



REPORT

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Cost estimates different Transport solutions



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1 Background

This report covers the investigation of how a Transport System for Talga Resources can be designed.

The report includes analysis of the material flow and logistic costs from Mine to Market through different locations for the Processing industry with different modes of transport and load carriers. It describes a permanent production with a lifecycle period of 20 years.

2 Prerequisites for the Process Industry

The mine where the graphite blocks are extracted is located in Nunasvaara in the North of Sweden. The choice of production method in this arctic climate will have an impact on the deliveries to the market throughout the year. The transportation on a yearly basis includes the same volume in concentrated parts for the different production time spans but the storage area needs to be larger to handle up-front volumes from the Mine to the Process Industry. This report covers a 12 months production in the Mine.

Four alternative locations for the Process Industry (Boden, Luleå, Piteå and Skellefteå) have been discussed and transport options for them will be analysed in this report.

The Processing Industry is divided into two types of production; processing of Graphite and a Graphene products. The Graphite products are expected to be co-localized at the Mine and the Graphene products in an Exfoliation plant by the Bothnian Bay coast with production ongoing throughout the year depending on market demand.

The products that are produced are insert materials which will be further processed to different types of finished products by other companies on the market. Because of this the customers have high demands on delivery precision to fit their own processes. Transport solutions must therefore be adapted to each customer's demand.

The market location is not set but the following assumptions have been made:

- the Swedish market is close to Gothenburg.
- products to the German market are delivered to a hub in Hamburg for further distribution to the European market
- Hull in England is the hub for the market in United Kingdom (UK)

3 Prerequisites for the Transport Volumes

The material flow from the mine through the processing industry to the market with an inflow of additive materials and outflow of waste material is described in the figures below. Inflow Fluid and Treated Effluent are also illustrated to show volumes needed in the Processing Industry. These volumes are not included in the analysis of transportation costs (see chapter 6.4.1).

3.1 Freight Volumes

Freight volumes and type of goods on annual basis are presented for Permanent Plants in the figure below.

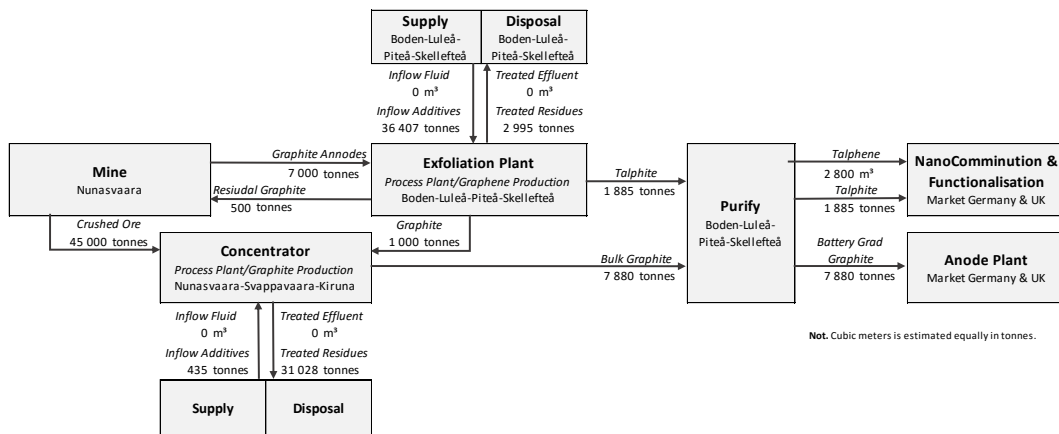


Figure 1. Annual volumes of goods transported between different sites within the lifecycle period.

4 Prerequisites for the Transport System

Figures 2 illustrates the transport system for Graphite and Graphene products from mine to customers through the Processing Industry with different modes of transport. The transport flows of Inflow fluid (supply and disposal from the refining process in the Processing Industry) are visualised in the flowchart below.

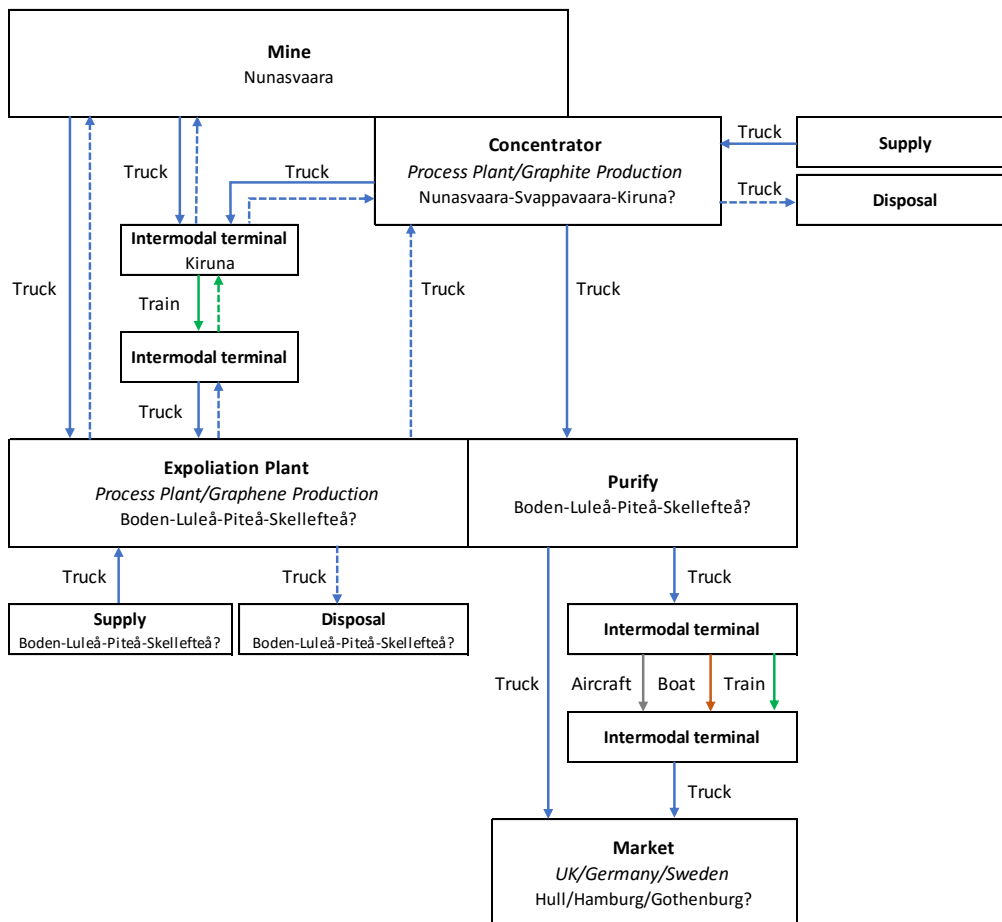


Figure 2. Alternative modes of transport between different facilities and markets.



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The ore or graphite anodes are transported from the Mine by truck to either nearby Concentrator Plant or to Exfoliation Plant by the coast. The transportation between the Mine and the Concentrator plant is treated as an in-house handling procedure.

In the beginning phases truck is the only available transportation solution since the volumes are low. When production is up and running there will also be possibilities to deliver by rail via Kiruna.

All goods that are not delivered by truck needs to pass through an intermodal terminal. All locations for intermodal terminals need to be adapted for loading and unloading goods and, to some extent, storage. The report assumes that such sites are prepared and/or accessible in Kiruna, by the Processing Industry (where needed), in the harbours, at airports and at the Markets. Intermodal terminals will be needed in Boden and Luleå. The locations in Piteå and Skellefteå are close to existing railway and will probably need some investment in siding-tracks and a hard-made surface for loading and unloading good but no intermodal terminals.

The Processing Industry by the coast (Exfoliation and Purify) is considered to be co-localized in Boden, Luleå, Piteå or Skellefteå. In this analysis, we assume that the two processes are co-located in the same building and moving between different processes is in-house handling. Waste graphite from processing will be transported back, partly to the Concentrator and partly to the Mine.

The Transport System also includes the supply of material needed for the production process and the deposit of waste from the refining process. These supplies are assumed (in a simplified way) to be provided from/to nearby locations.

From the Graphene production in the Exfoliation Plant, there is one wet graphene product (Talphone) and one dry graphene product (Talphite) delivered to the markets. There is also a Graphite product produced (Battery Grade Graphite) in the Concentrator for market demand. All products are pass through the Purify plant before they are delivered to the market. Since customers' location is not established today, we assume a 45% share to the UK and Germany respectively, and 10% of the products to western Sweden. Transportation to the Market can be performed by truck, train, ship or air-freight.

5 Prerequisites for pricing Transport

The logistic costs for different modes of transport and different locations for the Processing Industry and Markets are difficult to find out without a sharp offer from transport companies. Prices are often confidential and the companies are unwilling to disclose prices to the customer before actual contract negotiations. Also, it's rather difficult to identify correct transportation costs because of the variation of fixed and variable cost parameters and variance ways of calculating different mode of transport. For example, you need to choose suitable type of vehicle and load carrier, calculate distance and time depending cost, costs for various vehicle parameters, costs for loading/unloading, capital and operational costs, staff costs, various fuel costs and usage fees.

5.1 Theoretical Price Model

Due to the above-mentioned factors, the price model for the transportation chosen in this report will refer to a model developed in a study from Royal Institute of Technology (KTH) regarding "the Structure of Freight Transport Market and Railway



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Competition¹. The KTH study is based on confidential material delivered by market actors which forced the authors to simplify the model. In this case costs for transport buyers correspond in a simplified way with income for the transport company. The costs in the report are from 2005 and before and hasn't been adapted to today's situation where low-pricing road-carriers from eastern Europe have destabilized the market. However, the cost model has a high reliability when comparing costs between different modes of transport and different locations even if the right price level is hard to determine.

The comparing transport costs will be evaluated in Swedish kronor per ton kilometre (SEK/tonkm). Transported liquid products are evaluated in cubic metre per kilometre (SEK/m³km). According to the KTH report the relationship between the different mode of transport are corresponding according to Table 1 below:

Mode of transport	Cost/ tonkm	Cost/ m3
Truck	100	100
Rail	45	98
Shipping (Sea)	21	38

Table 1. Price relation between different mode of transports.

The differences in transport costs between truck and rail is smaller, which explains that the volume of liquid products is often dimensioning for the degree of filling of the transporters. Furthermore, the average costs for transporting low-value goods are calculated to 0,17 SEK/tonkm and high-value goods to 0,29 SEK/tonkm. For liquid goods, the average costs are 0,10 SEK/m³km. However, if one considers the load weight which is usually dimensioned, the cost will increase to 0,23 SEK/m³km

If rail transportation represents the average cost, the following comparison can be done between different modes of transport:

Mode of transport	Low-value goods	High-value goods	Liquid products
Rail	0,17 SEK/tonkm	0,29 SEK/tonkm	0,23 SEK/m ³ km
Truck	0,38 SEK/tonkm	0,64 SEK/tonkm	0,51 SEK/m ³ km
Shipping	0,08 SEK/tonkm	0,14 SEK/tonkm	0,11 SEK/m ³ km

Table 2. Price comparison between different mode of transports.

Notice that there are cost-levels which are lower than the ones above. Ex. bulk material in large volumes which can be put together in block trains and run in a system, like the Iron Ore Freight Trains, costs around 0,06 SEK/tonkm.

Costs for Air-freight is not included in the KTH report because it is very difficult to estimate and only related to high-value goods. To get a comparable value in this report we have assumed that the cost for air freight is doubled the costs for truck transportation, i.e. 1,28 SEK/tonkm for high-value goods and 1,02 SEK/m³km for liquid goods.

Intermodal terminals are needed when the goods must be moved from one mode of transport to another. Calculating reloading costs could either be done in SEK/ton or SEK/lift. In this report, we will use SEK/ton. Trafikverket estimate in their socio-economic analyses costs for reloading trucks to 9 SEK/ton, between truck and train or

¹ KTH Royal Institute of Technology – *Transportmarknadens struktur och järnvägens konkurrenskraft*, date June 2005.



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ship to 13 SEK/ton and aircraft 26 SEK/ton. The higher cost for aircraft is probably caused by reloading to smaller air-freight containers. Since transshipment is predominantly assumed to consist of containers a simplified reloading cost are set to 10 SEK/ton for all modes. Costs will be charge the mode of transport that needs transshipment. For example, moving goods from truck to rail, the rail transportation will be charged.

5.2 Price Indication

Talga has provided indicative pricing from freight forwarders (budget offers on rail, road and sea) as presented in the tables below.

Following price has been offered regarding truck transportation between the Mine and the Processing Industry.

Transportation Route		Road (SEK/ton)	Lifting goods (SEK/ton)		Total (SEK/ton)	Cost per truck (SEK)
			Loading	Unloading		
Mine, Nunasvaara	Processing Industry, Boden	318	40	40	358	11 814
Mine, Nunasvaara	Processing Industry, Luleå	324	40	40	364	12 012
Mine, Nunasvaara	Processing Industry, Piteå	342	40	40	382	12 606
Mine, Nunasvaara	Processing Industry, Skellefteå	364	40	40	404	13 332

Table 3. Price comparison between the Mine and different locations of the Processing Industry with truck.

In this solution goods pallets weighing 1.5 ton are lifted directly on trucks at the Mine site. Each truck will move 22 EU-pallets or 33 ton goods directly to the Processing Industry where it's unloaded. Shorter distance gives lower costs per truck.

Price for rail transport has also been offered passing an intermodal terminal in Kiruna. At the arrival stations by the trains will be unloaded and delivered to site by truck.

Transportation Route		Road (SEK/ton)	Rail (SEK/ton)	Lifting goods (SEK/ton)			Terminal handling			Total (SEK/ton)
				Loading	Reloading	Unloading	Time	SEK/h	SEK/ton	
Mine, Nunasvaara	Processing Industry, Boden	110	107	40	30	40	01:45	800	42	369
Mine, Nunasvaara	Processing Industry, Luleå	110	117	40	30	40	02:00	800	48	385
Mine, Nunasvaara	Processing Industry, Piteå	110	133	40	30	40				353
Mine, Nunasvaara	Processing Industry, Skellefteå	110	183	40	30	40				403

Table 4. Price comparison between the Mine and different locations of the Processing Industry with rail and truck.

Also in this case goods are loaded on EU-pallets. Rail transport is carried out between intermodal terminal and by truck between the Mine and intermodal terminal in Kiruna. At the intermodal terminal at the arrival rail station a terminal handling is calculated including truck transportation to the Processing Industry. Also in this case distance gives lower cost but if the railway is close to the Processing Industry, unloading can be done directly into the process and lower the costs further.

The same calculation as above have been done with sea-freight where price from harbor to harbor are offered. Piteå is the departure harbor in Sweden and the arrival harbor in UK is Hull and Hamburg in Germany. Price between Piteå and Hull is 550 SEK/ton and between Piteå and Hamburg 600 SEK/ton. This gives following price offer the Processing Industry and the connecting harbors in Europe.



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Transportation Route		Terminal handling				Total (SEK/ton)	Cost Hull (SEK/ton)	Cost Hamburg (SEK/ton)
		Loading	Time	SEK/h	SEK/ton			
Processing Industry, Boden	Harbour Piteå	20	03:15	800	79	99	649	699
Processing Industry, Luleå	Harbour Piteå	20	02:30	800	61	81	631	681
Processing Industry, Piteå	Harbour Piteå	20	01:45	800	42	62	612	662
Processing Industry, Skellefteå	Harbour Piteå	20	03:15	800	79	99	649	699

Table 5. Price comparison between different locations of the Processing Industry and connecting harbours in Europe with ship and truck.

Processing Industry's closeness to the harbor will give us a lower transport costs.

5.3 Summary Price Model

To evaluate different mode of transport and different locations for the Processing Industry and Market following estimated pricelist is set for calculating transportation costs.

Mode of transport	Transportation cost	Reloading cost
Rail	0,26 SEK/tonkm	20 SEK/ton
Truck	0,58 SEK/tonkm	20 SEK/ton
Shipping	0,12 SEK/tonkm	20 SEK/ton
Air-freight	1,16 SEK/tonkm	20 SEK/ton

Table 6. Price comparison between different mode of transports.

It is important to notice that this price model is used as a comparison between different transport solutions, it does not represent the market price. The price indication are not covering all alternative and cannot be used as a comparison and evaluation of different solutions. However, the price indication represents a market pricing and will be described in chapter 7.

6 Transport Conditions

6.1 Distances and travel time

Distances for road², rail³, and sea⁴ are collected from established sources. All destinations in the table below can be reached by road. Existing rail network allows freight transport from Kiruna through all proposed locations for the processing industry to Gothenburg or Hamburg.

The sea transports are calculated from the harbour in Piteå to corresponding harbours in Hull (UK) and Hamburg (Germany). The harbour in Piteå is used because it is the only port today which have regularly departures to Hull and Hamburg. Gothenburg has no regular shipping from Piteå today but it could be a possibility in the future.

Distance by air is estimated between airport in Luleå and Skellefteå and London-Heathrow, Hamburg Flughafen and Gothenburg-Landvetter. Luleå Airport is one of four Swedish state-owned airports, the only one in the northern part, which has sufficient capacity to accommodate larger aircraft (B747F). However, the airport has today no aircraft operators which handle regular freights. In this report airfreight will serve the locations in Boden, Luleå and Piteå. Skellefteå Airport is a municipality owned airport with no sufficient capacity to accommodate larger aircraft and no aircraft operators

² <http://se.vagavstand.himnera.com/>

³ <http://www.tydal.nu/article/avstandsberakning/> and <https://www.trafikverket.se>

⁴ <https://sea-distances.org/>



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which handle regular freights. However, in this report airfreight will serve the location in Skellefteå.

Travel time is estimated using the same established sources as the distances. Intermodal handling of the goods, change of drivers, turn-around locomotives and other minor time-consuming activities are not included in the travel time.

Transportation Rout		Transport Distance (km)				Transport Times (hh:mm)			
From	To	Road	Rail	Sea	Air	Road	Rail	Sea	Air
Mine/Concentrator, Nunasvaara	Terminal, Kiruna	47				00:45			
Terminal, Kiruna	Terminal, Boden		275				01:50		
Terminal, Boden	Exfoliation Plant/Purify, Boden	5				00:15			
Terminal, Kiruna	Terminal, Luleå		310				02:50		
Terminal, Luleå	Exfoliation Plant/Purify, Luleå	15				00:30			
Terminal, Kiruna	Exfoliation Plant/Purify, Piteå		374				03:50		
Terminal, Kiruna	Exfoliation Plant/Purify, Skellefteå		510				04:50		
Mine/Concentrator, Nunasvaara	Exfoliation Plant/Purify, Boden	311				04:30			
Mine/Concentrator, Nunasvaara	Exfoliation Plant/Purify, Luleå	354				04:45			
Mine/Concentrator, Nunasvaara	Exfoliation Plant/Purify, Piteå	402				05:05			
Mine/Concentrator, Nunasvaara	Exfoliation Plant, Skellefteå	476				06:00			
Terminal, Boden	Terminal, Hamburg		1 982				49:46		
Terminal, Luleå	Terminal, Hamburg		2 017				50:25		
Purify, Piteå	Terminal, Hamburg		1 987				48:32		
Purify, Skellefteå	Terminal, Hamburg		1 872				46:03		
Purify, Boden	Harbour Piteå	94				01:30			
Purify, Luleå	Harbour Piteå	70				01:05			
Purify, Piteå	Harbour Piteå	5				00:15			
Purify, Skellefteå	Harbour Piteå	93				01:30			
Harbour Piteå	Harbour, Hull			2 548				138:00	
Harbour Piteå	Harbour, Hamburg			1 754				95:00	
Purify, Boden	Airport, Luleå	42				00:45			
Purify, Luleå	Airport, Luleå	12				00:30			
Purify, Piteå	Airport, Luleå	67				01:00			
Purify, Skellefteå	Airport, Skellefteå	24				00:35			
Airport, Luleå	Airport, London-Heathrow				2 021				02:35
Airport, Luleå	Airport, Hamburg Flughafen				1 459				01:55
Airport, Luleå	Airport, Landvetter-Gothenburg				1 017				01:20
Airport, Skellefteå	Airport, London-Heathrow				1 917				02:25
Airport, Skellefteå	Airport, Hamburg Flughafen				1 373				01:45
Airport, Skellefteå	Airport, Landvetter-Gothenburg				905				01:10
Terminal, Boden	Terminal, Gothenburg		1 385			16:00	23:05		
Terminal, Luleå	Terminal, Gothenburg		1 420			15:44	23:44		
Purify, Piteå	Terminal, Gothenburg		1 390			15:00	23:10		
Purify, Skellefteå	Terminal, Gothenburg		1 275			14:00	21:15		
Terminal/Harbour/Airport	Market, UK/Germany/Western Sweden	50				01:00			
Purify, Boden	Market, Western Sweden	1 273				16:00			
Purify, Luleå	Market, Western Sweden	1 246				15:45			
Purify, Piteå	Market, Western Sweden	1 193				15:00			
Purify, Skellefteå	Market, Western Sweden	1 111				13:55			
Supply	Exfoliation Plant	20				00:30			
Exfoliation Plant, Boden	Disposal	5				00:10			
Exfoliation Plant, Luleå	Disposal	20				00:25			
Exfoliation Plant, Piteå	Disposal	1				00:05			
Exfoliation Plant, Skellefteå	Disposal	7				00:15			
Supply	Concentrator	20				00:25			
Concentrator	Disposal	5				00:10			

Estimated distance

Table 7. Freight distances and travel time between different locations.

6.2 Road and Rail Capacity

6.2.1 Road Capacity

The roads that are in scope in this logistic flow are all classed as BK1 and no accessibility problems have been identified. BK1 means that vehicles with a maximum of 64 tonnes gross weight are allowed to drive on the road network. For example, a semi-trailer with a tare weight of 20 ton can load 44 tonnes of goods. Trucks with load can have a maximum length of 24 m (25,25m under certain circumstances).



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Bearing capacity for the Swedish road system can be reviewed in the road authority Trafikverkets National Road Database (NVDB)⁵. Bearing capacity for the Swedish road network is classified as BK1 for 95% of the Swedish road system.

Due to the volumes and the restrictions for the maximum length of trucks above there are no need to widen the E45 at the junction with the mine access road. The road from Mine to E45 needs to be investigated further. Geotechnical fieldwork is needed.

In Appendix 2 bearing capacity maps which verify BK1 for the route from mine to Kiruna via Svappavaara can be seen.

6.2.2 Rail Capacity

The bearing capacity on the railway network in Sweden is in general classed with axel load 22,5 tonnes and weight per meter 6,4 tonnes. It means that a common four-axel container wagon has a maximum loading weight of about 60 tonnes (gross weight 80 tonnes) in Europe. There is also a maximum train length of 640-meter due to limitations on siding tracks at the Swedish rail network.

In Appendix 3 maps of the rail road for the logistic flow from the mine to the process industry can be seen with bearing capacity and general information noted.

The capacity on the rail road in northern Sweden is restricted but for the volumes that are in scope in this project no capacity problems can be found.

The accessibility of trains on the railway are in some parts strained. On the single-line between Kiruna and Luleå drives long and heavy Iron Ore Freight Trains. Further south from Luleå there are a mix of different types of freight trains and passenger trains and close to larger cities there are fervent traffic by regional and commuter trains. This affect which time-slots that are available for Talga transport system.

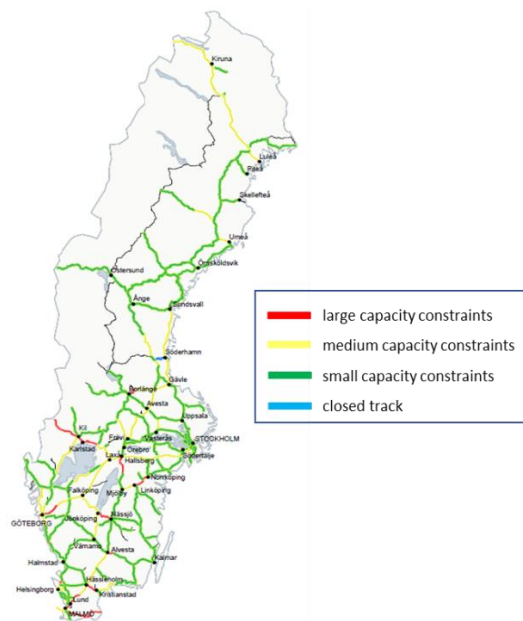


Figure 3. Capacity constraints on the Swedish railway net in 2017.

⁵ <https://nvdb2012.trafikverket.se/SeTransportnatverket>



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6.2.2.1 Svappavaara freight yards

The main freight yard in Svappavaara is owned by LKAB and adapted to their needs. LKAB have plans to expand the mining in Svappavaara which indicates that even though they open the freight yard to other operators it is very uncertain how much spare capacity that will be available.

When Northland Resources opened their operations in Kaunisvaara a new terminal was built in Pitkijärvi outside of Svappavaara. This terminal operated as an intermodal terminal for truck to train loading of the goods from Northlands mine. This terminal will probably be re-opened if Kaunis Iron will re-start the production in Kaunisvaara. The Pitkijärvi terminal will unfortunately be most suitable for the system trains run by Kaunis Iron.

No single-wagon distribution is planned for the terminals in Svappavaara which will make it a not suitable alternative due to high cost for the operations.

6.2.2.2 Gällivare freight yard

The freight yard in Gällivare was re-built last year. At the moment, no terminal operations are ongoing in Gällivare so no synergies with other transports can be found. The cost for starting up in Gällivare is too high with the volumes that are in scope at the moment.

For the future depending on where the processing industry will be situated, discussions with Boliden could be of interest since they have major transport flows from Gällivare-Aitik mine to Skellefteå harbour and their process industry- Rönnskärsverken.

6.2.2.3 Boden and Luleå freight yards

A location in Boden and Luleå requires a truck transportation the last distance from the railway which entails an extra intermodal handling to move the goods. The rail yards in Boden and Luleå stations are filled with both passenger and freight trains which reduces the accessibility to reload goods.

Boden – In the northern part of the freight yard in Boden an area which could be used as an intermodal terminal can be found see appendix 4. The transport from this terminal to the process industry is approximately 5 km.

In Luleå two different options for intermodal handling have been identified;

- Gammelstad, north of Luleå, is an existing intermodal terminal. The transport from Gammelstad to the process industry is approximately 17 km.
- The old LKAB harbour is another option for loading and unloading the trains. The transport to the process industry will still be approximately 11 km due to restriction for passage through the SSAB and LKAB sites in the harbour. The freight yard close to the SSAB Steelwork is currently fully utilized by LKAB and SSAB freight trains and more or less closed for other companies.

Another possible option for the future in Luleå is the Luleå harbour tracks. Luleå port is planning an expansion which will create better conditions for the rail capacity in the harbour area. It will probably also open up operations for other companies than SSAB and LKAB. There are also early plans to establish a railway vehicle workshop near SSAB's facility. If it will be built, it could include some space for intermodal handling.



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6.2.2.4 Piteå and Skellefteå freight yards

According to site investigations Piteå and Skellefteå is close to existing railroad. The goods could at both these sites be handled directly from the trains to the process Industry. However, a track and a hard-made area for loading and unloading would be needed to establish for the trains in order not to hinder other rail transportations. An approximately cost for a simple siding-track design is 5-10 MSEK depending on the ground conditions.

Skellefteå port is re-locating the container port to a location closer to the planned Processing industry. This will have a positive effect for any planned Sea transports but also for possibilities to consolidate logistic flows with other operators with container freights. However, they compete with Piteå on container freights and today Skellefteå have no regular shipping.

6.3 Cargo Transport Units

Transportation can be performed with different load carriers depending on the character of the cargo and suitable mode of transport. It is up to the transporter or freight intermediary to offer suitable transport units. This report is delimited to assumption on best practice load carrier for different types of cargo. To simplify the investigation, all goods are assumed to be transported in containers to facilitate intermodal handling.

Containers can be loaded and unloaded, stacked, transported efficiently over long distances, and transferred from one mode of transport to another—container ships, rail transport flatcars, and semi-trailer trucks—without being opened. The handling system is completely mechanized and all handling will be done with special forklift trucks. A standard container has a width of 2 438 m and a height of 2 591 m, adapted to be carried by a truck or rail flatcar. A 20-foot container maximum gross weight is 24 tonnes with 21,6 tonnes of cargo and could accommodate 32,1 m³ goods or 11 EU-pallets. The larger 40-foot container has a maximum gross weight of 30,48 tonnes with 26,5 tonnes of cargo and could accommodate 57,9 m³ goods or 24 EU-pallets.

A container or ULD (Unit Load Device) is a standardized, reusable container for, usually highly worthy or urgently needed goods, to be transported intermodally by aircraft, truck or sometimes freight trains. There is an international standard for air-containers, and air-freight pallets. The standard is chosen to take advantage of the space in most aircraft types. The volume of air-containers varies between 3,48-8,95 m³, depending on aircraft model. In this report, a LD1-container carrying 4,9 m³ or 1,4 tonnes is used.



Figure 4. LD3 containers on a Boeing 747.



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A tank container is an intermodal container for the transport of liquids, gases and powders as bulk cargo. It is built to the ISO standards, making it suitable for different modes of transportation. Both hazardous and non-hazardous products can be transported in tank containers. The contents of the tank ordinarily range from 17 500 to 26 000 litres, or 17,5 – 26 m³. Because 20-foot tank container can be transported with either truck, train or boat, it is used for making comparison between mode of transports in this report. An estimated volume is 20 000 litres or 20 m³.

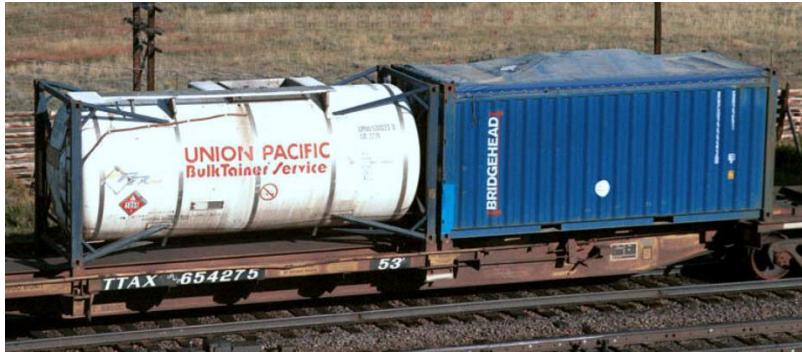


Figure 5. 20-foot standard container and 20-foot tank container on a rail flatcar.

Graphite anodes from the Mine to the Processing Industry are assumed to be cut into narrower slices, loaded on pallets and transported in 20-foot containers. Transportation will be done with semi-trailer truck carrying two 20-foot containers or by rail flatcars carrying two 20-foot containers per wagon.



Figure 6. Graphite blocks on EU-pallets.

The residual graphite back to the Mine and crushed graphite to the Concentrator is assumed to be transported in containers to optimise return transports, even if some type of open box should be preferable.

Inflow fluids and threatened effluent in the Processing Industry are transported in tank containers and inflow additives and treated residues in containers. From the Processing Industry, wet graphene is packed in bottles or IBC-package (intermediate bulk container) and dry graphene in drums. Both products are assumed to be transported in 20-foot containers.



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Figure 7. Wet graphene in bottles or IBC and dry graphene in drums.

6.4 Transport Economy

6.4.1 Supply and Disposal

All supply of material and disposal of waste for the Processing Industry are assumed to be served by truck on short distance by nearby locations.



Figure 8. Alternative transport solutions between the Mine and the Processing Industry.

The distance from Supply providers are assumed to be 20 km in the calculations in this report. The distance from the Process Industry to Disposal are shorter and calculations with more exact figures to nearby locations will influence costs.

Table 4 shows the average annual transport costs for supply and disposal of solid material, including reloading, for the Concentrator and Exfoliation Plant.

Transport Route		Product	Volume (tonnes)	Costs Truck (SEK)
Supply	Exfoliation Plant	Inflow Additives	36 407	1 148 844
Exfoliation Plant, Boden	Disposal	Treated Residues	2 995	68 552
Exfoliation Plant, Luleå	Disposal	Treated Residues	2 995	94 509
Exfoliation Plant, Piteå	Disposal	Treated Residues	2 995	61 630
Exfoliation Plant, Skellefteå	Disposal	Treated Residues	2 995	72 013
Supply	Concentrator	Inflow Additives	435	13 730
Concentrator	Disposal	Treated Residues	31 028	710 197

Table 8. Annual transport costs for inflow additives and treated residues to and from the Concentrator and Exfoliation Plant.

Regarding inflow of De-Ionised Water and outflow of treated effluent, it could either be transported from/to a nearby provider or provided through self-care. The volumes of in- and outcoming liquid material are very high and transport costs can be reduced considerably if a separate inhouse production of de-ionised water and water treatment plant is established.

For the following calculations, wet material is assumed to be handled in-house and all costs referring to transportation are set to zero.

6.4.2 Mine and Processing Industry by the coast

Between the Mine and the Processing Industry there are two solutions available, either a combination of truck and train or only by truck. A truck-train solution where the Processing Industry isn't close to existing railway need to have an extra handling on an Intermodal terminal.



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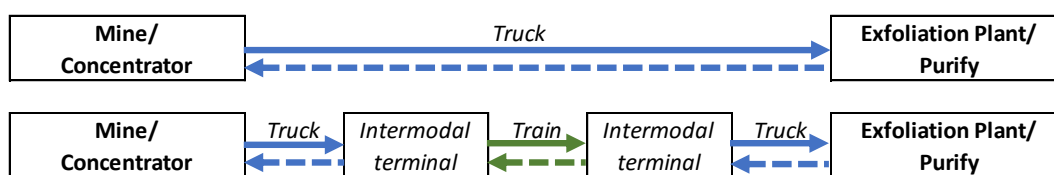


Figure 9. Alternative transport solutions between the Mine and the Processing Industry.

Truck is available to all locations of the Processing Industry. A more environmentally friendly solution could be a combination truck-train. Block train solution could be motivated between the Intermodal terminal in Kiruna and the Processing Industry if it occurs once a week. Otherwise, if delivery schedule need to be more frequent, a single-wagon solution where the train is shared with other customers could be an alternative.

On an annual basis, the following transport costs from the Mine to different Processing Industry location, including loading and unloading, will occur.

Transport Route		Product	Volume (tonnes)	Costs Truck (SEK)	Costs Train (SEK)
Mine, Nunasvaara	Exfoliation Plant, Boden	Graphite Anodes	7 000	1 397 831	1 130 816
Mine, Nunasvaara	Exfoliation Plant, Luleå	Graphite Anodes	7 000	1 571 744	1 234 961
Mine, Nunasvaara	Exfoliation Plant, Piteå	Graphite Anodes	7 000	1 765 878	1 150 775
Mine, Nunasvaara	Exfoliation Plant, Skellefteå	Graphite Anodes	7 000	2 065 169	1 398 297
Concentrator	Purify, Boden	Bulk Graphite	7 880	1 573 557	1 272 975
Concentrator	Purify, Luleå	Bulk Graphite	7 880	1 769 333	1 390 213
Concentrator	Purify, Piteå	Bulk Graphite	7 880	1 987 873	1 295 443
Concentrator	Purify, Skellefteå	Bulk Graphite	7 880	2 324 789	1 574 082
Exfoliation Plant, Boden	Mine/Concentrator	Residual Graphite	1 500	299 542	242 322
Exfoliation Plant, Luleå	Mine/Concentrator	Residual Graphite	1 500	336 810	264 639
Exfoliation Plant, Piteå	Mine/Concentrator	Residual Graphite	1 500	378 412	246 600
Exfoliation Plant, Skellefteå	Mine/Concentrator	Residual Graphite	1 500	442 547	299 641

Table 9. Annual cost comparison between the Mine and different locations of the Processing Industry.

Distance between the Mine and the Processing Industry gives a direct result in higher transport costs. The lowest transport costs are if the goods are carried out with train to Boden and the highest is by truck to Skellefteå.

6.4.3 Processing Industry and Markets

Three types of Graphene products will be transported from the Processing Industry to the Market; Talphene, Talphite and Battery Grad Graphite, with market hubs in Hull, Hamburg and Gothenburg for further distribution. In Sweden, the transport mode can either be by truck or train, while transport to Europe can be performed by truck, train or ship and occasionally by aircraft.

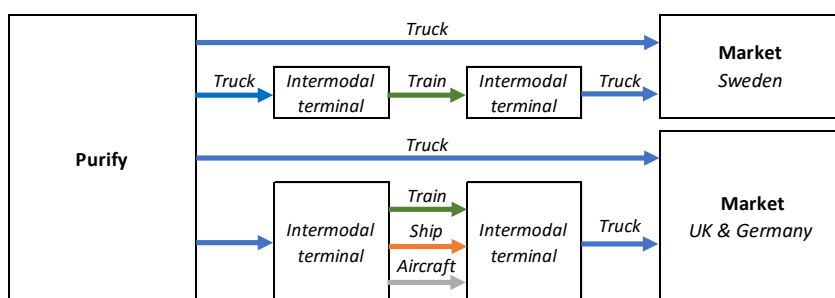


Figure 10. Alternative transport from the Processing Industry to the Markets in Sweden and Europe.



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Also among these transports alternatives, the simplest solution to set up is by truck. In the early phases of production, truck is the preferred alternative due to low number of containers to be carried out. On longer terms, truck is available in all situations, as sole solution or in combination with other modes of transport. Train between the Processing Industry and the Markets could be an alternative solution with single-wagon transportation. Also, sea-freight could be a good solution with regular and grouped sending's. Transportation by ship needs to be planned thoroughly after market demand due to long travelling time. Air-freight could arise occasionally as a single time-sensitive transport in small volumes or as a long-distance transportation to a customer outside Europe.

On an annual basis, the following transport costs from the Processing Industry to the Markets, including reloading, will occur.

Transport Route		Product	Volume (tonnes)	Costs Truck (SEK)	Costs Train (SEK)	Costs Ship (SEK)	Costs Aircraft (SEK)
Purify, Boden	Market, UK	45% final products	5 654			2 557 760	13 979 989
Purify, Luleå	Market, UK	45% final products	5 654			2 479 354	13 782 667
Purify, Piteå	Market, UK	45% final products	5 654			2 267 004	14 143 334
Purify, Skellefteå	Market, UK	45% final products	5 654			2 554 493	13 185 472
Purify, Boden	Market, Germany	45% final products	5 654		3 432 710	2 013 032	10 306 000
Purify, Luleå	Market, Germany	45% final products	5 654		3 516 833	1 934 626	10 108 679
Purify, Piteå	Market, Germany	45% final products	5 654		3 310 641	1 722 277	10 469 346
Purify, Skellefteå	Market, Germany	45% final products	5 654		3 141 577	2 009 765	9 625 826
Purify, Boden	Market, Western Sweden	10% final products	1 257	949 336	567 804		1 861 720
Purify, Luleå	Market, Western Sweden	10% final products	1 257	929 734	586 499		1 664 398
Purify, Piteå	Market, Western Sweden	10% final products	1 257	891 982	540 678		2 025 065
Purify, Skellefteå	Market, Western Sweden	10% final products	1 257	835 353	503 107		1 567 468

Table 10. Annual cost comparison between different mode of transport, locations of Processing Industry and Markets.

In the table above, Skellefteå has the lowest costs due to its closeness to the Markets. Cost change depending how available the Processing Industry is to other modes of transportation, Boden and Luleå aren't close to railway, Boden and Piteå aren't close to airports and Boden isn't close to a harbour. To mention is that train with single-wagon solutions, despite several transshipments, is more favourable than truck on long distance due to lower cost per ton. Sea-freight are most price worthy and calculated from Piteå to Hull and Hamburg due to today existing transport links. Aircraft costs are calculated from Luleå and Skellefteå Airport to all Markets but are approximately five times more expensive than rail or sea-freights.

6.4.4 Summary Mine and Market

In a summary, transport costs from the Mine to the Markets passing Processing Industry will change which mode of transport and locations that are most promising.

Transport Route			Costs Truck (SEK)	Costs Truck-Train (SEK)	Costs Train-Train (SEK)	Costs Truck-Ship (SEK)	Costs Train-Ship (SEK)	Costs Truck-Aircraft (SEK)	Costs Train-Aircraft (SEK)
Mine, Nunansvaara	Purify, Boden	Market, UK				7 770 014	7 145 196	19 192 243	18 567 425
Mine, Nunansvaara	Purify, Luleå	Market, UK				8 124 521	7 336 447	19 427 834	18 639 761
Mine, Nunansvaara	Purify, Piteå	Market, UK				8 333 568	6 894 223	20 209 898	18 770 553
Mine, Nunansvaara	Purify, Skellefteå	Market, UK				9 331 782	7 771 297	19 962 761	18 402 276
Mine, Nunansvaara	Purify, Boden	Market, Germany		8 644 964	8 020 146	7 225 286	6 600 468	15 518 254	14 893 437
Mine, Nunansvaara	Purify, Luleå	Market, Germany		9 162 000	8 373 927	7 579 793	6 791 720	15 753 846	14 965 772
Mine, Nunansvaara	Purify, Piteå	Market, Germany		9 377 205	7 937 860	7 788 841	6 349 496	16 535 910	15 096 565
Mine, Nunansvaara	Purify, Skellefteå	Market, Germany		9 918 867	8 358 381	8 787 054	7 226 569	16 403 116	14 842 630
Mine, Nunansvaara	Purify, Boden	Market, Western Sweden	6 161 590	5 780 058	5 155 240			7 073 974	6 449 156
Mine, Nunansvaara	Purify, Luleå	Market, Western Sweden	6 574 901	6 231 666	5 443 592			7 309 565	6 521 492
Mine, Nunansvaara	Purify, Piteå	Market, Western Sweden	6 958 546	6 607 241	5 167 897			8 091 629	6 652 284
Mine, Nunansvaara	Purify, Skellefteå	Market, Western Sweden	7 612 643	7 280 396	5 719 911			8 344 758	6 784 272

Table 11. Annual cost comparison between different mode of transport, locations of Processing Industry and Markets from Mine to Market.



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To the Market in Western Sweden, train is the most cost-efficient transport solution, both from Mine to Processing Industry and further to market. The most promising location for Processing Industry are in Boden.

To the Market in UK, sea and air-freight are the solutions from the Processing Industry were sea-freight with a combination of rail transportation from the Mine is most cost efficient. Piteå has the most promising location for the Processing Industry.

The German Market are similar with the UK market but has also been calculated with a train solution. Sea-freight with a combination is most cost-efficient but rail could be an alternative solution if other locations for the Processing Industry than Piteå will be more favourable.

6.5 Transport Capacity

Assumption must be made when choosing mode of transport. For example, a semi-trailer truck and a rail flatcar could carry two 20-foot containers, one container ship could take all annual containers on one journey and a Boeing 747 could load 32 LD1-containers per aircraft. To notice is that some rail flatcars can carry three 20-foot container. Regarding liquid material a semi-trailer isn't available due to road bearing capacity and a flatcar could carry two 20-foot tank container but the loading must be reduced depending which axel load is allowed. However, this can be customized to the needs with other more suitable load carrier.

Transport capacity is calculated as the number of load carriers needed to transport a weekly volume of different types of goods. Containers could either be 20-foot standard container or 20-foot tank container depending if the goods are solid or liquid. LD1-container are used in air-freight for market distribution.

Type of goods	Volumes		Weekly number of containers/LD1		Weekly number of transport carrier				
	Weekly	Unit	Container	LD1	Single truck	Semi-trailer	Rail wagon	Ship	Aircraft
Graphite Anodes	135	tonnes	8,2		1	4	5		
Residual Graphite	10	tonnes	0,6		1		1		
Inflow Additives, Concentrator	8	tonnes	0,5		1				
Treated Residues, Concentrator	597	tonnes	36,2		1	18			
Crushed Graphite	19	tonnes	1,2			1	1		
Bulk Graphite/Battery Grad Graphite	152	tonnes	9,2	106,9		5	5	1	3
Inflow Additives, Exfoliation Plant	700	tonnes	42,4		1	21			
Treated Residues, Exfoliation Plant	58	tonnes	3,5			2			
Talphen	54	m³	3,3	38,0		2	2	1	2
Talphen	36	tonnes	2,2	2,1		2	2	1	1

Table 12. Number of freight carriers needed to transport weekly volumes of goods.

The weekly numbers of containers to be transported in the early phases are low and suitable to handle with truck on a daily basis. Rail could be an option as a single-wagon concept. For example, once a week a train with 10 wagons (Graphite Anodes and Bulk Graphite) could run between the Intermodal terminal in Kiruna and Processing Industry instead of 2-3 trucks per day. Also, a train with modern traction power can increase capacity and pull 32 wagons in one trip, while every additional container requires one extra truck.

Sea-freight could be done with one ship per week taking all containers in one sending. Aircraft could be an option to the market if this is the best practise.



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There are some synergies in return transportation. For example, the same truck or train with graphite anodes from the Mine could return from the Processing Industry with residual graphite. However, this transport will only fill 30-40 % of returning carriers. For the Market and transport of supply and disposal, no available returning transportation are assumed.

7 Price Indication for Transport System

In this chapter, calculations have been made on recommendation by Talga and with budget offers from freight forwarders on rail, road and sea that Talga have collected. The purpose is to illustrate the cost for a suggested solution for freight from mine to market in the same way as in the chapters above. However, there are some differences as follow:

- Calculation above are based on SEK per tonkm as described in chapter 5 and the budget offers are based on SEK per ton transported.
- Goods from the Mine to the Processing Industry are not loaded into containers before transportation as presented above. In this solution goods pallets weighing 1.5 ton are lifted directly on trucks at the Mine site, and either go directly to the Processing Industry or reloaded onto rail flatcars at the Intermodal terminal.
- Each truck will move 22 EU-pallets or 33 ton goods which will be reloaded onto one flatcar if train are included in the transport solution.
- All products from the Processing Industry to the Market will be loaded into containers which includes 11 EU-pallets or 16.5 ton goods per container.
- We assume a 50-50 share between the UK and Germany Markets.

In following tables, total cost on an annual basis are showed. These costs are representing a fairly good picture of market price. However, not all transport relation and mode of transport are illustrated. But the results are similar to what is described in chapter 6.

Transport Route		Product	Volume (tonnes)	Costs Truck (SEK)	Costs Train (SEK)
Mine, Nunasvaara	Exfoliation Plant, Boden	Graphite Anodes	7 000	2 506 000	2 585 970
Mine, Nunasvaara	Exfoliation Plant, Luleå	Graphite Anodes	7 000	2 548 000	2 698 394
Mine, Nunasvaara	Exfoliation Plant, Piteå	Graphite Anodes	7 000	2 674 000	2 191 000
Mine, Nunasvaara	Exfoliation Plant, Skellefteå	Graphite Anodes	7 000	2 828 000	2 541 000
Concentrator	Purify, Boden	Bulk Graphite	7 880	358 000	369 424
Concentrator	Purify, Luleå	Bulk Graphite	7 880	364 000	385 485
Concentrator	Purify, Piteå	Bulk Graphite	7 880	382 000	313 000
Concentrator	Purify, Skellefteå	Bulk Graphite	7 880	404 000	363 000
Exfoliation Plant, Boden	Mine/Concentrator	Residual Graphite	1 500	716 000	738 848
Exfoliation Plant, Luleå	Mine/Concentrator	Residual Graphite	1 500	728 000	770 970
Exfoliation Plant, Piteå	Mine/Concentrator	Residual Graphite	1 500	764 000	626 000
Exfoliation Plant, Skellefteå	Mine/Concentrator	Residual Graphite	1 500	808 000	726 000

Table 13. Annual cost comparison between the Mine and different locations of the Processing Industry by truck or a combination truck-train.

In the table above all volumes of goods between the Mine or Concentrator and the Processing Industry are included.



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Transport Route		Product	Volume (tonnes)	Costs Ship (SEK)
Purify, Boden	Harbour, Hull	50% final products	6 283	4 076 010
Purify, Luleå	Harbour, Hull	50% final products	6 283	3 961 783
Purify, Piteå	Harbour, Hull	50% final products	6 283	3 847 555
Purify, Skellefteå	Harbour, Hull	50% final products	6 283	4 076 010
Purify, Boden	Harbour, Hamburg	50% final products	6 283	4 390 135
Purify, Luleå	Harbour, Hamburg	50% final products	6 283	4 275 908
Purify, Piteå	Harbour, Hamburg	50% final products	6 283	4 161 680
Purify, Skellefteå	Harbour, Hamburg	50% final products	6 283	4 390 135

Table 14. Annual cost comparison between different locations of Processing Industry and arrival harbour by a combination truck-ship.

Cost for transportation from harbour to market are not included in the table above.

Transport Route			Costs Truck-Ship (SEK)	Costs Train-Ship (SEK)
Mine, Nunansvaara	Purify, Boden	Harbour, Hull	8 086 266	8 200 508
Mine, Nunansvaara	Purify, Luleå	Harbour, Hull	8 032 039	8 246 887
Mine, Nunansvaara	Purify, Piteå	Harbour, Hull	8 097 811	7 407 811
Mine, Nunansvaara	Purify, Skellefteå	Harbour, Hull	8 546 266	8 136 266
Mine, Nunansvaara	Purify, Boden	Harbour, Hamburg	8 400 391	8 514 633
Mine, Nunansvaara	Purify, Luleå	Harbour, Hamburg	8 346 164	8 561 012
Mine, Nunansvaara	Purify, Piteå	Harbour, Hamburg	8 411 936	7 721 936
Mine, Nunansvaara	Purify, Skellefteå	Harbour, Hamburg	8 860 391	8 450 391

Table 15. Annual cost comparison between different locations of Processing Industry from Mine to arrival harbour.

In the total cost from Mine to arrival harbour, in the table above, cost for supply and disposal are not included. If the indicative pricelist for these transports is used an estimation is that it will double the total price, approximately 9.0-9.3 MSEK.

8 Conclusions

Cargo freights can be combined with different mode of transport for various reasons, such as environmental aspect, transport economy or more efficient logistics. To consider is, when moving goods from one mode of transport to another, an extra terminal handling is added which can be costly for the system.

To notice is that volumes of final products to the Markets are estimated in the theoretical price model to 45% UK and Germany respectively and 10% to Western Sweden. In the indicative price model, the distribution is set to 50-50 between UK and Germany. Also, a difference is that in theoretical price transport costs between supply and disposal are included which is missing in indicative price model.

In this report, the conclusion is that train and ship solution joint with intermodal truck transportation is the most cost-efficient alternative from Mine to European Market. Locations for the Processing Industry do not differ too much, but Piteå (6.9 MSEK) seems to be the best alternative for the UK market and Luleå (6.8 MSEK) for the German market related to transport distance. According to indicative pricing Piteå is the most favourable for both markets with a train and ship solution (Hull 7.4 MSEK and Hamburg 7.7 MSEK).



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If an investment in siding track close to the Process Industry are included (approx. 5-10 MSEK), Luleå will be the best option on an annual basis. In this case indicative pricing shows that trucking from the Mine combined with sea-freight to the Markets are most cost-efficient (indicative cost 8.0 MSEK). However, investment in siding track on a lifecycle cost for 20 years will not be an issue.

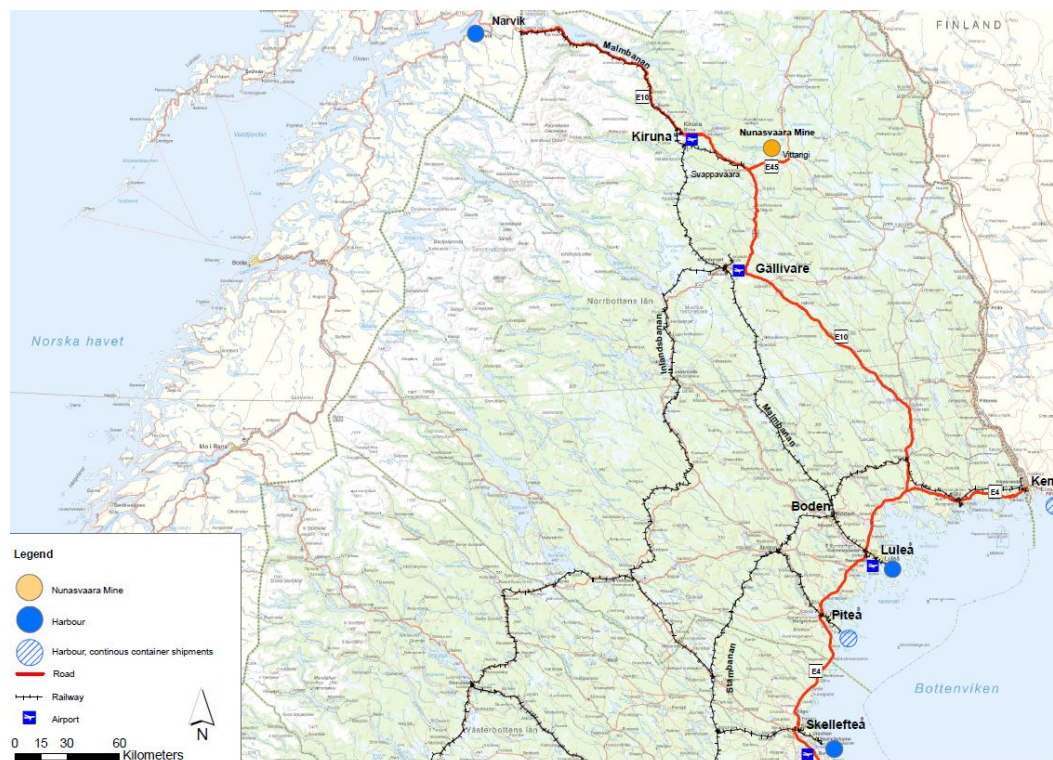
For the Market in Western Sweden which has been assumed to be 10% of total volumes to market, train combined with intermodal truck transportation is the best option, and Boden (5.16 MSEK) or Piteå (5.17 MSEK, excluding siding track) has the lowest costs for the Processing Industry location.

The conclusion of this report is that out of a transportation perspective Piteå seems to have the best location for the Processing Industry. Piteå has accessibility to all types of transport modes, regular shipping from the harbour and seems to be the best solution referring to lowest costs. However, there are some issues which hasn't been analysed regarding location of supplying additives and more specified market locations which could cause a re-evaluation of the results.

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Appendix 1. Maps road and rail

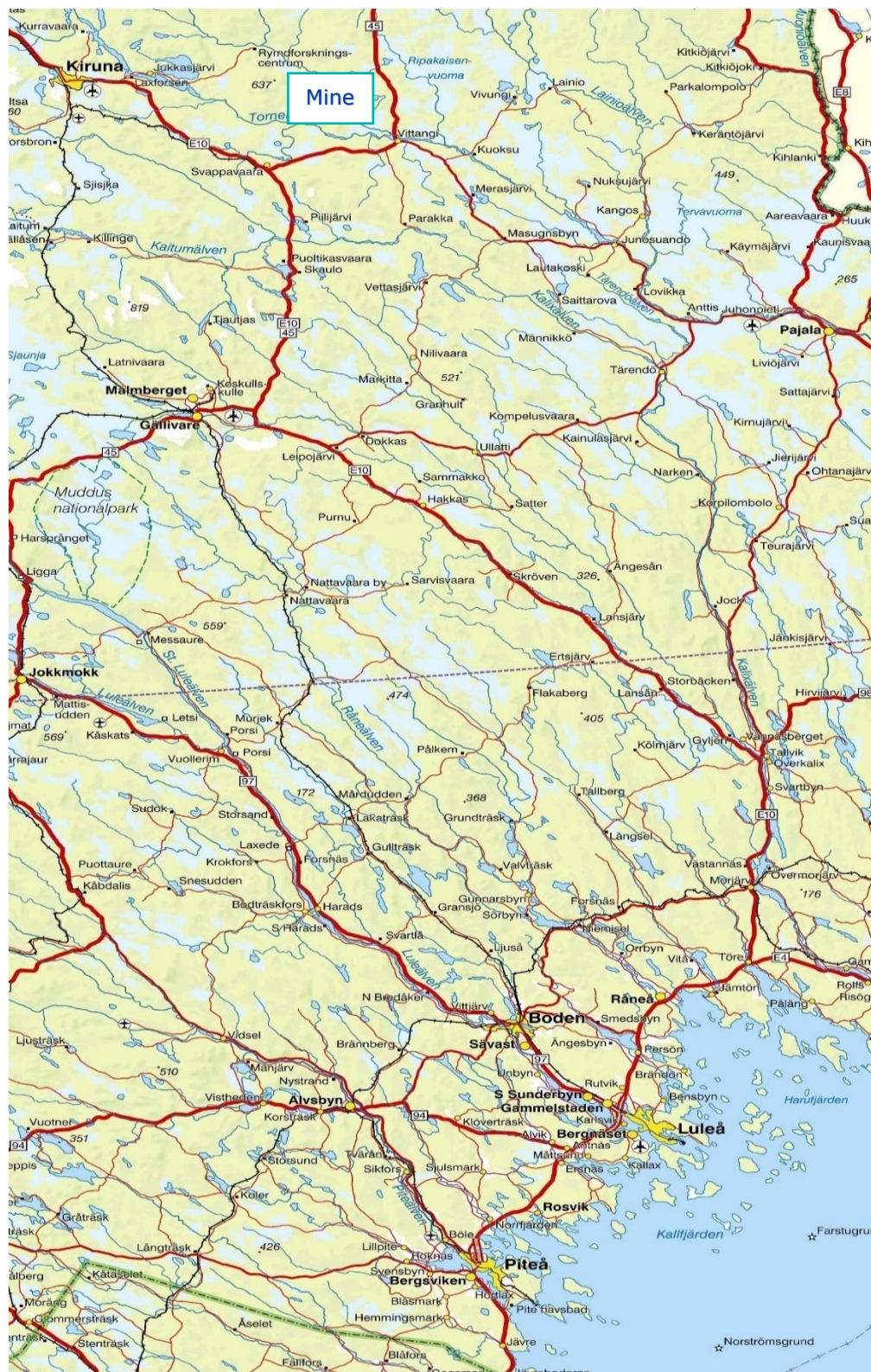


1a. Overall Infrastructure map

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1b. Road map Norrbotten



Transport route (truck from mine to industry):

E45 from mine to Svappavaara - E10 Svappavaara- Töre - E4 Töre-Luleå- LULEÅ
 99 Luleå- BODEN
 E4 Luleå - Piteå PITEÅ/SKELLEFTEÅ

A detailed map of the Bergslagen region in Sweden. The map shows a network of roads, including major highways like E4 and E6, and numerous smaller towns and villages. Key cities labeled include Piteå, Boliden, Skellefteå, and Umeå. The map also depicts various water bodies, such as lakes and rivers, and includes a coordinate grid. The terrain is shown with green and brown shading, indicating different elevations and land use.

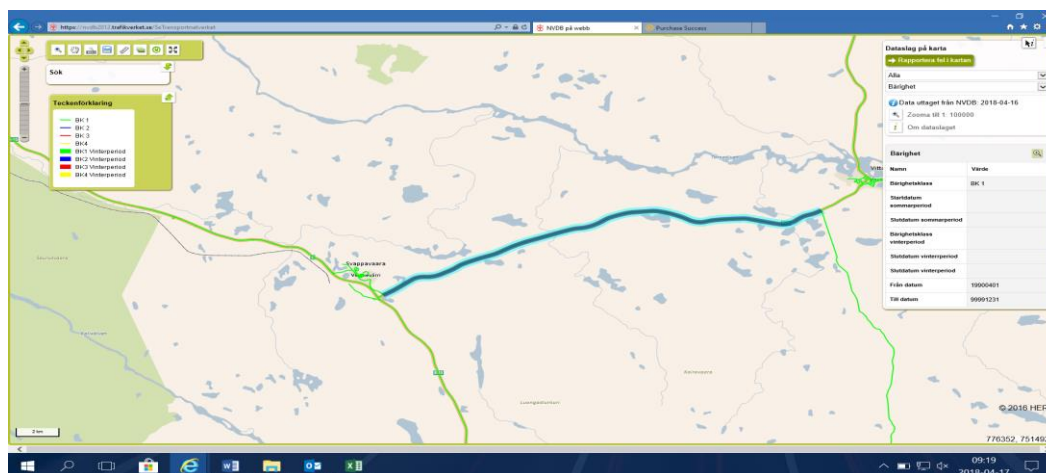
E4 Piteå-Skellefteå
372 Skellefteå-SKELLEFTEÅ (Skelleftehamn)



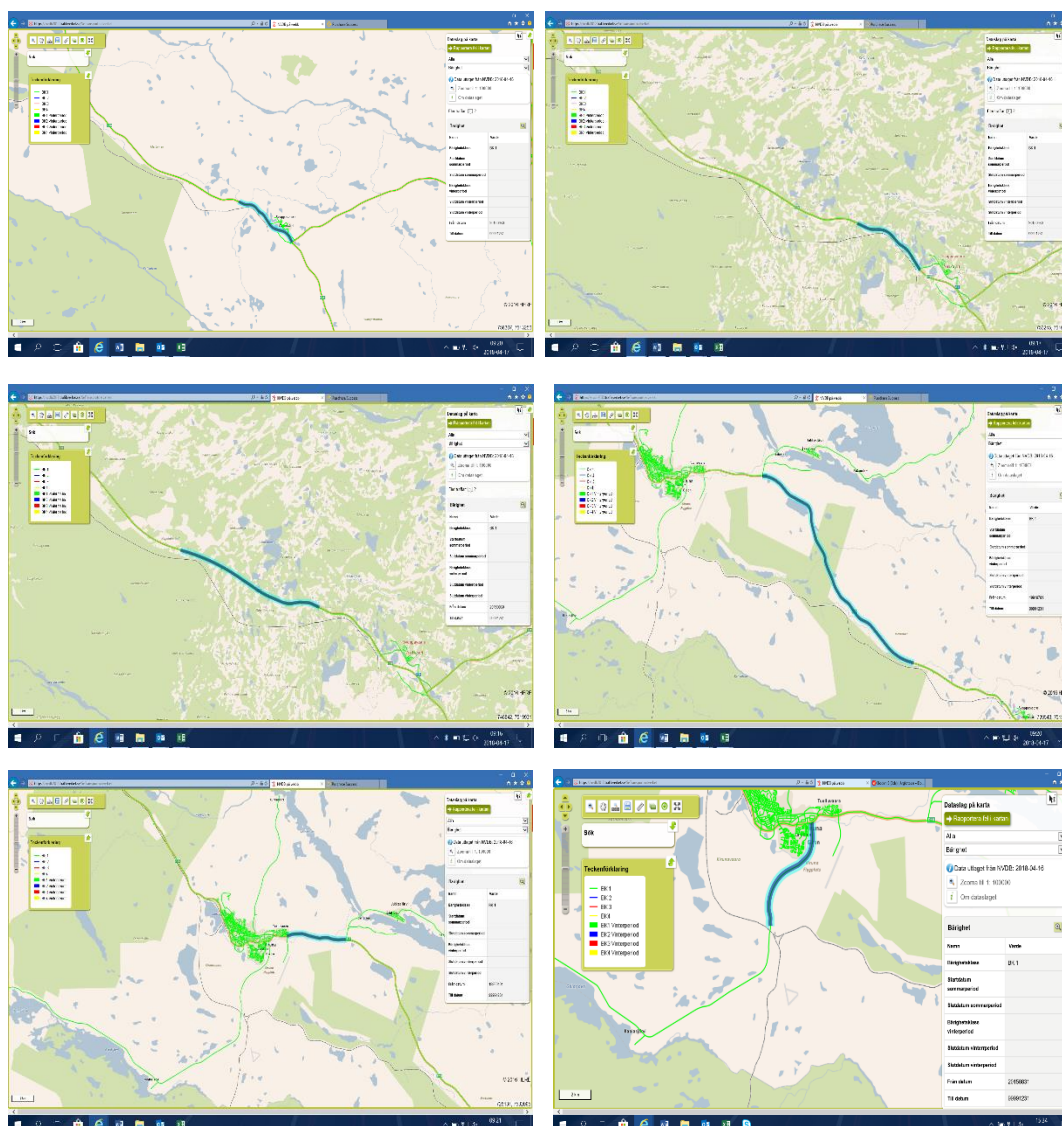
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Appendix 2. Bearing capacity (source www.trafikerket.se)

E45 from mine to E10 BK1



E10 from mine to Kiruna Combi terminal



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Appendix 3. Rail road maps (source www.trafikverket.se)



Malmbanan (Iron ore railway)

Iron ore, passenger and freight trains run on the 50-mile-long track. The Southern Circuit (Luleå-Boden-Gällivare-Kiruna) carries 7 million net tonnage.

Between Riksgränsen and Gällivare 30 tons of axle load is approved.

On the route Gällivare-Luleå 32,5 tonnes of axle load is approved.

Remote controlled, electrified track.



Stambanan Övre Norrland

Mainly trafficked by freight trains but also some passenger trains (night trains and some regional traffic between Luleå- Umeå)

25 tonnes of axle load is approved.

Remote controlled, electrified track.



Nyfors-Piteå:

Only trafficked by freight trains. 25 tonnes of axle load is approved.

Remote controlled, electrified track.

Bastuträsk-Skellefteå-Rönnskärsverken:

Only trafficked by freight trains. 25 tonnes of axle load is approved.

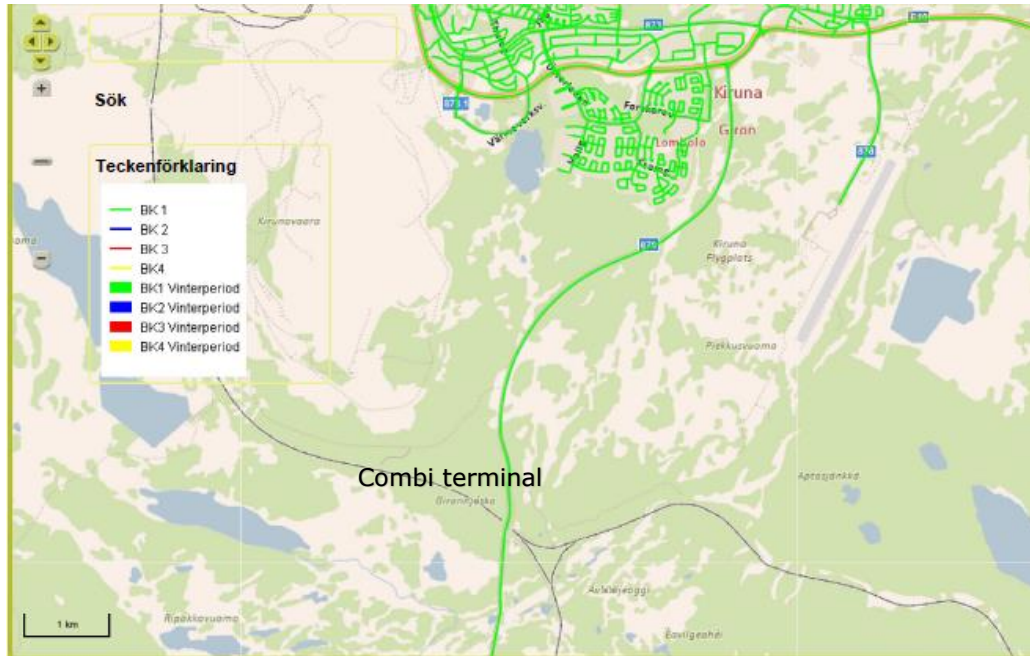
Manually controlled, electrified track.



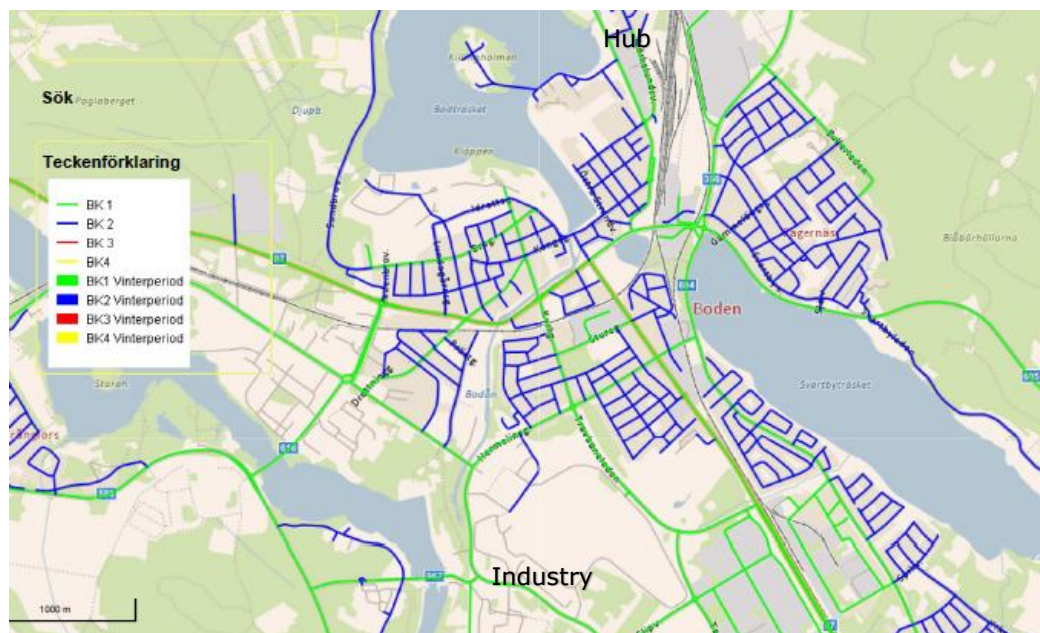
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Appendix 4. Possible intermodal hubs and terminals

Kiruna (Combi terminal truck-train)



Boden (hub north of railway station-shuttle transport to Industry)

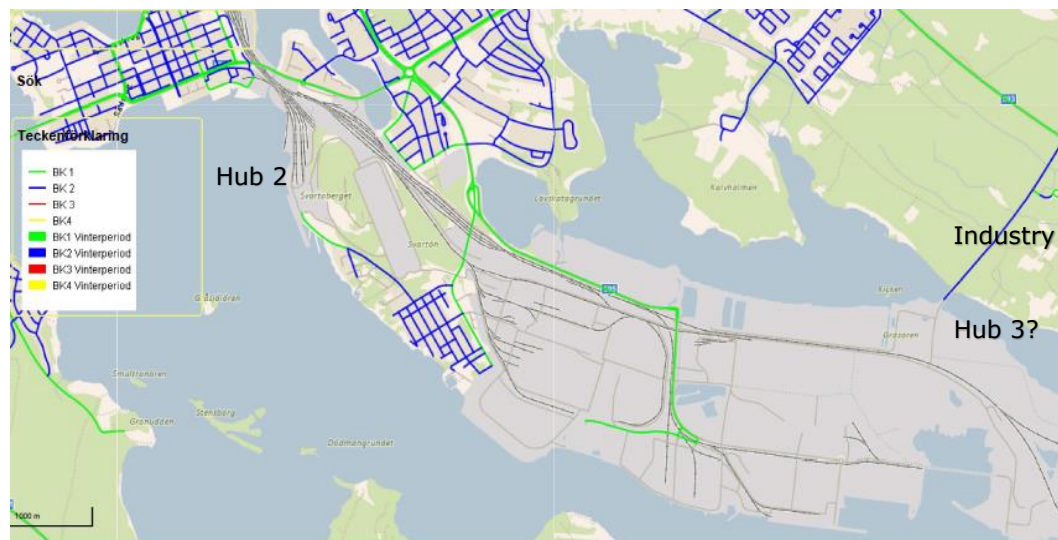
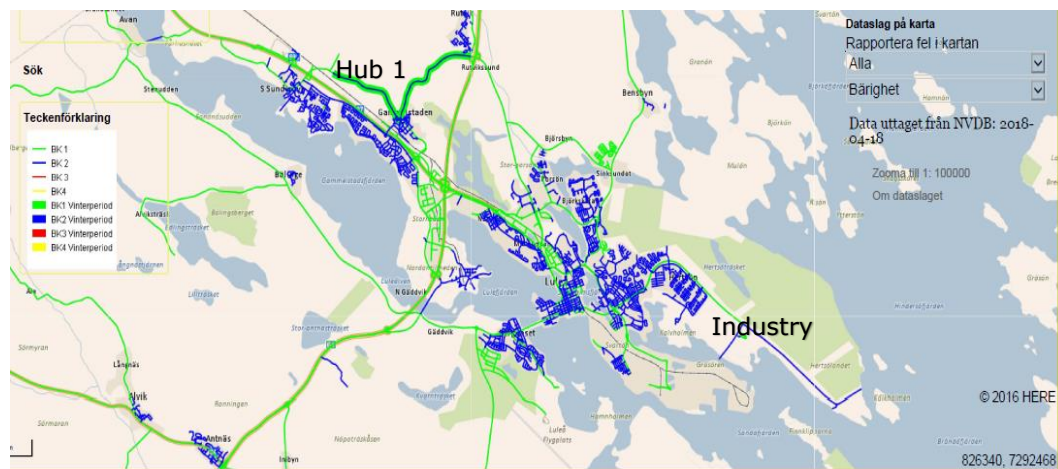


Distance from Hub to Industry approx. 5 km (10 min) shuttle traffic through Boden City

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Luleå



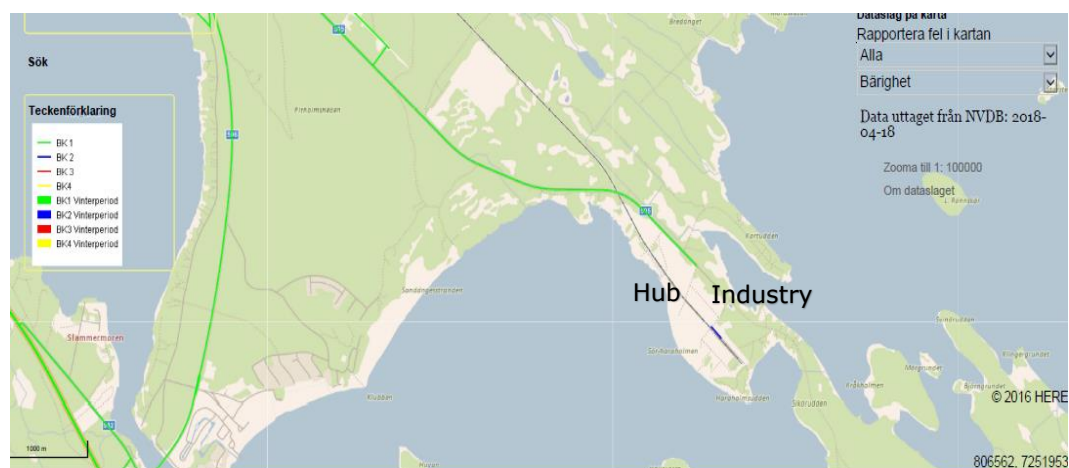
Distance from

Hub 1 to Industry approx. 17 km (20 min), via road 99 and through Luleå City to Industry

Hub 2 to Industry approx. 11 km (15 min), traffic through Luleå City to Industry

Hub 3 close to the Industry (not existing today)

Piteå Haraholmen

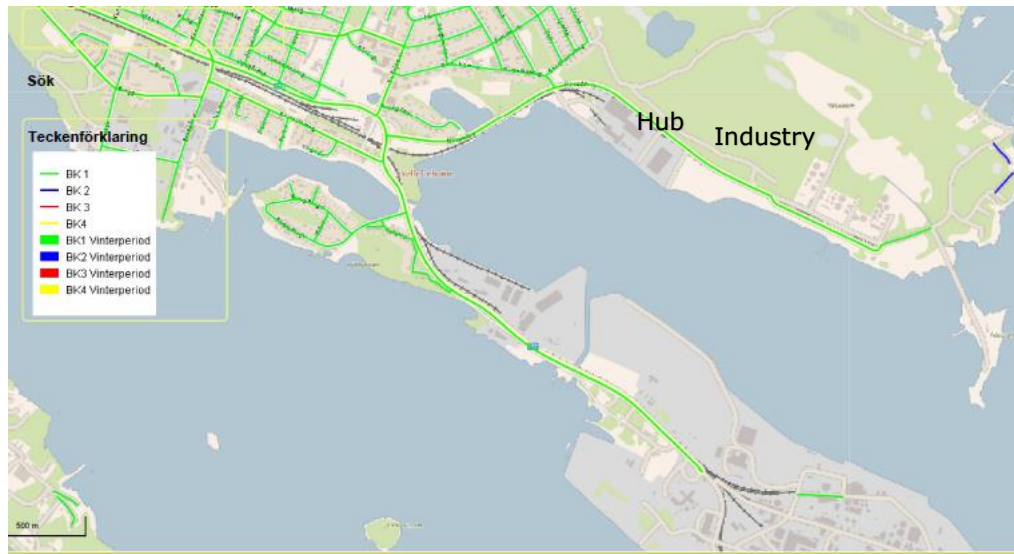


The hub/terminal is in direct connection with Industry

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Skellefteå



The hub/terminal is in direct connection with Industry