reservoir tunnel south-mid (L = 1581m)**				
1.4.1	Excavation (A=233,3m²)	m³	336.112	1,5	504.168
1.4.2	Securing	m²	81.831		
1.4.3	Shotcrete (thickness = 20cm)	m³	16.366		
1.5	**Reservoir tunnel south (L = 1470m)**				
1.5.1	Excavation (A=233,3m²)	m³	309.748	1,5	464.622
1.5.2	Securing	m²	75.763		
1.5.3	Shotcrete (thickness = 20cm)	m³	15.153		
1.5	**Inflowcavern**				
1.5.1	Excavation incl. Surge tank (A=564,4m²)	m³	39.977	1,5	59.966
1.5.2	Securing	m²	8.754		
1.5.3	Shotcrete (thickness = 20cm)	m³	1.751		
1.6	**Transprotation tunnel (L = 126m)**				
1.6.1	Excavation tunnel (A=35,8m²)	m³	4.511	1,5	6.766
1.6.2	Excavation valley	m³	4.230	1,5	6.345
1.6.3	Securing - (U=21,6m)	m²	2.722		
1.6.4	Shotcrete (thickness = 15cm)	m³	416		
1.7	**Acess tunnel (L = 586m)**				
1.7.1	Excavation tunnel (A=35,8m²)	m³	20.979	1,5	31.468
1.7.2	Excavation valley (Übertage)	m³	6.352	1,5	9.528
1.7.3	Securing - (U=21,6m)	m²	12.658		
1.7.4	Shotcrete (thickness = 15cm)	m³	1.934		
1.8	**Ventilation tunnel surge tank (L =133m)**				
1.8.1	Excavation Tunnel Untertage (A=16,5m²)	m³	2.204	1,5	3.306
1.8.2	Securing - (U=15,35m)	m²	2.049		
1.8.3	Shotcrete (thickness = 15cm)	m³	298		

1.9	**Ventilation tunnel machine chamber (L =237m)**				
1.9.1	Excavation Tunnel Untertage (A=16,5m²)	m³	3.913	1,5	5.869
1.9.2	Securing - (U=15,35m)	m²	3.638		
1.9.3	Shotcrete (thickness = 15cm)	m³	529		
	Sum amount firm [m³]		**1.668.269**		
	Sum amount excavated [m³]				**2.562.369**
	Sum shotcrete [m³]		**84.067**		
	Sum shotcrete aggregate [m³]		**64.732**		

Machine chamber					
		Unit	Amount Firm	Factor	Ammount Excavated
2.1	**Machine chamber**				
2.1.1	Excavation chamber (15,8x21,5x15,1)	m³	5.145	1,5	7.718
2.1.2	Excavation tunnel in chamber (A=132m², L=72m)	m³	9.504	1,5	14.256
2.1.3	Securing	m²	1.657		
2.1.4	Shotcrete	m³	248		
2.1.5	Reinforced concrete	m³	232		
2.2	**Acess tunnel to machine chamber (L = 1864m)**				
2.2.1	Excavation tunnel (A=35,8m²)	m³	66.731	1,5	100.097
2.2.2	Securing - (U=21,6m)	m²	40.262		
2.2.3	Shotcrete	m³	6.151		
	Sum amount firm [m³]		**71.876**		
	Sum amount excavated [m³]				**21.974**
	Sum shotcrete [m³]		**6.399**		
	Sum shotcrete aggregate [m³]		**4.927**		
	Sum concrete [m³]		**232**		
	Sum concrete aggregate [m³]		**186**		

Water pipe

		Unit	Amount Firm	Factor	Ammount Excavated
3.1	**Highpressure pipe (Tunnel 1) (L = 167m)**				
3.1.1	Excavated - (A=12,6m²)	m³	2.104	1,5	3.156
3.1.2	Securing - (U=10m)	m²	1.670		
3.1.3	Shotcrete (A=1m²)	m³	167		
3.1.4	Concrete (Backfill: 4m²)	m³	668		
3.1.5	Steel tube	to	143		
3.1.6	Injections	to	10		
3.2	**Highpressure pipe (Shaft 1) (L = 322m)**				
3.2.1	Excavated - raise boring (A=11,9m²)	m³	3.832	1,3	4.981
3.2.2	Securing - (U=12,25m)	m²	3.945		
3.2.3	Shotcrete (A=1,2m²)	m³	386		
3.2.4	Concrete (Backfill: 3,2m²)	m³	1.030		
3.2.5	Steel tube	to	2.982		
3.2.6	Injections	to	20		
3.3	**Highpressure pipe (Tunnel 2) (L = 897,6m)**				
3.3.1	Excavated - (A=12,6m²)	m³	11.310	1,5	16.965
3.3.2	Securing - (U=10m)	m²	8.976		
3.3.3	Shotcrete (A=1m²)	m³	898		
3.3.4	Concrete (Backfill: 4m²)	m³	3.590		
3.3.5	Steel tube	to	siehe 3.2		
3.3.6	Injections	to	55		
3.4	**Highpressure pipe (Shaft 2) (L = 160,6m)**				
3.4.1	Excavated - raise boring (A=11,9m²)	m³	1.911	1,3	2.484
3.4.2	Securing - (U=12,25m)	m²	1.967		
3.4.3	Shotcrete (A=1,2m²)	m³	193		
3.4.4	Concrete (Backfill: 3,2m²)	m³	514		
3.4.5	Steel tube	to	siehe 3.2		
3.4.6	Injections	to	10		
3.5	**Highpressure pipe (Tunel 3) (L = 295m)**				
3.5.1	Excavated - (A=12,6m²)	m³	3.717	1,5	5.576
3.5.2	Securing - (U=10m)	m²	2.950		
3.5.3	Shotcrete (A=1m²)	m³	295		
3.5.4	Concrete (Backfill: 4m²)	m³	1.180		
3.5.5	Steel tube	to	siehe 3.2		
3.5.6	Injections	to	18		
3.6	**Highpressure pipe (split up) (L = 2x14m)**				
3.6.1	Excavated - (A=12,6m²)	m³	353	1,5	529
3.6.2	Securing - (U=10m)	m²	280		
3.6.3	Shotcrete (A=1m²)	m³	28		
3.6.4	Concrete (Backfill: 4m²)	m³	112		
3.6.5	Steel tube	to	198		
3.6.6	Injections	to	1		

3.7	**Lowpressure pipe (split up) (L = 79m)**				
3.7.1	Excavated - (A=12,6m²)	m³	995	1,5	1.493
3.7.2	Securing - (U=10m)	m²	790		
3.7.3	Shotcrete (A=1m²)	m³	79		
3.7.4	Concrete (Backfill: 4m²)	m³	316		
3.7.5	Steel tube	to	48		
3.7.6	Injections	to	3		
3.8	**Lowpressure pipe (L = 552m)**				
3.8.1	Excavated - (A=23,2m²)	m³	11.414	1,5	17.122
3.8.2	Securing - (U=13,5m)	m²	6.544		
3.8.3	Shotcrete (A=1,75m²)	m³	861		
3.8.4	Concrete (Backfill: 9,5m²)	m³	4.674		
3.8.5	Steel tube	to	801		
3.8.6	Injections	to	45		
3.9	**Transportation tunnel to "Elfi tunnel" (L = 200m)**				
3.9.1	Excavated (A=26,5m²)	m³	7.160	1,5	10.740
3.9.2	Securing - (U=21,6m)	m²	4.320		
3.9.3	Shotcrete (A=3,3 m² bei mittlerer Stärke = 15cm)	m³	660		
3.10	**Bypass (L = 115m)**				
3.10.1	Excavated (A=14,3m²)	m³	1.898	1,5	2.846
3.10.2	Securing - (U=15,4m)	m²	1.771		
3.10.3	Shotcrete (A=2,23 m² bei mittlerer Stärke = 15cm)	m³	256		
	Sum amount firm [m³]		**44.694**		
	Sum amount excavated [m³]				**62.736**
	Sum shotcrete [m³]		**3.823**		
	Sum shotcrete aggregate [m³]		**2.944**		
	Sum concrete [m³]		**12.085**		
	Sum concrete aggregate [m³]		**9.668**		

Powerhouse shaft

		Area	Heigth	Volume Firm
4.0	**Powerhouse shaft + Shotcrete**			148.522 m³
4.0.1	Excavation shaft 333-416,7 m.a.s.l	620,16 m²	83,70 m	51.907 m³
4.0.2	Excavation shaft 416,7-434 m.a.s.l	725,83 m²	17,30 m	12.557 m³
4.0.3	Excavation inlet water pipe	16,63 m²	32,00 m	605 m³
4.0.4	Excavation anchorpoints			290 m³
4.0.5	Erosion			32.227 m³
4.0.6	Erosion backfill			16.490 m³
4.0.7	Erosion transportation			31.851 m³
4.0.8	Shotcrete			2.595 m³
4.1	**Level 1 333,00 m**			2.049 m³
4.2	**Level 2 337,90 m**			1.807 m³
4.3	**Level 3 343,56 m**			990 m³
4.4	**Level 4 349,22 m**			1.372 m³
4.5	**Level 5 355,22 m**			841 m³
4.6	**Level 6 360,55 m**			473 m³
4.7	**Level 7 366,20 m**			441 m³
4.8	**Level 8 371,87 m**			475 m³
4.9	**Level 9 377,53 m**			455 m³
4.10	**Level 10 383,19 m**			459 m³
4.11	**Level 11 388,85 m**			443 m³
4.12	**Level 12 394,51 m**			464 m³
4.13	**Level 13 400,17 m**			305 m³
4.14	**Level 14 405,83 m**			222 m³
4.15	**Level 15 411,49 m**			226 m³
4.16	**Level 16 417,151 m**			335 m³
4.17	**Level 17 422,812 m**			370 m³
4.18	**Level 18 428,48 m**			253 m³
4.19	**Levels 13-17**			464 m³

4.20	Exit secondary staircase	88 m³
4.21	Generator output	2.666 m³
4.22	Crane foundations + retaining wall	2.218 m³
4.23	Shaftring	2.221 m³
4.24	Schaft cover	324 m³
4.25	Foundation for shaft cover	51 m³
4.26	Main staircase Level 2-17	92 m³
4.27	Secondary staircase Level 5-18 + Ausgang	113 m³
4.28	Anchorpoints Level 2	271 m³

Sum amount firm [m³]	**97.586 m³**
Sum amount excavated [m³]	**146.379 m³**
Sum shotcrete [m³]	**2.595 m³**
Sum shotcrete aggregate [m³]	**1.998 m³**
Sum concrete [m³]	**20.490 m³**
Sum concrete aggregate [m³]	**16.392 m³**

Switch panel

		Unit	Amount Firm	Factor	Ammount Excavated
5.1	**Switch panel**				
5.1.1	Excavation	m³	200.000	1,2	240.000
5.1.2	Backfill	m³	35.000		
5.1.3	Transportation	m³	205.000		
5.1.4	Gravel layer (A=13.500m², t=50cm)	m³	6.750		
	Sum amount firm [m³]		**200.000**		
	Sum amount excavated [m³]				**240.000**
	Sum Backfills [m³]		**41.750**		

Lower reservoir

		Unit	Amount Firm	Factor	Ammount Excavated
6.1	**Reservoir (raw version)**				
6.1.1	Excavation	m³	1.076.674	1,2	1.292.009
6.1.2	Backfill	m³	70.410		
6.1.3	Transportation	m³	1.221.599		
6.2	**Bottom (Sealing Layer) (A=54.509 m²)**				
6.2.1	Mastix	m²	54.509		
6.2.2	Asphalt (8cm)	m³	4.361		
6.2.3	Binder (9cm)	m³	4.906		
6.2.4	Mineral filter (4/32) (30cm)	m³	16.353		
6.2.5	Regulating layer (0/32) (i.M. 10cm)	m³	5.451		
6.3	**Dam (Sealing Layer) (A=58.583 m²)**				
6.3.1	Mastix	m²	58.583		
6.3.2	Asphalt (9cm)	m³	5.272		
6.3.3	Binder (8cm)	m³	4.687		
6.3.4	Mineral filter (30cm)	m³	17.575		
6.4	**Road on dam crest (Layers) (A=6.614 m²)**				
6.4.1	Asphalt (7cm)	m³	463		
6.4.2	Asphalt supporting (8cm)	m³	529		
6.4.3	Gravel layer (30cm)	m³	1.984		
6.5	**Inlet Building**				
6.5.1	Shotcrete (A=1000m²)	m³	100		
6.5.2	Concrete building	m³	1.300		

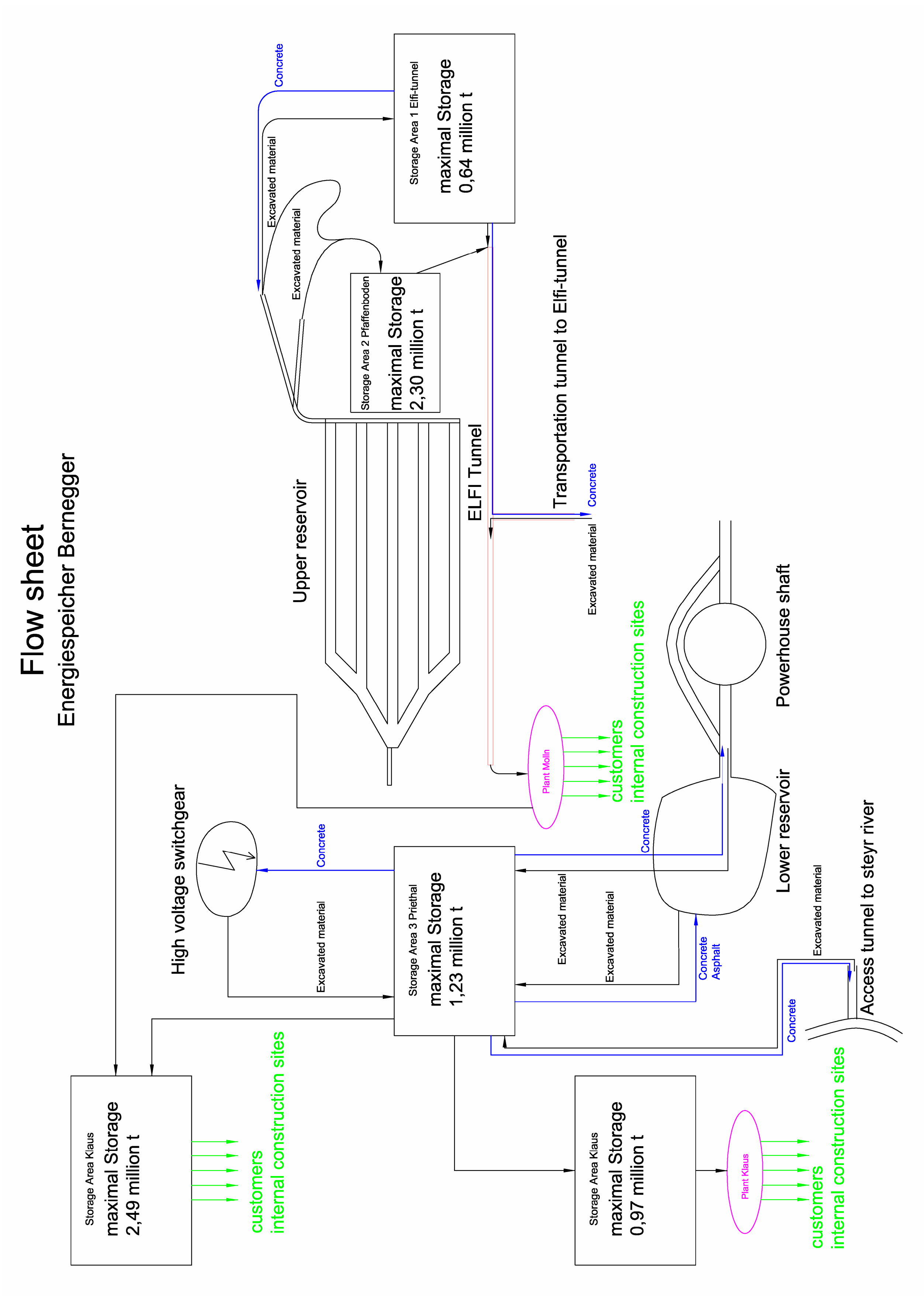
Sum amount firm [m³]	**1.076.674**		
Sum amount excavated [m³]			**1.292.009**
Sum concrete [m³]	**1.400**		
Sum concrete aggregate [m³]	**1.120**		
Summe asphalt [m³]	**10.096**		
Summe binder [m³]	**10.122**		
Summe mineral filter [m³]	**35.912**		
Sum regulating layer [m³]	**5.451**		

Steyr-tunnel

		Unit	Amount Firm	Factor	Ammount Excavated
7.1	**Tunnel**				
7.1.1	Valley	m³	19.170	1,5	28.755
7.1.2	Excavation tunnel (A=18,7m²)	m³	2.431	1,5	3.647
7.1.3	Securing - (U=16,3m)	m²	2.119		
7.1.4	Shotcrete (A=10,85 m²)	m³	299		

Sum amount firm [m³]	**21.601**	
Sum amount excavated [m³]		**32.402**

Sum shotcrete [m³]	**299**
Sum shotcrete aggregate [m³]	**230**


Flow sheet
Energiespeicher Bernegger
Storage Area 1 Elfi-tunnel
maximal Storage
0,64 million t
Storage Area 2 Pfaffenboden
maximal Storage
2,30 million t
Storage Area 3 Priethal
maximal Storage
1,23 million t
Storage Area Klaus
maximal Storage
2,49 million t
Storage Area Klaus
maximal Storage
0,97 million t
Concrete
Excavated material
Upper reservoir
ELFI Tunnel
Transportation tunnel to Elfi-tunnel
Powerhouse shaft
Lower reservoir
Access tunnel to steyr river
High voltage switchgear
Plant Molln
Plant Klaus
customers
internal construction sites
Asphalt