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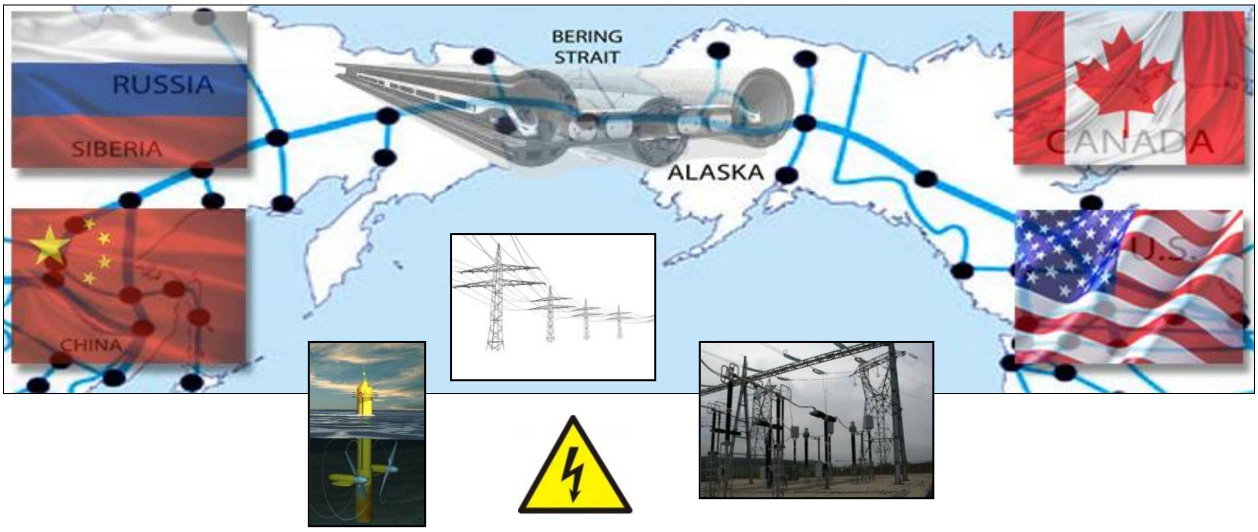

# Concept Study on the Electric Power Supply of the Bering Strait Tunnel

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# ABSTRACT

Numerous studies dealing with concepts of a railroad tunnel under the Bering Strait exist. However, this is the first examination on the traction power supply of electric trains running through such a tunnel. To begin with, the current market situation for trains between Eurasia and North America is analyzed in order to gain knowledge of the expected loading cases. This railroad corridor is suited for medium-weight loads to be hauled between East Asia and North America within one week. After considering the loading cases the speed is prioritized over the total weight of the trains. A load assumption of a total weight of 10,000 metric tons per train has been specified. The tunnel design of Inter Bering LLC indicates a length of 113 km for the Bering Strait Tunnel. Considering a total load of 10,000 metric tons and a speed of 100 km/h per train imply relatively high performance values (for European train systems). This report assessed the latter with regards to the electrical power supply. The results display that a sophisticated traction power supply is required to allow the specified trains to roll through the tunnel. These data are mainly used for designing the appropriate energy concept of the traction power supply. To feed the tunnel with the required power this concept study examines in a holistic view all elements of traction power: types of transmission lines, substations, frequency converters and contact lines. It recommends one system for each category. The suggested option envisions natural gas, geothermal, hydro and tidal power stations as the means of electricity generation. In terms of transmission high voltage direct current (HVDC) transmission lines are suggested. Moreover, modern static frequency converters, powerful substations with the latest technology of HVDC switchgear, autotransformers and an overhead conductor rail as contact line are proposed. The results of this concept study are considered to be a first approach for further inquiries of an energy concept for the tunnel. The ambition is to advance these rough data and simulate the entire traction power system of the tunnel and beyond. This is the only way to acquire proper results for the design and planning of the energy supply system of the Bering Strait Tunnel.

# CONTENT

# 1 Introduction

An official media report of the Chinese government mid 2014 was reason for sensation as the Chinese published their idea of both a new Silk Road and the feasibility of a Bering Strait Tunnel as the next projects in the future of transport. [35] With the participation of China a realization of a tunnel under the Bering Strait is becoming more and more likely. Several feasibility studies on the construction of a Bering Strait Tunnel are already available. However, the energy supply of such a tunnel including traction power is hardly mentioned or left out completely in those analyses.

The aim of this study is to point out the possibilities as well as the challenges which have consequences not only for the construction but also for the energy supply. Based on the available data and assumptions this study gives a general idea on possible scenarios of an energy supply for the Bering Strait Tunnel with traction power and offers an approximate suggestion of an energy concept. Due to the size and complexity of the overall project this study outlines the needed energy infrastructure only on a relatively superficial level. Details on construction are not mentioned in this document. Only a profound simulation can deliver detailed data on an energy system. Such an analysis is the next step in the design of the traction power system of the Bering Strait Tunnel.

As a preface to the project a short summary of the history of the tunnel and the boundary conditions is presented. Then, a review of available studies follows. Before potential alternatives of a possible traction power supply are illustrated a systemic analysis is conducted in order to outline all factors which affect the design of a power system inside this railroad tunnel and beyond. After this discussion the elements and the criteria of the traction power supply system are selected. These are evaluated and lead to a proposal of a complete traction power supply system of the tunnel. The study concludes with a summary and an outlook of the next necessary steps as well as further issues to be addressed.

## 1.1 History

For more than 100 years there have been studies on a railroad tunnel underneath the Bering Strait. In 1902 French engineer de Lobel convinced the governments of Russia, France, Canada and the US to support his plans of a tunnel. [65] Tsar Nikolai II endorsed this endeavor. So, in 1905 the planning of the project began but as well-known it was never realized. [66] This is mainly due to political and economic reasons. With the arms race, nationalism and developing conflicts in the beginning of the 20th century, World War I in particular, a physical link between North America and Russia became more and more difficult. After WWI the first communist state, the Soviet Union, had been established. It later became a powerful counter-pole to the capitalist West. During WWII the tunnel made it on the agenda again, since war material from the US needed to be shipped to the Soviet Western front. But the war ended before construction of the tunnel started and the project was stopped. [65] High levels of distrust between the two superpowers of the SU and the US characterized their relationship during the Cold War until the collapse of the Soviet Empire in 1991. A political rapprochement took place in the 1990s between Russia and the West. Ever since there have been efforts by US and Russian engineers for political support of a common link through the Bering Strait. [1][65] In 2011 the Kremlin issued its support for a 99 billion US dollar program to build the Bering Strait Tunnel. [67]

## 1.2 Politics

The route between Russia and North America not only means new economic and geographic connections but also new political ties between the two countries. This bears much symbolism. It is a link between the liberal West and the rather conservative Asia, for instance Russia and China.

As mentioned earlier, the plan for a tunnel under the Bering Strait is more than a hundred years old. Although technology plays an important role for the construction of the tunnel, this endeavor has been failing due to political reasons. The tunnel links Russia and the US. Both countries share a tradition of suspicion against each other. After a short period of rapprochement after the Cold War the relationship between the two countries is now back to another ice age. Due to the current crisis in Ukraine and the Western sanctions against Russia the climate between both countries can be described as chilling. Thus, the reality of the tunnel project becomes more distant. However, the Kremlin's support remains. [67] The Arctic is of extremely high strategic significance for Russia. A tunnel under the Bering Strait would underline the importance of the region. [40][57][58][36]

Though, one new player on the stage of world superpowers could turn the page towards the realization of the venture: China. Both Russia and the US are interested in a good relationship with China. With financial and diplomatic support the plan of the tunnel is becoming reasonable. In the diplomatic arena China is one of the few countries currently able to bring Russia and the US to the table and cooperate. [27][22]

## 1.3 Economics

From a trade perspective the construction of a tunnel under the Bering Strait would give the world economy strong headway. With the Chinese program of a "New Silk Road" [68] Europe is going to be linked closer to Asia, especially China. The next step would be the development of railroad lines in Russia from Yakutsk to the Bering Strait and the expansion in Western Canada and Alaska to the Eastern shore of the Bering Strait. Both serve as development of rural areas and as distributor railroads to the Bering Strait. By means of a tunnel the railroad networks of North America, Asia and Europe would be connected. The transportation of goods by rail is generally faster than by ship. Strong trade relations between certain countries such as the US and China would thrive even more than today.

Another aspect of developing the railroad in remote areas in Eastern Russia and Alaska is the exploitation of the local and regional natural resources. [35][36][1][66] Precious metals and other resources such as natural gas and oil are suspected in those areas. The regions along the railroads would benefit from development and attract more people to work and settle there. For more details on economics please refer to chapter 2 "ancillary conditions."

Considering the current economic situation of the countries involved, a realization of the projection appears rather unlikely. Canada is in a recession, Russia suffers from the Western sanctions and from the low oil price, the US is heavily in debt and is still ailing because of the 2008 economic crisis. There is not much support expected from Europe, either. The project is outside of its zone of interest. Moreover, the EU is busy with challenges on its territory such as the refugees coming in from its vicinity, the debt crisis and saving the Euro. China features relatively low growth rates this year and the Chinese economy appears flagging. At present it seems quite unclear how the total amount of 134 billion US dollars [1] for the Bering Strait Tunnel and the 6000 kilometers of conventional railroad could be financed. Without the participation of the neighboring countries this project cannot be realized. On the other hand, China seems to follow Keynesian economics especially due to the current situation: in order to keep the economy afloat it is investing in the development of infrastructure, for instance high speed railroads to Western China, Vietnam, Central Asia and Russia. [68] This Chinese version of the New Deal could be the lifesaver for the project of.

**Figure 1.1: Outline of the Eurasian and North American rail network including the new section between Yakutsk to Fort Nelson [3]**

## 1.4 Further Challenges

Besides the vast expense the arctic climate and the geology play an important role. The tunnel and much of the distributor railroads are to be built on permafrost in the arctic tundra. This is feasible but requires an extreme engineering effort. In addition, the generation of electricity for the traction of the trains needs to be transmitted over enormous distances. Furthermore, there are administrative challenges such as diverse regulations, different languages, various minimum clearance outlines and diverse track gauges. Those challenges can be even amplified by different mindsets in culture. More of those implications are addressed in the following chapter.

# 2 Ancillary Conditions

This chapter deals with several important parameters for this survey. At first, existing studies for the construction of a Bering Strait Tunnel are evaluated. Then, a systemic analysis follows by illustrating the influencing factors for the traction power supply of the tunnel. A coarse examination on the profitability of the project comes next. The last part of this chapter explains the load assumptions for all calculations in this study.

## 2.1 Existing Studies

There are numerous feasibility studies about the construction of a Bering Strait Tunnel. Though, a number of them are considered as unrealistic. The proposals range from supersonic magnetic levitation trains to a three-level tunnel design including roads, railroads and magnetic trains as well as several cables and pipelines. [1]

The design closest to the current reality has been issued by Inter Bering LLC. This design proposes a 113 km long tunnel route between the Chukotka Peninsula, the Diomede Islands and Alaska (see figure 2.2). The engineers at Inter Bering have already carried out a geological survey (see figure 2.2). This tunnel model is similar to the Euro Tunnel between Britain and France. It consists of two tunnel tubes equipped with railroad installations and a third tunnel in between used for service, maintenance and evacuation in emergency with interconnecting tunnel sections at every 375 m. Yet, the Inter Bering design is not consistent in terms of conflicting cross sections. One plan displays the design as in the Euro Tunnel (see figure 2.1). Another cross section indicates that there is a three floor design per tube.

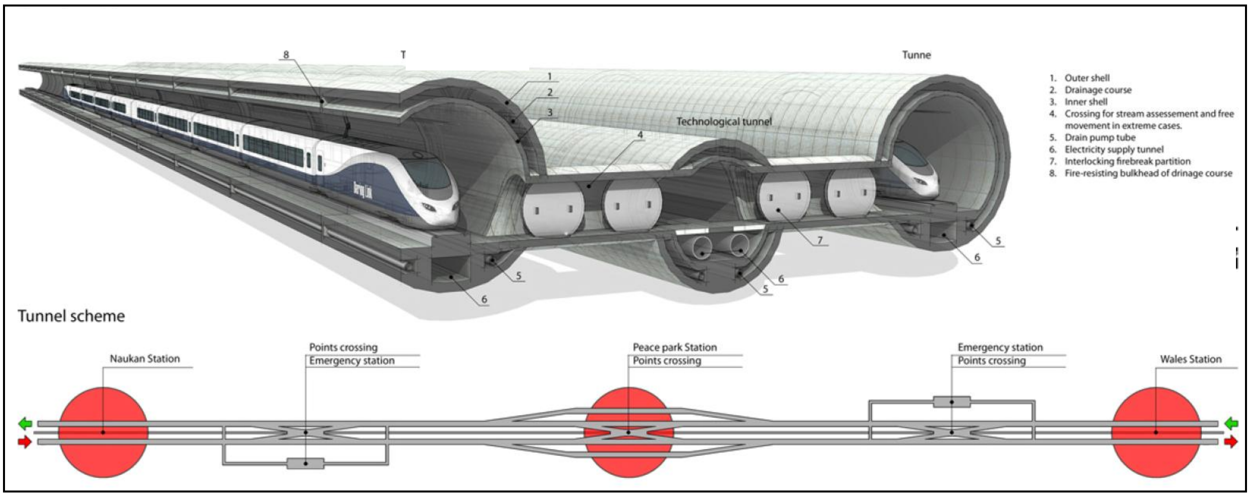


**Figure 2.1: Design of the Bering Strait Tunnel by Inter Bering LLC [5]**

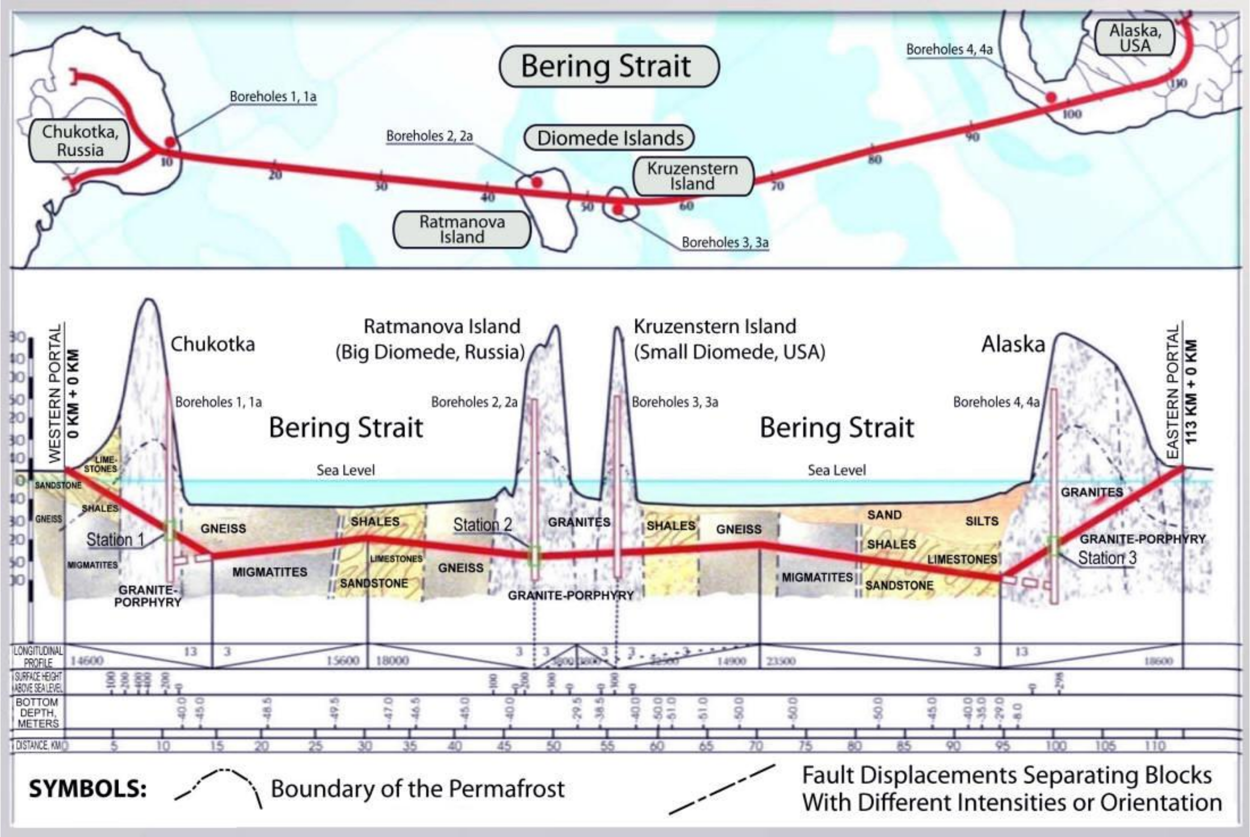


**Figure 2.2: Longitudinal section and layout of the projected tunnel route under the Bering Strait [4]**

The study conducted by Inter Bering proposes freight trains as main users of the tunnel, followed by communication lines and pipelines for oil and natural gas. The incurring costs of approx. 35 billion US dollars for the tunnel only are to be amortized after 15 years as Inter Bering assumes 10 billion US dollars of annual income. [1] By the year 2050 an annual turnover of 550 million tons of freight is estimated for the tunnel. [6] If converted into potential train loads this would mean e.g. 7 trains carrying a load of around 9,000 tons crossing the tunnel every hour (tunnel closings for maintenance and services not considered). This sounds ambitious but feasible.

For transferring electricity to the trains the study suggests transmission lines with a power of 15 GW and 1.5 MV of voltage alternating current (AC). [6] The electricity is going to be generated in very distant river and tidal power stations.

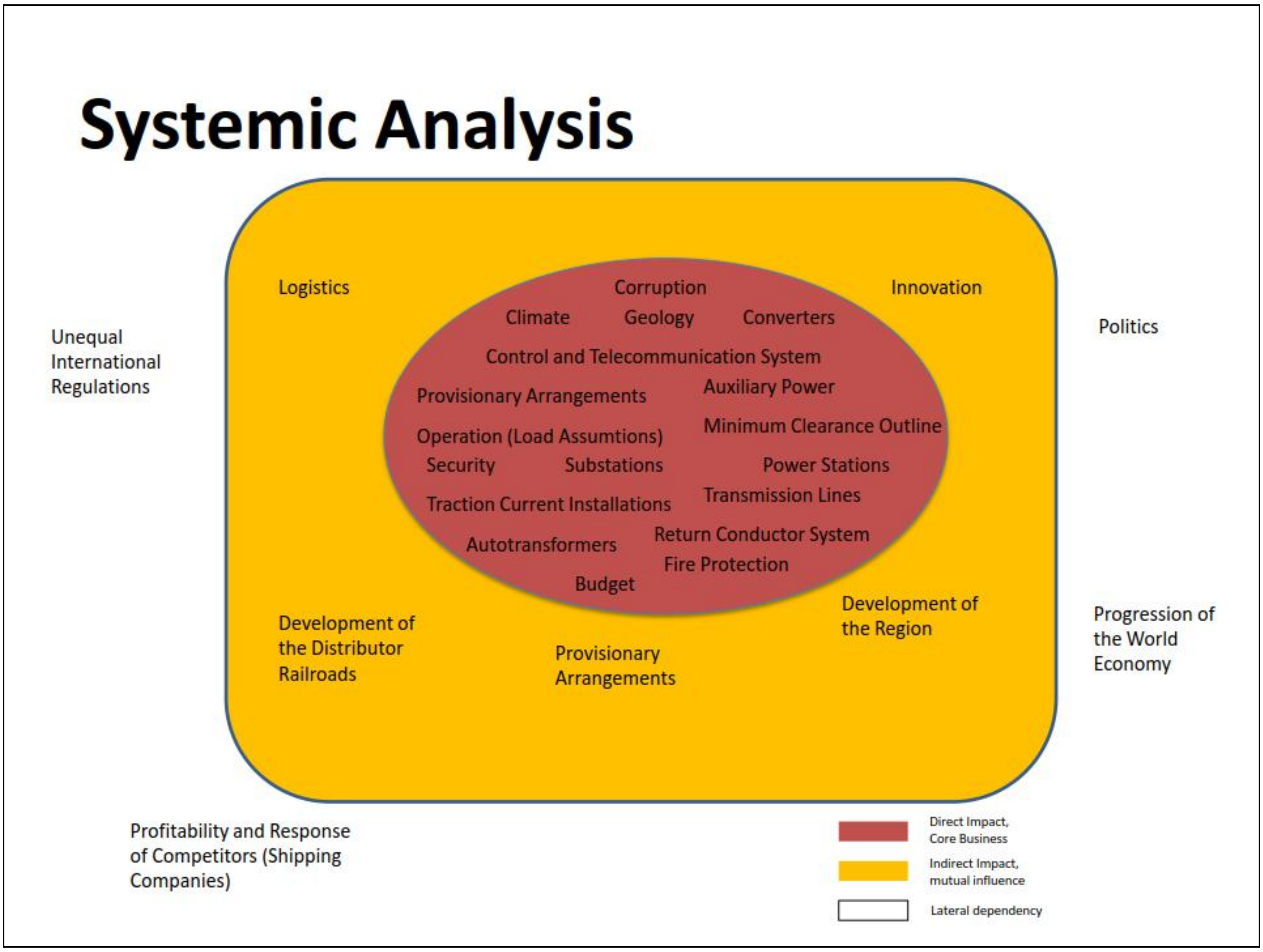
This survey issued by Inter Bering LLC is considered as a basis for further investigations in this concept study. It will analyze the ancillary conditions, confirm or challenge them and set additional ones.

Besides Inter Bering LLC there are further sources for works on a Bering Strait Tunnel. They are specified in the list of references in the back of the document.

## 2.2 Systemic Analysis

The systemic analysis comprises an illustration (see figure 2.3) of ancillary conditions which influence the energy supply of the Bering Tunnel directly, indirectly and tangential. Some of these factors stick to the project from the beginning and will still be present during operation. Others appear only in certain phases of the project. By means of this graphic (figure 2.3), it is more comprehensible which aspects need to be taken into account when analyzing the situation and the requirements. The majority of the named parameters in the systemic analysis have a direct impact on the design of the traction power supply in the tunnel.

In appendix 1 all of these factors are explained and associated with the energy system of the Bering Strait Tunnel. In addition to the load assumptions a sophisticated maintenance concept needs to be implemented. One of the most important factors for designing the tunnel is the tunnel cross section, integrated in the minimum clearance outline in the systemic analysis. The more narrow the tunnel cross section the higher the aerodynamic resistance and the higher the necessary electric power to resist the air drag according to the demanded speed of the train. This dilemma reflects only one area of attention to be considered in advance when projecting a railtunnel. [70]



Systemic Analysis

Unequal International Regulations

Logistics

Corruption

Innovation

Politics

Climate

Geology

Converters

Control and Telecommunication System

Provisionary Arrangements

Auxiliary Power

Operation (Load Assumtions)

Minimum Clearance Outline

Security

Substations

Power Stations

Traction Current Installations

Transmission Lines

Autotransformers

Return Conductor System

Fire Protection

Budget

Development of the Distributor Railroads

Development of the Region

Progression of the World Economy

Provisionary Arrangements

Profitability and Response of Competitors (Shipping Companies)

🟥 Direct Impact, Core Business

🟨 Indirect Impact, mutual influence

⬜ Lateral dependency

**Figure 2.3: Systemic Analysis illustrating dependencies of the energy system from direct, indirect and lateral aspects**

## 2.3 Profitability of the Tunnel

Before analyzing any technical details of the tunnel it is necessary to point out that a tunnel under the Bering Strait is reasonable and can be proficient. In chapter 2.1 the study carried out by Inter Bering LLC has been acknowledged as the main source for this report. This study assumes seven trains per hour inside the tunnel with a load of 9,000 tons each (for more information see appendix 2). As a specification this fact leads to an important reference in the economic feasibility study.

This concept study considers airplanes only in a marginal fashion. Airplanes are used for shipping urgent goods which are relatively lightweight. A Boeing 747-500 ERF cargo plane has a maximum payload of approx. 113 tons. It takes 12 hours for a flight from Shanghai to Los Angeles and 15 hours from Shanghai to New York. [70] Thus, airplanes are fast but have a limited capacity. They are declared noncompetitive for heavy freight. A cargo ship of the MOL 20,000 TEU freighter class covers the distance of 10,570 km between Shanghai and Los Angeles in 11 days [28][10] at a cruising speed of 21 knots carrying 20,000 conventional 20 ft containers and 10,000 common 40 ft containers respectively. This is equivalent to a maximum load capacity of 200,000 tdw (tons deadweight). [32][31] A freight train crossing the Bering Tunnel would cover this distance within 6 days at a speed of 100 km/h and 10,000 tons of weight. [30] Table 2.1 compares further routes. The specified category of ships belongs to the Post Panamax class. Those vessels are too large for traversing the Panama Canal. [10] Nevertheless, these routes are listed in the following table.

| Route | Means of Transport | Distance in km | Speed in km/h | Duration in d |
|---|---|---|---|---|
| Shanghai – LA (Pacific Ocean) | Ship | 10,570 | 39 (21 kts) | 11,0 |
| Shanghai – LA (via Bering Tunnel) | Train | 14,200 | 100 | 6,0 |
| Shanghai – New York (via Panama Canal) | Ship | 19,600 | 39 (21 kts) | 21,0 |
| Shanghai – New York (via Northwest Passage) | Ship | 17,000 | 39 (21 kts) | 18,0 |
| Shanghai – New York (via LA intermodal) | Ship, Train | 15,600 | 39 (21 kts) ; 100 | 18,0 |
| Shanghai – New York (via Bering Tunnel) | Train | 15,700 | 100 | 6,5 |

**Tabe 2.1: Transport routes from Asia to North America [28][31][32]**

It is obvious that freight trains can neither take on airplanes regarding speed nor ships in terms of load capacity. However, the freight train does not need to take on any of the two. Rather, it should close the gap between both means of shipping. Yet, the economy of several days in comparison to the ship should be capitalized and propagated, i.e. the freight train should be used in order to transport relatively heavy goods and semi-finished products in high speed. The plane would be more suitable for urgent finished products. The ship would be more appropriate for raw materials which are less time sensitive than certain elements in a supply chain. On this account a reasonably high speed for freight trains is estimated. A freight train load of 10,000 tons is not unusual for trains in North America and Asia. Since the trains are supposed to run on electrical power on the Asian side and inside the tunnel this implies quite high electrical power for the engines. Thus, at least the Asian distributor railroads as well as the tunnel itself need to be equipped with large electrical installations.

In order to realize the criterion from chapter 2.1 of seven freight trains per hour (not considering the maintenance interruption of eight hours once a week; for more detail see appendix 1) one question needs to be addressed: are the trains coming from Asia going to continue their journey or is their load going to be transshipped to waiting trains? One reason to argue against the former is the Department of Homeland Security's customs procedures checking all incoming goods. Furthermore, the trains need to undergo a track adaptation process since the Russian broad gauge (1520 mm) is different from the standard gauge (1435 mm) used in North America.

The minimum clearance outline in North America is different as well. In North America two standard containers are allowed to be stacked on top of each other on one rail car. There is only one efficient system changing the track composition of the trains: the Talgo System. [72] However, this system is only used by passenger trains. It is not applicable for heavy freight trains. New rail cars would have to be developed to ensure the same functionality. There is one more possible solution for the rolling stock. Every locomotive and every rail car need to be equipped with two different wheel sets. If such a system is going to be developed for the rolling stock until the end of construction of the Bering Tunnel, the freight trains would be able to continue rolling nonstop on both sides of the tunnel. However, as already addressed, this would compromise the Russian and US custom laws. Moreover, at least the container trains cannot take advantage of the North American minimum clearance outline. This would mean inefficient logistics.

One solution to tackle this challenge is the rapid transshipment of containers from a train with broad gauge wheel sets to waiting trains with standard gauge wheel sets. This facility would be very large and would be located near the North American entrance of the tunnel as illustrated in figure 2.4.

At seven trains per hour the transshipment process is a very ambitious goal. The locomotives coming from Asia need to be changed on the American continent since it is not assumed that the North American railroad is going to be electrified, at the most the new line from Fort Nelson to Wales at the Bering Strait. Though, this would reduce the efficiency of the North American minimum clearance outline. On the other hand, a large transshipment facility outside of the Arctic region would be less vulnerable to the harsh climate near the Bering Strait. In a future planning stage the loss of time caused by the transshipment has to be compared to the opportunity costs of the unemployed minimum clearance outline on the American side if the wheel sets can be adapted or new rolling stock with two wheel sets are developed and used. Only after such a cost-benefit analysis has been carried out it can be decided between either a system for efficient axle-gauge changeover or a large transshipment facility or both. A combination of the two as shown in figure 2.4 would be feasible as well. Thus, a freight train carrying containers could be transshipped. A train carrying no containers but raw materials could change the track gauge without transshipment.

Due to reasons of efficiency the change of locomotives, the transshipment and the examination of the load (customs) is suggested to take place on the American side of the Bering Strait. This comes with a large freight terminal including a transshipment facility and an axle-gauge changeover point as well as robust switch point heaters (for more detail see figure 2.4). A sizeable passing area with a number of tracks near the tunnel entrance makes sense for safety reasons and train accumulations in front of the tunnel. Several parallel transshipment tracks arranged with numerous successive traveling cranes would make the goal of seven trains an hour possible. The biggest challenge is the length of the transshipment facility. A train with 230 rail cars class UIC 571-4 for 40 ft containers [7] combined with two locomotives CR HXD1B would be 3,228 m long and would have a total weight of approx. 10,000 tons if every container is loaded at maximum capacity. Any train at the freight terminal should stay there not longer than one hour.

Another challenge is freight trains which do not come with containers but alternative load carriers such as coal cars. Those would have to be transshipped as well. The more efficient solution for this kind of trains would be the axle-gauge changeover point similar to the Talgo technology. The construction of an efficient and robust transshipment facility and a temperature resistant axle-gauge changeover point should be subject to the following planning stage. A first approach is illustrated in figure 2.4. However, this topic will not be exhausted in this study.

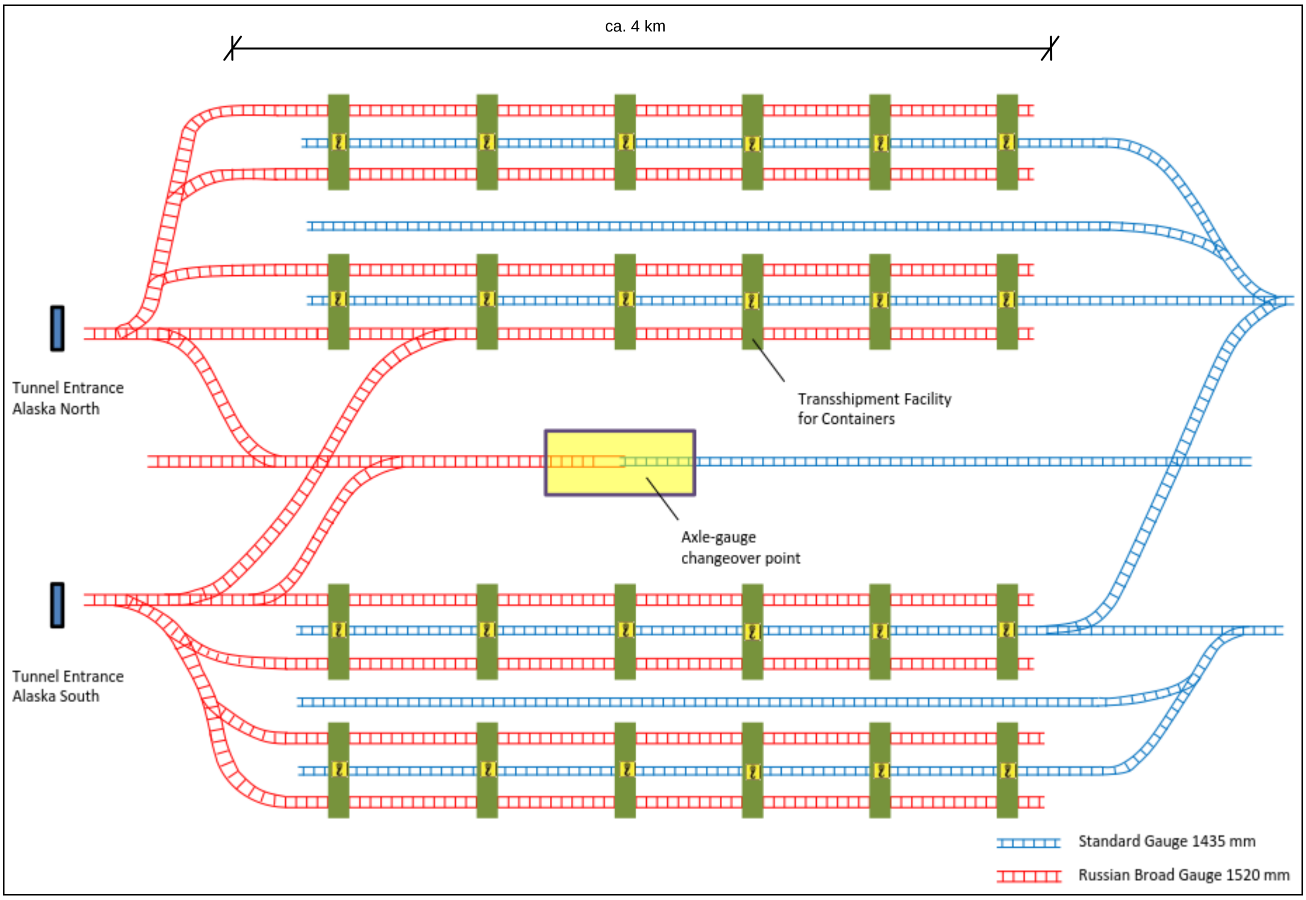


**Figure 2.4: Potential transshipment facility layout including an axle-gauge changeover point at the Alaska tunnel entrance [17]**

## 2.4 Load Assumptions

This chapter explains the assumed load specifications which are necessary for determining the required traction power in the tunnel. Only freight trains driven by electric power are going to cross the tunnel. Passenger trains are considered irrelevant to this study since such a journey is much faster and cheaper when traveling on a plane.

The most important specifications are the speed of the trains and their expected gross weight. In this report the trains are assumed to have a total weight of 10,000 tons each. Their speed is supposed to be at 100 km/h when crossing the tunnel. Both values need to be sustained as load specifications for the distributor railroads in Asia and North America. Otherwise the electrical installations in the tunnel are going to be oversized. The fundamental values of frequency and voltage will comply with the Siberian system of 50 Hz 1 AC at 25 kV.

The main means of conveyance for goods will be 40 ft containers at a length of 12.19 m and a maximum weight of 30 tons. [8] The corresponding rail cars conform to the UIC 571-4 standard.

Their empty weight lists 12 tons at a length of 13.86 m. [7] The standard engine is expected to be the powerful Chinese HXD1B CSR Zhuzhou Electric Locomotive based on the Siemens Eurosprinter. It has a length of 20 m, a weight of 150 tons each, 9.6 MVA of traction power and 120 km/h of top speed. [9] According to the media two of these locomotives are supposed to be sufficient to move a 20,000 ton train. [12] For safety and redundancy reasons it is assumed that each standard train at 10,000 tons will be powered by two of the mentioned engines during the tunnel crossing. Table 2.2 displays the train data in more detail.

| Engines | Train Load | Number of rail cars | Train weight in tons | Train length in meters |
|---|---|---|---|---|
| 1 x HXD1B | Container (40 ft) | 100 (42 tons each) | 4.350 | 1.406 |
| 2 x HXD1B | Container (40 ft) | 200 (42 tons each) | 8.700 | 2.832 |
| 2 x HXD1B | Container (40 ft) | 230 (42 tons each) | 9.960 | 3.228 |
| 2 x HXD1B | Open Loading | 120 (80 tons; 12 m each) | 9.900 | 1.480 |

**Table 2.2: Train weights and train lengths of freight trains crossing the Bering Tunnel [7][8][9] (See Appendix 2 for Calculation)**

After listing the general assumptions there are further specifications necessary to be able to calculate the tractive force. In order to determine grade resistance it is to be clarified which slope in the tunnel the trains need to overcome. Pursuant to the longitudinal section (see figure 2.2) the highest incline is at 1.2 percent. The curve resistance is considered to be irrelevant for this calculation. There is a slight curve visible in the horizontal projection but the radius is large enough to regard it as infinite. Thus, the curve resistance is expected to be zero. For gauging the necessary accelerating force ξ as the parameter for rotating masses of trains is set to 0.1. [34] A constant value of 0.05 m/s$^2$ is assumed for the acceleration of the entire train. The assessment of the resistance to rolling is different depending on the source. [59] This study employs the equation by Strahl according to Filipovic [34]:

$$wf = 2{,}5 + k(v + \Delta v)^2 \bullet 10^{-3} \frac{N}{\mathrm{kN}}$$

The k value is set to 0.25 for heavy freight trains. According to Filipovic the aerodynamic resistance increases up to threefold inside single track tunnels. [34] Thus, a velocity delta of Δv=45 km/h is set. Considering a speed of 100 km/h leaves 7.8 N/kN as a credible value for resistance to rolling.

In order to determine the required electric power the efficiency η of the electric engines is assumed to stand at 85 % at their operating point after reaching cruising speed. For the calculation of the electric power it is essential to point out that the locomotives are considered to run on 100 % active power. Further computations of energy conversions will consider a differing efficiency factor depending on the selected energy transformation process. For the entire energy conversion process from e.g. potential hydro power all the way to the locomotive an efficiency factor of 70 percent seems to be reasonable.

# 3 Obtained Results

The next step in designing the traction power supply system is the computation of the required traction power considering the load assumptions. At first, the tractive force of a specific train configuration is determined (see chapter 2.4). The calculation of the traction power follows. This is the input value for computing the required electric current in the contact line. Finally, the estimated efficiency factor for the whole electrical system from the generator to the engine is applied. By means of this value the total electrical power can be determined. The latter needs to be generated in the power stations in order to realize the load assumptions estimated in the beginning such as the speed of 100 km/h and 10,000 tons of weight for each train. For more detail concerning the derivation of the computations, the applied equations and the calculation method please refer to appendix 2. Table 3.1 lists the fundamental results which are important for further deductions on the design of the energy system of the tunnel. All the following data refer to only one train. They reflect the most conservative scenario. Recuperation is not considered in this calculation. Moreover, the slope of the stretch might not incline permanently. In some tunnels the slope rather descends after any tunnel entrance and ascends before the tunnel exit, respectively. If these constraints had been considered, smaller values for the required traction power would result. Only two realistic scenarios have been analyzed: with regards to acceleration and without acceleration. Since the latter requires the higher power output it is considered as the design loading condition for the projected traction power system. The following table demonstrates the calculated data per train:

| Loading Condition / Motion | Tractive Force in MN | Tractive Power in MW | Electrical Power (Active Power) in MVA | Required Current in the Contact Line in A | Required potential power in MVA |
|---|---:|---:|---:|---:|---:|
| constant | 1.942 | 53.988 | 63.515 | 2,540.612 | 90.736 |
| accelerated | 2.492 | 69.288 | 81.515 | 3,260.619 | 116.450 |

**Table 3.1: Results of the calculation of the required traction power (see appendix 2 for the calculation in detail)**

# 4 Conclusions from Obtained Results

Due to the elevated load specifications of 10,000 tons and a speed of 100 km/h per train the resulting data are higher than common train requirements. This is why relatively high power rates are needed. The energy installations are to generate such high traction power outputs primarily for the tunnel. Again, the determined numbers reflect the requirements only for one single train. Considering the requirement of seven trains in the tunnel per hour at once the required traction power inside the tunnel needs to be multiplied by seven. Since distributed throughout the entire 113 km long tunnel this implies an available traction power of 570.605 MVA and an exceptionally elevated amperage of 22.824 kA during ordinary operation. Such high amperages entail significant challenges for the electrical protection system. Even reducing the weight requirement of 10,000 tons to 9,000 tons per train does not help decreasing the necessary power and the high amperage. Thus, this difference is disregarded due to insignificance. The worst case requires even more elevated traction power implying higher amperage numbers as well.

A deadlock of the tunnel because of malfunction of any train must be avoided. Functioning trains should be pulled out of the tunnel in case of emergency but should be able to leave themselves as long as there is power in the tunnel with live contact lines. For this worst case scenario a maximum accumulation of five trains per tube during emergency is assumed. After reaching this threshold the tunnel must be closed to traffic. At a total of ten trains in the tunnel (5 in each tube) the required electrical power increases to 815.15 MVA accompanied by an amperage of 32.606 kA on the whole contact line if all trains accelerate at the same time, not considering auxiliary power of the installations. In case of evacuation the performance of this power output is essential. This amount is similar to the power output of a medium-sized nuclear reactor. [2]

A discussion on the traction power generation at this level follows in the next chapter. It is a fact that several power stations are necessary to secure the energy supply for the tunnel and the open railroads leading towards it. The energy is distributed evenly in the tunnel thanks to the high number of trains inside the tunnel. Power surges are not expected to be remarkable. However, compared to the relatively low need of power to cushion the impact of power surges, the required base load is quite high.

Transmission lines able to convey high power rates must feature very high voltage at AC or must be designed as high voltage direct current (HVDC) links. Thus, the power constraint cited by Inter Bering LCC of 15 GW of electrical power for transmission lines seems to be not far-fetched. Further information concerning energy transmission is given in the following chapter.

In order to minimize the number of phase separation points in the catenary the system will consist of several static frequency converter stations. These sites are each going to be placed near the respective tunnel entrances and on Big Diomede Island. For further information on static frequency converter technology please see the next chapter.

There will be more than one substation. This makes sense not only for capacity reasons but also with regards to impedance and the distance between feeder stations. Another important aspect is redundancy. Three substations would make sense considering all listed priorities. Thus, the tunnel can be operated flexibly and evenly energized, even during malfunction of one entire substation. Moreover, the high demand for power could be ensured from three different sites during normal operation.

Concerning return circuit an appropriate diameter needs to be selected for the conductors directing the current back to the substations. This can also be achieved by using several parallel conductors. Another way to optimize the feeder and return circuit system would be the utilization of booster transformers. Combined with autotransformers they could form a feasible system for the tunnel. However, booster transformers are not recommended for the tunnel due to too much electrical equipment inside the tunnel which bears an increased fire load density and thus, an increased fire hazard as well as higher maintenance effort.

In terms of the catenary such high amperage implies very large profiles of the contact line. Thus, an overhead conductor rail design is suggested as contact line. Conventional overhead traction wires are not able to sustain an amperage of 3,261 A per train. Overhead conductor rails make this possible. [50] An alternative to the latter would be the installation of several parallel overhead wires. Additional overhead wires would add extra wires to the already high amount of copper wires inside the tunnel, considering feeder wires and return circuit wires. An overhead conductor rail does not require additional feeder wires. Yet, the alternative solution must be subject to further investigation. From a current point of view an overhead conductor rail seems to be more economical, not necessarily regarding investment but certainly in terms of maintenance.

Due to the high demands of the traction power system autotransformers are necessary to be installed in the tunnel. Though, a simulation is required to confirm this proposition. Geographically, there are only three spots from where electricity can be injected into the traction power system of the tunnel: the Alaska portal, the Siberia portal and Big Diomede Island via a shaft in the middle of the tunnel stretch. Supposedly, another substation could be erected on Small Diomede Island as a redundancy. Further information on the energy concept follows in the next chapter.

One general problem with the proposed traction power system is the high power requirement and thus, high amperage necessary in the contact line. This has an impact on the electrical protection system. Short-circuits must be detected. With very high amperage on the contact line this is a challenge. This problem is going to be examined in the following project planning stage.

In order to decrease high amperage, voltage can be increased, e.g. from 25 kV to 50 kV. This is not common in conventional rail networks. However, voltage of 50 kV can be applied where heavy trains are used such as in mines. With less amperage in the contact line overhead wires would become more attractive. This suggestion would require more sophisticated locomotives, though. It is to be analyzed in the next project stage.

# 5 Suggested Traction Power Systems

After the load assumptions have been defined, the first coarse calculations are being conducted and the appropriate conclusions are being drawn. Afterwards, a feasible traction power system for the Bering Tunnel can be elaborated. At first, the components of the traction power system are to be pointed out and described one by one. Subsequently the criteria for the configuration of the components are illustrated. The point is to achieve an objective selection of the most appropriate alternative. In this analysis the author proposes the most suitable assortment of components. This gives the process of selecting the right components a subjective touch. Though, the selection process is transparent.

## 5.1 Criteria for System Components

The viable versions of the traction power system of the Bering Tunnel are subject to several criteria. All of them are weighted equally while in the study stage. Each of the selected criteria is being described as follows: the highest possible score is three points with the highest score representing the best alternative. In this study only the author assigns the scores. If allocated by other parties the results are likely to change which in turn could lead to a different suggestion.

### 5.1.1 Availability

In order to maintain sustained operation of the tunnel without interruption the availability of the energy system is a very important criterion. Redundant components are part of the design of the tunnel's power supply. This comprises electricity generation, transmission, conversion, feed, auxiliary power plus the control and communication system.

### 5.1.2 Safety

Alternative options must not compromise safety in the tunnel. If safety is affected in a negative way by any of the given alternatives the entire option will be discarded from further analysis.

### 5.1.3 Maintainability

Depending on the system, maintainability is going to be either simple and cheap or extensive and expensive. Accessibility is one decisive factor in this context. If a system component is remote, hard to access or complicated in design, the maintainability will be difficult. The most undemanding maintainability catches the highest scores. Thus, maintenance intervals as well as maintenance induced disconnections can be reduced to a minimum.

### 5.1.4 Life Cycle

This criterion reflects the technical life cycle of the energy system. Life cycle costs (LCC) are included in the costs criterion. The longest life cycle reaches the highest score.

### 5.1.5 Flexibility

This indicator illustrates the operational flexibility in terms of using the energy system. Covering peak demands is one requirement. Another obligation is to deliver the base load. The system which is capable of dealing with both loading cases gets the highest scores.

### 5.1.6 Costs

There is no explanation necessary for this criterion. Most credit is assigned to the system with the lowest costs. LCC are included in the examination. In this report costs are rendered only in a qualitative manner. Further investigation into prices for certain components of the system has not been conducted. However, this is compulsory in the following project stage.

### 5.1.7 Environmental Consideration

The ecological compatibility plays a major role in this project. The system generating the smallest environmental impact is given the highest scores in terms of this criterion.

## 5.2 Variable Designs of Traction Power Systems for the Bering Tunnel

The traction power system consists of several different elements. The consumer load (i.e. the electric engine) is the last link in the electrical chain from electricity generation in the power station to power transmission, frequency conversion, switching, transformation, more switching and eventually the power supply on the contact line. In addition, the return circuit and the auxiliary power systems are to be considered in this complex system. This chapter analyzes the complete energy system and describes the possible designs of the individual components resulting in a suggestion for each individual element as well as for the whole traction power system.

### 5.2.1 Power Stations

As indicated in the systemic analysis in chapter 2.1 (see appendix 1), the power stations form a central piece in the energy system. Since there are no existing power stations in the area, new power stations and substations need to be installed. The intention of this study is to focus on economically sustainable electricity generation. On this account, coal and oil related power generation is excluded. Efficient natural gas-fired power plants with combined heat and power generation should be well considered on both sides (US and Russia). An existing natural gas network could alternatively be used for methane which is produced by power-to-gas conversion devices from spare renewable electrical power (wind, marine current or solar). Thus, both the heat energy demand of the surrounding areas and the demand for electricity including traction power can be satisfied. Moreover, there is natural gas in place at sources on the Chukchi Peninsula which need to be developed. [1] In terms of operation, natural gas-fired power plants also bear advantages since they can be powered up in relatively short time. This allows for cushioning power peaks. However, it is questionable if this is really necessary in the intended operational scenario. The mode of operation of the electrical system needs to be analyzed in the next project phase.

In addition to the advantages mentioned earlier, it makes sense to secure the base load with run-of-river power stations, as explained in the appendix. However, those rivers must not freeze up in winter. If river power stations are not feasible, marine current power stations and tidal power stations would be an alternative. The former can be installed near the coast and they also operate at temperatures well below freezing and underneath an ice cover. However, turbines at only 1.5 MW each are available at the moment. [45] Yet, development is quite promising in this field. Tidal power stations hold higher power ratings. The tidal potential in the North Pacific is high. [18] The Rance power station in France has a power rating of 240 MW. [43] Nevertheless, this kind of power generation would have a high ecological impact on the regional environment. Those possible consequences need to be analyzed in a separate environmental impact assessment.

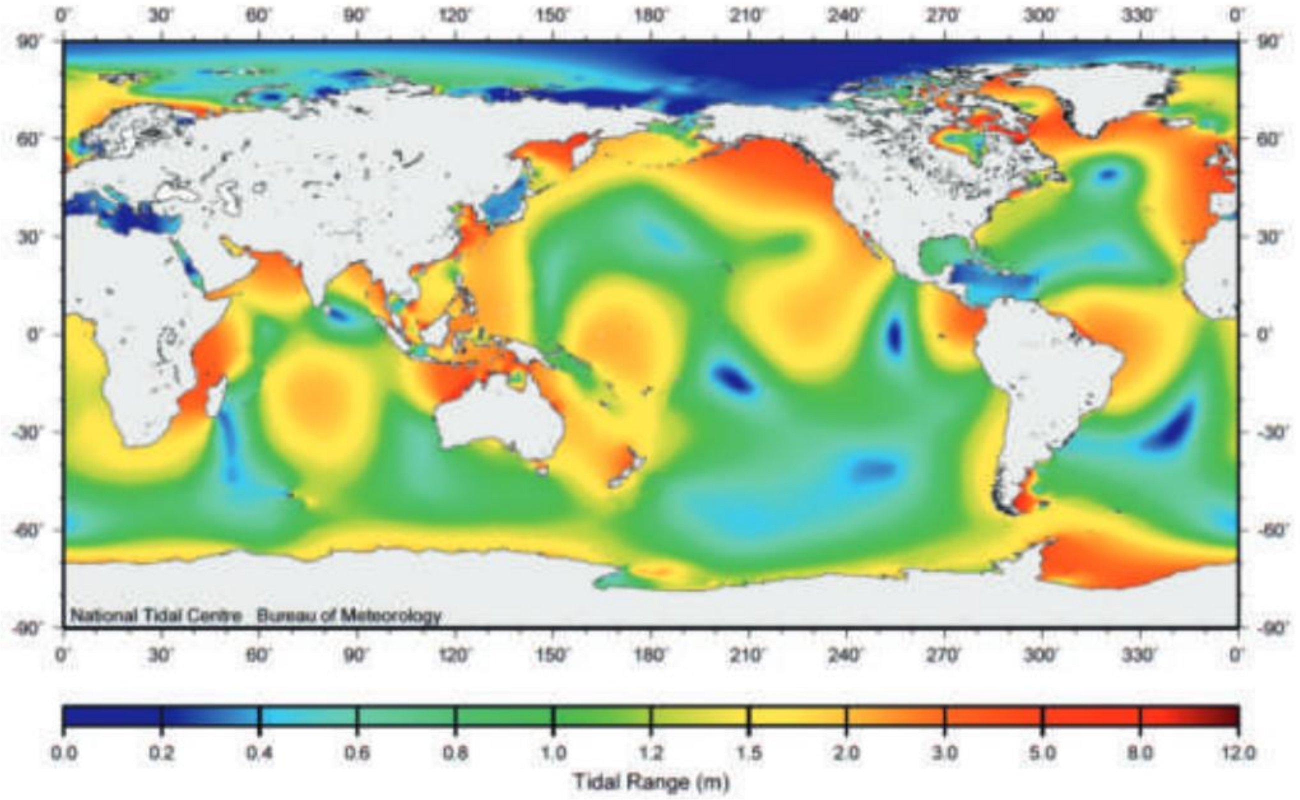


**Figure 5.1: Energy potential of tidal power [18]**

The potential of geothermal energy is to be investigated as well. The construction of this kind of power plants on the Kamchatka Peninsula seems to be efficient. This area is promising since it is shaped by volcanic action similar to Iceland where geothermal energy is a very important energy source. Plus, this type of energy is constant. Thus, it is very suitable for base load. However, the distance to cover from Kamchatka to the railroads or even to the tunnel is quite long.

Wind turbines combined with an energy storage system can absorb peak loads. A further development of effective and reliable storage systems is mandatory, though. Yet, it is possible to connect wind turbines to a methanation plant, i.e. an electrolytic unit with in-line hydrogen and methane production. The latter is linked to a natural gas power station. Hence, the natural gas power station could be turned into a sustainable device. [43]

Wave energy is no option in this region. Wave heights along the shoreline are too small. Moreover, the sea freezes up in winter. [43] Hydro power stations in the greater region of Alaska and Eastern Siberia are dealing with the same problem but could still be used effectively during summer.

One option which is not considered to be regenerative but free of carbon dioxide production is nuclear power. This study considers only the relatively safe version of a molten salt reactor (MSR). In comparison to the other listed energy sources the great benefit of this kind of power generation is its independence from geography. It does not rely on any force of nature. In addition, its power rating is quite high. Due to its inertia it is more appropriate for the generation of base load versus peak load. It is also very reliable and it does not need any energy storage facility. Thus, it is definitely feasible if not oversized as a potential traction power generator. Nuclear waste is minimal compared to other fission reactors. However, some nuclear residue remains which cannot be recycled and must be stored in a safe place for approx. 300 years. Thus, an ecological impact exists which makes this system not the preferred energy source. For more information on MSR please refer to appendix 1.

After this broad analysis, the further investigation in the following power sources is proposed: run-of-river, natural gas, hydro, wind combined with methanation, geothermal, MSR and tidal energy. Marine current turbines off the coast are another option. There is much potential of that energy source in the region. Modern control systems are to be optimized in order to simulate a number of virtual power stations. Each virtual station combines several different power stations which generate power from various energy sources. Table 5.1 illustrates and points out the most feasible energy sources.

| Type of power plant | Availability | Safety | Flexibility | Ecology | Maintainability | Life Cycle | Cost | Sum |
|---|---|---|---|---|---|---|---|---|
| Natural Gas | 3 | 2 | 3 | 1 | 2 | 2 | 3 | **16** |
| Wind + Natural Gas | 3 | 3 | 3 | 3 | 1 | 2 | 2 | **17** |
| Wind | 1 | 3 | 1 | 3 | 1 | 2 | 2 | 13 |
| Nuclear (MSR) | 3 | 2 | 3 | 1 | 2 | 2 | 1 | **14** |
| Wave | 1 | 3 | 1 | 3 | 1 | 1 | 2 | 12 |
| Geothermal | 3 | 2 | 1 | 2 | 2 | 3 | 2 | **15** |
| Marine Current | 2 | 2 | 2 | 3 | 1 | 1 | 2 | 13 |
| Tidal | 3 | 2 | 1 | 2 | 2 | 3 | 1 | **14** |

**Table 5.1: Potential energy sources for traction power**

### 5.2.2 Energy Transmission

This chapter reflects on the energy transmission from electricity generation (power stations) to the Bering Tunnel where the electricity is consumed (not considering the consumption at the distributor railroads). Further explanations concerning transmission lines are described in appendix 1. Power transmission via HVDC overhead lines or cables is recommended if long distances need to be covered between power generation sites and power consumption. Taking into account all advantages and disadvantages this solution is preferred since there is no reactive power, less infrastructure necessary and thus, lower maintenance and possibly lower costs. Moreover, DC power lines have a smaller diameter, no skin effect and no capacity problem with cables (no reactive power). The efficiency losses due to the use of rectifiers are compensated after approx. 70 km. [2] Nearby wind and marine current power stations are to be linked to electrical devices with three phase AC power connections. Also feasible would be a long redundant super high voltage 50 Hz 3 AC overhead line parallel to the DC line which would supply the railroad track as well as households and businesses in the proximity. However, the same effect could be achieved using HVDC combined with solid state converters along the line. Though, an HVDC grid should be argued due to the absence of experience with HVDC power switches. The latter exist [11] but research and development in this field has yet to prove successful long-term use.

Another question to study is how to hookup the HVDC line to a substation. One way is to connect this line to a static converter in order to transfer DC to AC one phase (1AC) in a direct manner. A different approach is a process in several stages: first step would be a conversion from DC to AC three phase (3AC) and then to AC one phase (1AC) power. The second alternative would leave the option to utilize the power not only for traction power supply but also for devices working with three phase AC power.

In terms of availability a parallel transmission line corridor would be beneficial. Flexibility and voltage stability could be increased that way. However, regarding financial and ecological aspects this option would leave a higher impact on both features. Also, the visible effect of an additional overhead line is stronger than having only one. Of course, this solution is more expensive than just one line. From an ecological perspective, HVDC cables would be the best idea. But this proposition is even more expensive than overhead lines and it is very challenging to install the cables in permafrost soil. In spite of the listed difficulties both proposals of HVDC cables and overhead lines are suggested. The availability of cables is probably higher than overhead lines since the harsh environmental conditions have a higher impact on free-standing pylons than on cables.

For reasons of availability more parallel lines could be allotted along the corridor. Thus, every substation is provided with two parallel and independent power lines. Moreover, HVDC lines can be designed in a bipolar fashion, i.e. one line equipped with two conductors. This bears advantages in terms of higher transmitted voltage and electrical grounding. Precautionary measures against corrosion must be taken though if this version of power transmission is chosen. The specified transmission capacity for the tunnel of 15 GW [6] can be realized with both kinds of current. The detailed design and number of transmission lines is configured according to the size of the power stations and the length of the transmission corridor. Table 5.2 illustrates the possible propositions of energy transmission between power stations and the Bering tunnel according to the most important criteria such as availability, safety, flexibility, ecology, maintainability, life cycle duration and costs.

| Type of Transmission | Availability | Safety | Flexibility | Ecology | Maintainability | Life Cycle | Costs | Sum |
|---|---|---|---|---|---|---|---|---|
| HVDC overhead | 2 | 2 | 2 | 2 | 2 | 3 | 3 | **16** |
| HVDC cables | 3 | 3 | 2 | 3 | 1 | 3 | 2 | **16** |
| 3AC overhead | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 14 |
| 3AC cables | 2 | 2 | 1 | 3 | 1 | 3 | 2 | 14 |
| HVDC + 3AC overhead | 3 | 2 | 3 | 1 | 2 | 2 | 2 | 15 |
| HVDC + 3AC cables | 3 | 1 | 3 | 3 | 1 | 3 | 1 | 15 |

**Table 5.2: Propositions of energy transmission**

### 5.2.3 Static Converters

The conversion of the current is an essential element in the system of the electrical power supply for the Bering Tunnel. The Russian 3AC 50 Hz power grid supplies the Russian 1AC 50 Hz 25 kV traction power system. In order to utilize this type of electricity several phase separations are required for stabilizing the 1AC current running through the contact lines. Besides a higher demand for infrastructure, maintenance and investment, these separations create an imbalance in the 3AC power grid. [56] The Australian Bauhinia Line operates a static converter [41] which transforms 3AC current from the public mains supply into 1AC traction power. Thus, phase separations are made unnecessary and money is saved. Moreover, using this converter the 3AC power grid is stabilized. The traction power system in the tunnel can be easily connected to such a converter. The contact lines only need to be separated in certain areas where necessary for reasons of protection.

Another way of obtaining traction power is the direct conversion from HVDC into 1AC 50 Hz 25 kV. Inverters changing DC into AC exist but they are built for 3 phase AC power. Quick research for an inverter generating one phase current, i.e. a static DC-1AC inverter, rendered no findings. It is expected though, that due to the long time for the Bering Tunnel to become reality, the development of such a device will be possible in the meantime.

Also possible but much more complex would be a double conversion from HVDC to 3AC and again from 3AC to 1AC 50 HZ 25 kV. This solution is inferior to the direct conversion in terms of efficiency since the conversion losses are lower in the direct form of conversion.

The conventional method of traction power supply, mentioned above, is also possible but the number of phase separations in the contact line on the track make this approach both more expensive and more complex. Moreover, there would be more technology put inside the tunnel which needs to be maintained. For this project, the goal is to minimize the elements necessary to maintain, especially inside the tunnel.

This study proposes a direct conversion, depending on the method of transmission, from 3AC to 1AC or from HVDC to 1AC. This suggestion is confirmed in the table (5.3) below.

| Conversion | Availability | Safety | Flexibility | Ecology | Maintenance | Life Cycle | Costs | Sum |
|---|---|---|---|---|---|---|---|---|
| none: 3AC | 2 | 1 | 1 | 2 | 1 | 2 | 1 | 10 |
| DC → 1AC | 2 | 2 | 2 | 3 | 2 | 2 | 2 | **15** |
| DC → 3AC → 1AC | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 10 |
| 3AC → 1AC | 2 | 2 | 2 | 2 | 2 | 2 | 3 | **15** |

**Table 5.3: Options for power conversion**

### 5.2.4 Power Supply Concept

On the basis of the length of the tunnel and its high demands the power supply concept will be very ambitious. As the required amperage is relatively high an overhead conductor rail would prove beneficial. An alternative would be additional contact lines for each track. However, this is ruled out due to high maintenance effort. In order to maintain voltage on a stable level over a long distance an autotransformer system (AT) is suitable. This is a passive system without additional energy supply. On the other hand, it has an adverse effect on maintenance and fire protection since it is placed inside the tunnel. Several ATs installed along the track contribute to an increased fire hazard. In terms of maintenance, every additional wire and electrical part is subject to maintenance. Again, the goal is to keep those parts on a minimum. Moreover, an additional negative feeder line needs to be installed in the tunnel. Furthermore, the switchgear has to be designed in a bipolar design. If selected for the supply concept, 12 ATs in a distance of approx. 10 km are installed inside the tunnel. A simulation has to be carried out for a more accurate design.

An alternative to an AT system is a static var compensator (SVC). This is a power electronic system placed on each end of the tunnel. SVCs have to be supplied with auxiliary power. The better option of either using ATs or SVCs for the power supply concept must be determined in a simulation process.

A power supply without any auxiliary means to stabilize voltage is unrealistic. However, this pretension has to be proven by another simulation.

Although afflicted with the listed shortcomings this review favors the AT system as this kind of voltage stabilization comes with high availability, is proven and tested, works passive and is considered flexible. Table 5.4 illustrates this statement. The line stating “no auxiliary means” for voltage stabilization is only listed for the sake of completeness. Its presence distorts the results though since it is very likely that this option is physically not feasible.

| Auxiliary | Availability | Safety | Flexibility | Ecology | Maintenance | Life Cycle | Costs | Sum |
|---|---|---|---|---|---|---|---|---|
| No auxiliary means | 1 | 1 | 1 | 3 | 3 | 1 | 3 | 13 |
| AT | 3 | 2 | 3 | 2 | 2 | 3 | 1 | **16** |
| SVC | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 15 |

**Table 5.4: Options for minimizing voltage drop in long distances without further active power in-feed**

### 5.2.5 Substations / Switchgear

The switchyards are the connective link between transmitted high voltage energy and traction energy with relatively high amperage levels. They are interconnected with converter stations. According to the calculations prior to this chapter the Bering Tunnel at a length of 113 km needs to be fed with 815.15 MVA and 32.606 kA considering the entire contact line. In theory, one single substation could be able to perform such a task. This is impossible though for technical and most notably for availability reasons.

For a tunnel of this kind, availability is a very important criterion. Operating only one single substation for the entire tunnel is a high safety hazard. The tunnel requires multiple substations based on redundancy, i.e. if one substation fails the other substations must be able to take over its operation in a worst case scenario [24], given that the electrical lines are still intact. The higher the number of substations and their redundant arrangement the more available and expensive the whole traction power supply system becomes. This applies similarly for the number of transformers and bus bars per substation as well as the number of converters.

The proposed locations for combined substation and converter sites are situated near the portals and on the Diomede Islands, i.e. one substation and converter on the Siberian side, one substation and converter on the Alaskan side and one substation plus converter on Big Diomede Island. Another backup substation and converter facility can be installed on Little Diomede Island. This configuration implies that three substations must be able to provide the demanded power of the worst case scenario, i.e. 815.15 MVA, not considering auxiliary circuits. That means they must yield 272 MVA per substation. The fourth substation would be redundant in this layout. If only three substations are going to be considered, 408nMVA must be possible to be delivered by each substation. For monetary reasons the report suggests the option containing three substations.

All substations shall be equipped with double bus bars (DBB) and a redundant transformer. A single bus bar does not comply with the requirement of availability. The same goes with the number of transformers.

The substations are designed to feed both tunnel tracks, i.e. both directions. In order to minimize differences in voltage the 25 kV contact lines shall be interconnected. This also allows the substations to become available in switch mode in case the upper voltage supply fails.

There is almost no limit regarding transformer size. However, the larger the transformer, the more complicated shipping and the more expensive the transformer will be. A considerable size of 100 MVA appears to be appropriate. If available, the same power size is valid for the converters. For the option considering 4 substations this means 4 transformers (including 1 redundant) at 100 MVA as well as the same number (4) of converters per substation. The other option counting 3 substations requires 5 transformers (1 redundancy) und 5 converters for each substation. In addition, there are input and output transformers to consider for each converter, regardless of AC or DC input.

Besides the number of substations and transformers, it remains unclear how the middle substation on Big Diomede Island is fed with electric energy. There are several ways for solving this problem: supply from both shores with a number of cables on the seabed, supply cables along the tunnel, overhead transmission lines in a separate tunnel chamber of the supply tunnel between the two main tubes or even the installation of an individual power station including a substation on Big Diomede Island with an additional connection to the substations at the tunnel portals.

Another challenge is the design of the layout of the substations. Regarding high voltage they can be either installed as air insulated switchgear (AIS) or as gas insulated switchgear (GIS). The traction power part can be also arranged in either AIS design or in a modern indoor layout. In terms of the application of HVDC a new kind of HVDC switchgear (HVDCS, to be developed) will be used. Due to the local harsh climate an enclosure of the AIS system is possible and necessary but very expensive and inefficient. GIS and indoor designs are much less spacious. Thus, indoor systems as well as GIS are the suggested option for the substation layout. Instead of enclosing the switchgears in a building they ought to be installed underground. For safety reasons these subsurface substation caverns should be installed as separate underground chambers, detached from the tunnel. Here, the permafrost comes into play. The structure of the substation caverns must be designed in a permafrost resistant construction, i.e. the chamber construction needs to consist of a stiff building frame such as a static cage, according to current regulations. [20][21]

The proposition considering high voltage 3AC supply leads to three subterranean substations. The substation located on Big Diomede Island is going to be fed with electric cables on the seabed from both Russian and US shores. The evaluation (see table 5.5) leaves an AIS system as the favorite switchgear solution. However, GIS is proposed as the AC switchgear design since the climate requires indoor switchgears. The cables on the ocean floor are proposed as the alternative options are being refused for safety reasons. Overhead lines inside the tunnel are too dangerous and very costly due to the construction of an extra compartment inside the tunnel (a tunnel in the tunnel). Moreover, installing the lines inside the tunnel also means a greater fire hazard and more material subject to maintenance in the tunnel. This is mainly why the submarine cables are preferred. Yet, high-voltage cables have been installed in tunnels before. The Lötschbergtunnel in Switzerland is one example. The profile of the cables needs to be determined though. For physical reasons (most notably heat) cables cannot transmit the same degree of electrical power as overhead lines. The cable insulations trap heat. Since the required power for the substations is very high including the one on Big Diomede Island, there will be lots of cables having to be installed in the tunnel. Yet, if safety is guaranteed, e.g. by separate flame-resistant cable chambers in the tunnel, the option considering cables running through the tunnel should be included in further studies.

In order to save on copper for the 25 kV feeder cables the transformer bus bar of the middle substation on Big Diomede Island can be placed in a cavern inside the tunnel instead of being installed within the substation structure on the island. Yet, this implies there are more 25 kV feeder lines (feeder points) than cables running from the transformers to the transformer bus bar. A similar concept is applied at Faido substation which (among other substations) supplies the Gotthard Base Tunnel. [71] Worth considering is the fact that when using an autotransformer system all elements of the switchgear must be installed in a bipolar fashion. Due to the high amperage the number of cables will be relatively high. Currently, the cables with the highest capacity have a diameter of 500 mm$^2$ with a maximum current rating of 830 A and a transmission capacity of 20.75 MVA at a voltage of 25 kV. [25] In order to meet the required maximum current of 32,606 A overall 40 cables of this kind are necessary to run between the transformer bus bar and the contact lines.

Table 5.5 displays possible options regarding substation designs. All layout combinations can be compared with one another. Every possible solution is listed in the left column: GIS or AIS, a number of 2, 3 or 4 substations or even a power station. Furthermore, it illustrates the difference between a single and a double bus bar, the type of feed-in of the substations such as cables or overhead lines in the tunnel. Yet, this table assumes that the high voltage side (transmission lines) of the substations is fed with HVDC connected to a converter station and modern HVDC switchgear equipped with the latest HVDC power switches [11] and a 25 kV indoor switchgear. If eventually the transmission lines are going to be AC systems the upper high voltage facility should be equipped with conventional GIS instead of the HVDC power switches.

| Substation Elements | Availability | Safety | Flexibility | Ecology | Maintainability | Life Cycle | Costs | Sum |
|---|---|---|---|---|---|---|---|---|
| GIS / HVDCS | 3 | 3 | 2 | 2 | 2 | 2 | 2 | **16** |
| AIS | 2 | 2 | 2 | 2 | 3 | 3 | 2 | **16** |
| Number of Substations: 2 | 1 | 1 | 1 | 2 | 3 | 2 | 3 | 13 |
| Number of Substations: 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | **14** |
| Number of Substations: 4 | 3 | 2 | 3 | 1 | 1 | 2 | 1 | 13 |
| Power Station | 2 | 2 | 3 | 1 | 1 | 3 | 1 | 13 |
| Double Bus Bar | 3 | 2 | 3 | 2 | 2 | 2 | 1 | **15** |
| Single Bus Bar | 1 | 2 | 1 | 3 | 3 | 2 | 2 | 14 |
| Cables inside Tunnel | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 13 |
| Cables on the Seabed | 2 | 2 | 2 | 1 | 1 | 1 | 2 | **11** |
| Overhead Line in Tunnel | 3 | 1 | 2 | 2 | 3 | 3 | 2 | 16 |

**Table 5.5: Illustration of possible layout options for substations feeding the Bering Tunnel**

### 5.2.6 Return Circuit

A traction power system does not only consist of power supply but also of a current return system. Such a concept is the subject of this chapter. Older railway installations do not have any dedicated return conductors. Thus, the return current runs back to the transformer the shortest and the least resistant way possible, i.e. through the rails and the earth. If applied to the tunnel the absence of a proper return system would energize the tunnel tubes. This in turn is an intolerable safety risk. Consequently, as much of the return current as possible must be directed back to its source (the transformers). Since the expected amperage is quite high, the wire size must be selected accordingly. This can be achieved by using a single wide return conductor rope. The more flexible option is to employ several return conductor ropes. This solution has been put into operation in the Gotthard Base Tunnel. Here, three conductor ropes are installed in parallel along the ceiling of each tunnel tube. [70][71] Another option to force the return current entirely back to its source is the application of booster transformers. These devices work extremely effective and they don't need any extra power source. However, again, they represent an additional maintenance effort and a higher fire hazard. Moreover, if applied in combination with autotransformers they intensify abrasion of the contact lines, create challenges regarding circular currents and increase impedance. [51] That is why a return circuit system similar to the Gotthard Base Tunnel is proposed as an appropriate solution for the return current challenge. Yet, due to the high currents on the contact line in the Bering Tunnel this return circuit system should consist of at least 4 return conductor ropes which are connected to the rails every 300 Meters. The design of the return conductor system must be subject to a simulation at a later date. The following table 5.6 recaps the explanations made earlier.

| Type of Return Circuit | Availability | Safety | Flexibility | Ecology | Maintainability | Life Cycle | Costs | Sum |
|---|---|---|---|---|---|---|---|---|
| No Return Circuit | 1 | 0 ! | 1 | 3 | 3 | 1 | 3 | 12 |
| 1 Return Conductor Rope | 2 | 1 | 1 | 2 | 3 | 2 | 3 | 14 |
| 4 Return Conductor Ropes | 3 | 3 | 3 | 2 | 2 | 3 | 2 | **18** |
| Booster Transformers | 3 | 2 | 3 | 1 | 1 | 2 | 1 | 15 |

**Table 5.6: Options of return circuit systems for the Bering Tunnel**

### 5.2.7 Auxiliary Power

Often omitted but utterly necessary and very important to consider is the auxiliary power operating the entire tunnel infrastructure. These include not only illumination, but also fire protection equipment as well as high-performance ventilation and exhaust air systems. The whole auxiliary power needed in the tunnel can be assessed only very coarsely. The Euro Tunnel, which has been built using a similar construction concept, claims 45 MVA of auxiliary power. [24] Yet, this tunnel is only about half the span of the future Bering Tunnel. The exact requirement for its auxiliary is to be determined in a further study. For this report 80 MVA are assumed. This value is drawn from the Euro Tunnel data. That tunnel was built in the 1990s. With more than double the stretch the Bering Tunnel would supposedly need double the value of the Euro Tunnel's auxiliary power: 90 MVA. However, increased efficiency can be supposed for a tunnel which is built some decades later. The 80 MVA are estimated based on this train of thought. Included in this power demand are water pumps, ventilation and more appliances such as lighting. The energy supply of the transfer terminals, e.g. point heating, is considered as well in this figure. If added to the traction power demand a value of 895.15 MVA amounts as the total power requirement for the tunnel which still can be supplied by three substations. The emergency facilities such as ventilation and smoke extraction need to be equipped with a twice redundant power source. They must be connected to an uninterruptible power supply (UPS-system).

The energy source for auxiliary power should be the same as the one for traction. Auxiliary power can be tapped into the HVDC supply of the converters or straight from the substation by auxiliary transformers if the upper high voltage side is served with 3AC power. A further option is to use small local renewable power stations combined with an energy storage system. The coastlines and the Diomede Islands in the Bering Strait offer a considerable supply of wind and ocean current energy. Additional UPS-systems must be installed in each substation as a backup for auxiliary power. Diesel generators are to be positioned outside of the tunnel in a detached but sheltered area. The proposed auxiliary power system draws its energy from the converters. This option is conventional but safe. Table 5.7 lists all options with their corresponding evaluation.

| Source AP | Availability | Safety | Flexibility | Ecology | Maintenance | Life Cycle | Costs | Sum |
|---|---|---|---|---|---|---|---|---|
| Converter | 3 | 2 | 3 | 2 | 2 | 2 | 3 | **17** |
| Direct AP | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 16 |
| Diesel | 2 | 2 | 3 | 1 | 2 | 2 | 2 | 14 |
| Renewable Sources | 1 | 2 | 2 | 3 | 1 | 2 | 1 | 12 |

**Table 5.7: Potential sources for auxiliary power**

### 5.2.8 General Suggestion

Concluding, the following plant components should complete the electrical installations consisting of traction power facilities and auxiliary power.

| **Plant Components** | **Composition** |
|---|---|
| Power Plants | combined natural gas & wind, geothermal, hydro, tidal power |
| Transmission | 2 parallel lines of HVDC |
| Conversion | If possible DC → 1AC, else 3AC → 1AC |
| Contact Line Feed | 12 autotransformers, overhead conductor rail as contact line |
| Substations | 3 HVDCS underground, island substation via seabed cables, DBB |
| Return Circuit | several ropes, maybe 4, exact number to be defined by simulation |
| Auxiliary Power | feed from converters via AP-transformers + several Diesel + UPS |

**Table 5.8: Summary of the elements comprising the suggested plant composition of the electrical system of the tunnel**

Again, it is stressed that this evaluation is being carried out by the author only. A different panel might define different criteria and come to different conclusions for the most appropriate energy system serving the tunnel and beyond.

### 5.2.9 Production of the Suggestions

The defined proposals are being illustrated in order to get a clear picture of the energy system. This report is limited to a simplified electrical diagram and individual plans showing potential building compositions and locations of energy installations.

#### *5.2.9.1 Simplified Electrical Diagram*

Relevant elements of the electrical system are displayed in a simplified diagram in order to get a better idea of the system as a whole. The numbers in brackets represent the number of components of each substation or converter station, respectively. Individual transformers, power switches and bus bars are omitted for reasons of simplification and clarity. For the complete diagram please see appendix 3. On this plan one can spot the application of HVDC as the transmission method for long distance energy transportation as suggested for the electrical system of the Bering Tunnel.

If an individual power station is designated to simply feed traction power all the way to the tunnel without any other consumption in between it is possible to install a DC generator instead of an AC one. Thus, one converter (rectifier) could be saved. The HVDC line is directed through HVDC switchgear (HVDCS) into the converters of the tunnel substations. Due to the intended use of autotransformers two phases have to be supplied. From the transformers the 25 kV current runs through indoor switchgear and to the contact line (in this case a ceiling-mounted conductor bar). The consumer (locomotive) alters the electrical energy into mechanical energy. The residual electrical current is collected from the rails with return circuit ropes and is redirected either through the autotransformers or straight back to the transformers in the substations. Eventually, this circuit starts again.

This report does not include any plans illustrating the concept of auxiliary power. As explained earlier, auxiliary power is supposed to be drawn from the converters via auxiliary power transformers. Each substation consists of five converters and five transformers designated for traction power. The autotransformer system entails 12 autotransformers which are installed every 10 km along the tunnel stretch (see figure 5.7). All autotransformers are remote controlled from a central control center. This sounds like augmented convenience and efficiency. However, the preventive maintenance effort is increasing due to the higher amount of sensitive material and controls in the tunnel which are subject to failure if not checked regularly.

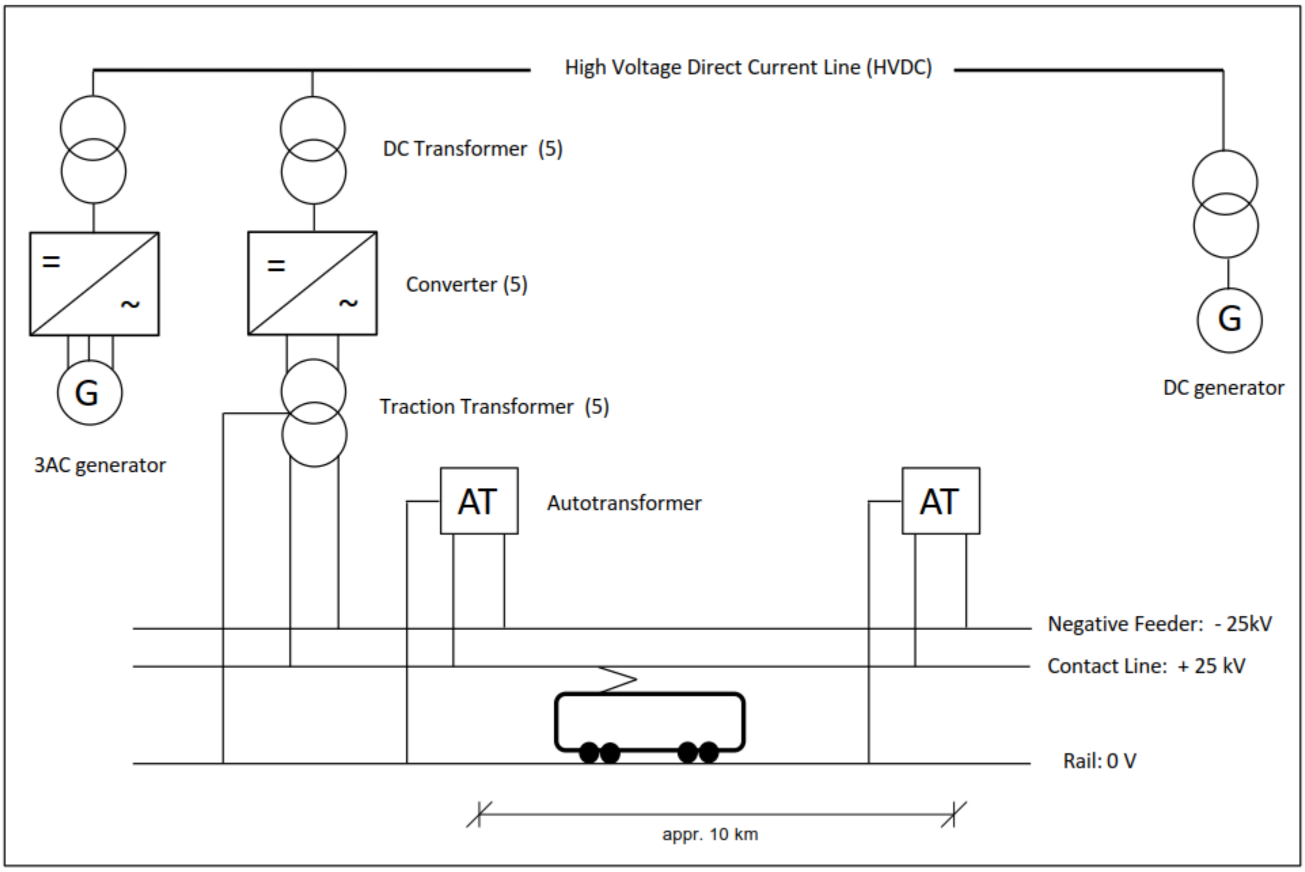


**Figure 5.2: Simplified electrical diagram of the Bering Tunnel energy system**

### *5.2.9.2 Substation Layout*

The plant layout allows for a superficial assessment of the space requirements of the substations. The outline of the energy facilities is kept in a compact fashion. Practical questions are raised though, such as on access for heavy loads, e.g. transformers. Potential access is possible via road, ship or rail after temporary rails are installed. The transformers intended for the substation on Big Diomede Island can only be brought there by boat and via new roads to be built. This concept of combined (intermodal) transport is also feasible for the mainland. Carriage by air might be possible in the future with supersized airships. Today, airlift is impossible due to the heavy load of more than 100 metric tons per transformer. The highest ever lifted load by a helicopter is at 20 metric tons. [29]

All substations should be designed in a compact fashion and with good access for maintenance. It needs to be studied if the transformers should be placed underground as well or outside in special buildings or without shelter withstanding the elements. However, there are basically no restrictions on noise or electromagnetic radiation. For fire protection reasons positioning of the transformers in an open space would be more secure. This means though, they are subject to the harsh climate conditions which might influence the lifetime of the transformers in total. In general, strict fire prevention regulations have to be met if the transformers are to move inside a covered structure but this solution is possible and nothing new. The plans displayed in figures 5.3 - 5.6 (not drawn to scale) illustrate the explained concept. This applies to all substations. A layout of the HVDCS is missing though since there is no template of an HVDCS yet.

The converters are put above the cable vault and adjacent to the HVDCS hall where they can be easily connected to the HVDCS. The corresponding choking coils are installed one floor above on a terrace (distinct platform). The traction power transformers are placed in front of the building separated from one another by fire protection barriers. The control cabinets are situated in the HVDCS room. The first floor houses the 25 kV indoor switchgear. Telecommunication and auxiliary controls as well as the battery room including the UPS are installed on the second floor. The sketches in the following figures represent a qualitative display of a possible layout. They characterize a superstructure. If the substation facilities are put underground as recommended the transformers and choking coils will either be placed in an outside shelter where they are protected against wind or they will be installed in a separate room. In an underground layout the structure will be designed upside down with the cable vault on top (first basement floor), the converters and the HVDCS on the second basement floor and the 25kV indoor switchgear together with the UPS and auxiliary power control panel on the third basement floor.

Each substation shall be occupied with personnel. Due to the relatively bad weather conditions in the area there should be no separate staff building, i.e. the employees are accommodated in the service building where they remain most of the time. Service buildings are supposed to be built at both tunnel portals. Those are being equipped with recreational facilities, a canteen, medical facilities and further amenities. Moreover, the rescue teams are going to be housed there as well. A small part of the rescue team staff will be stationed in the substation on Big Diomede Island.

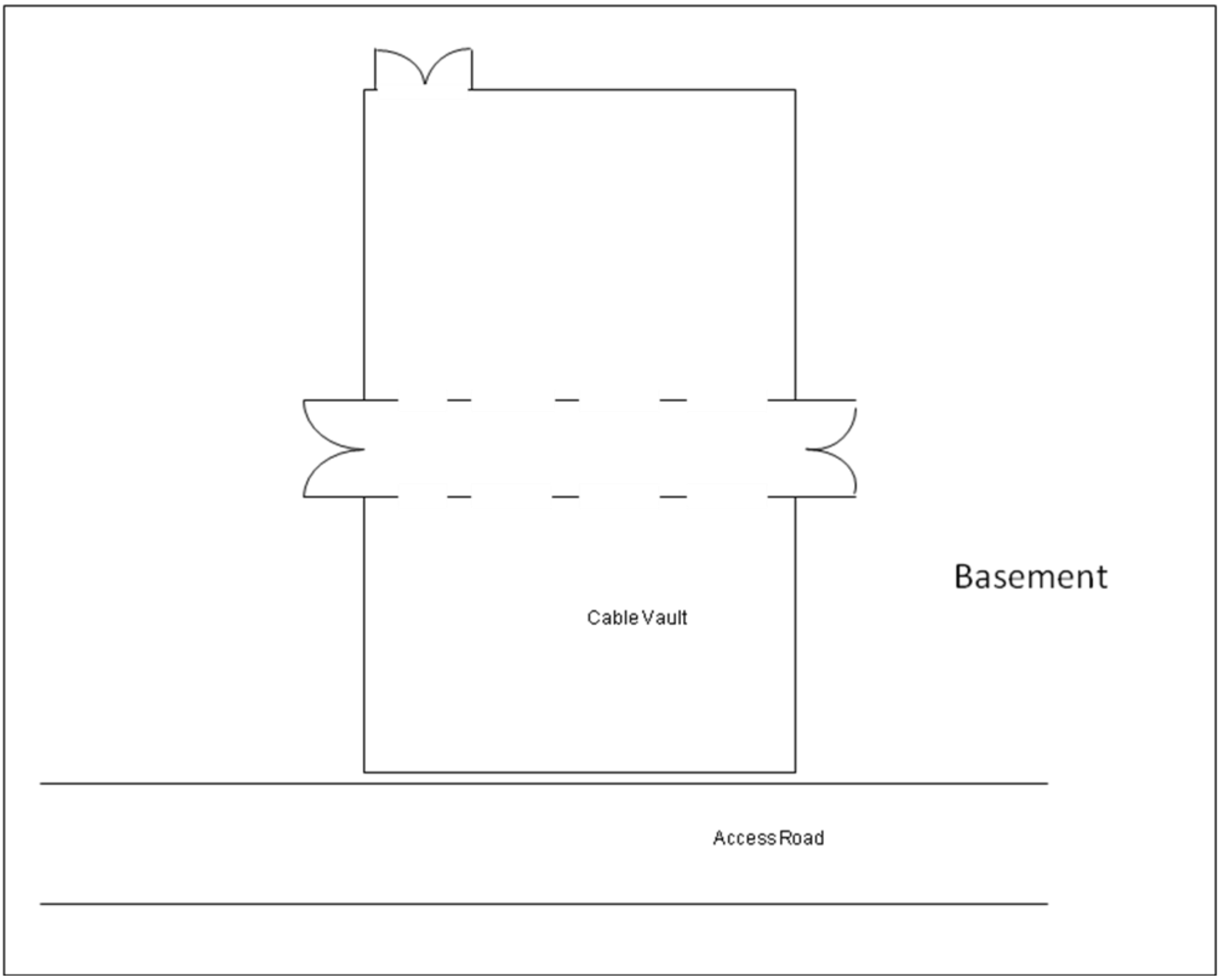


**Figure 5.3: Substation building plan – basement**

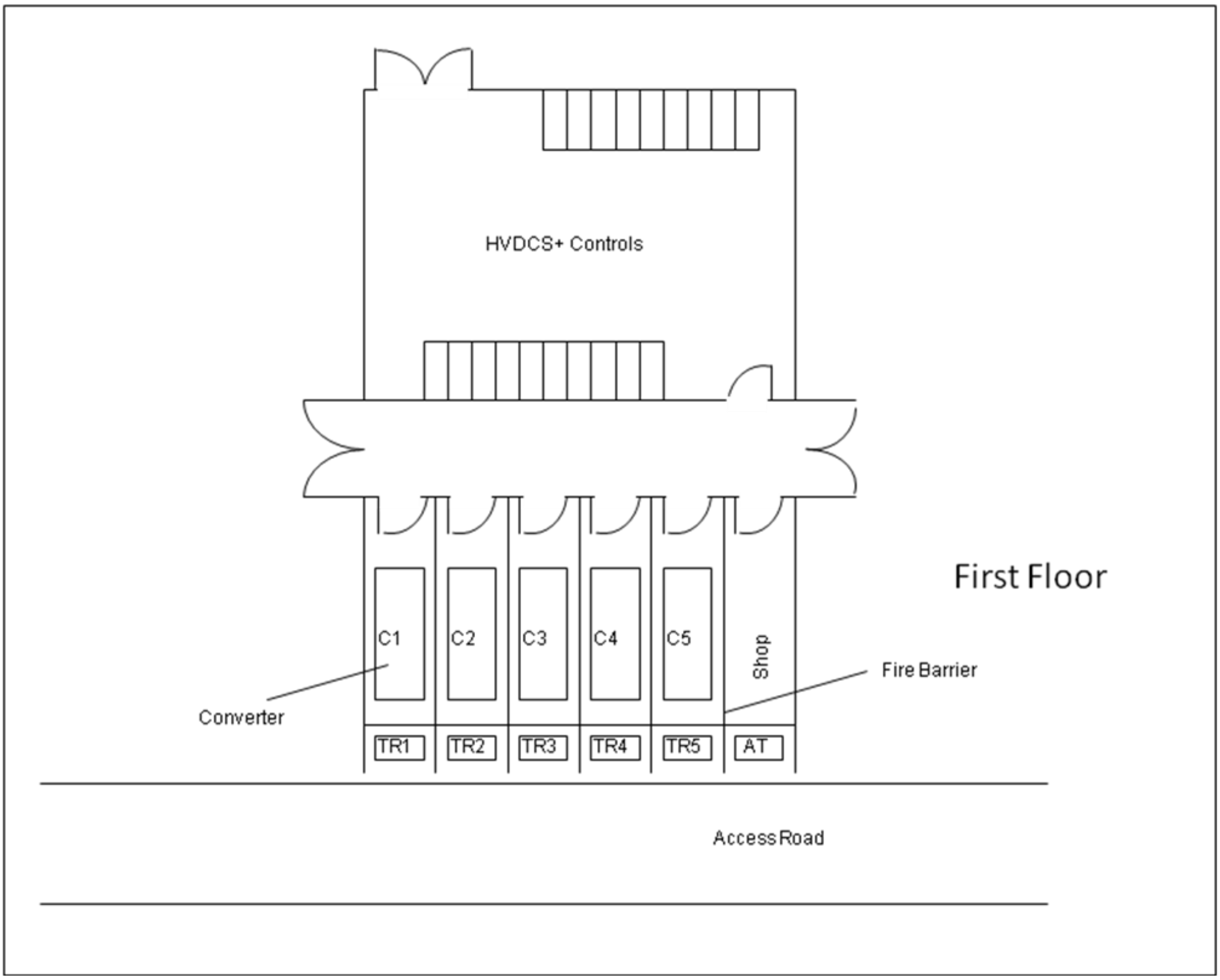


**Figure 5.4: Substation building plan – first floor**

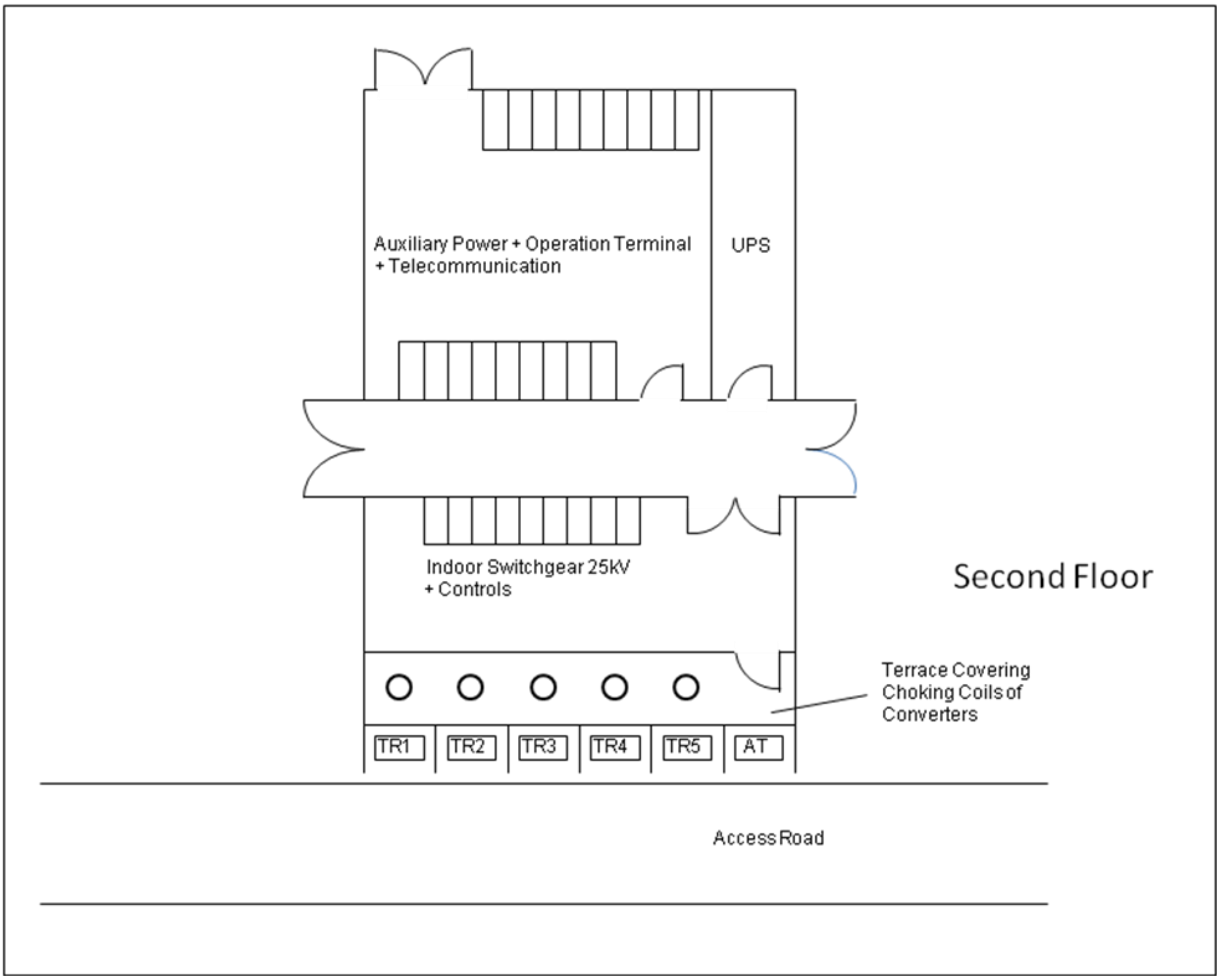


**Figure 5.5: Substation building plan – second floor**

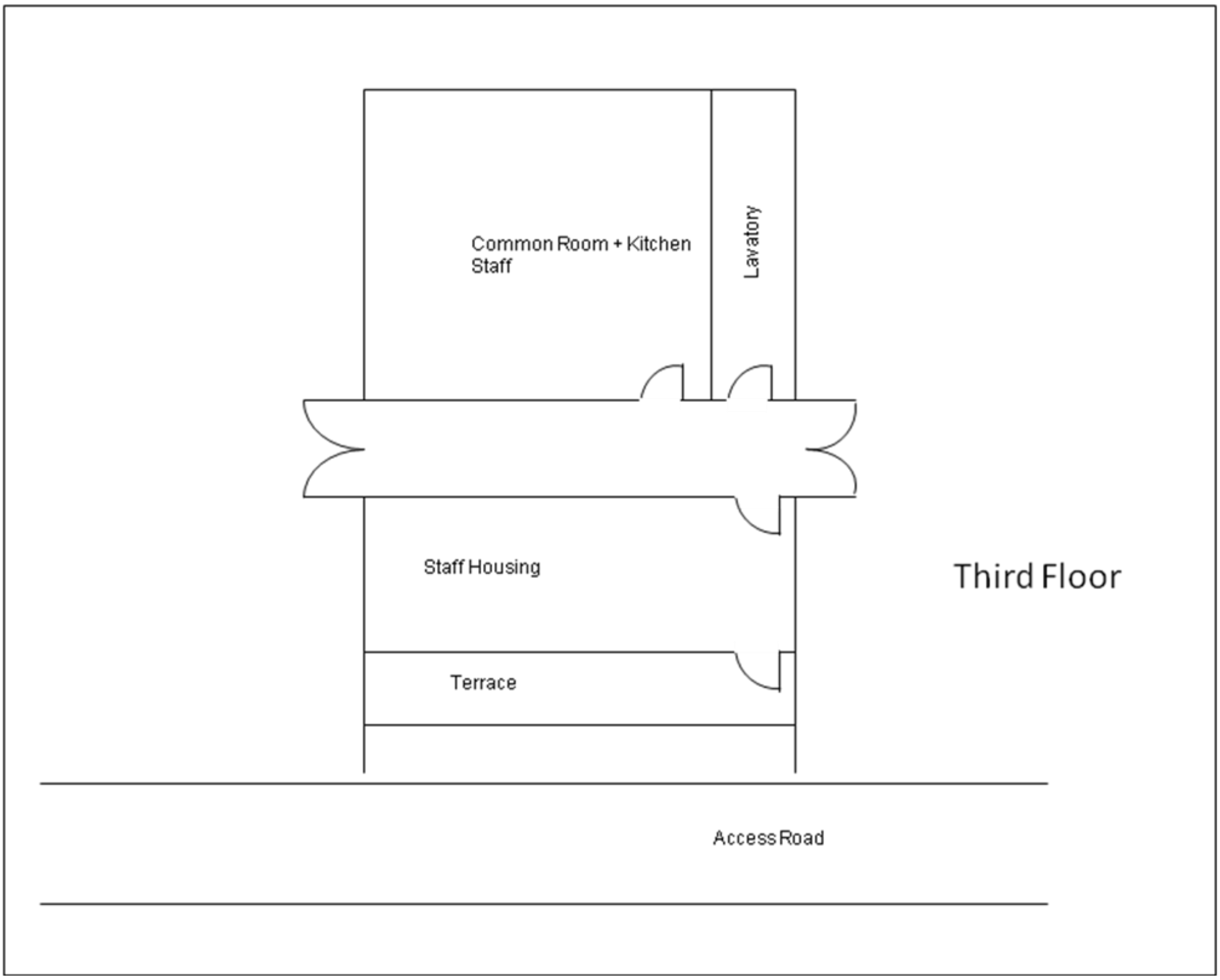
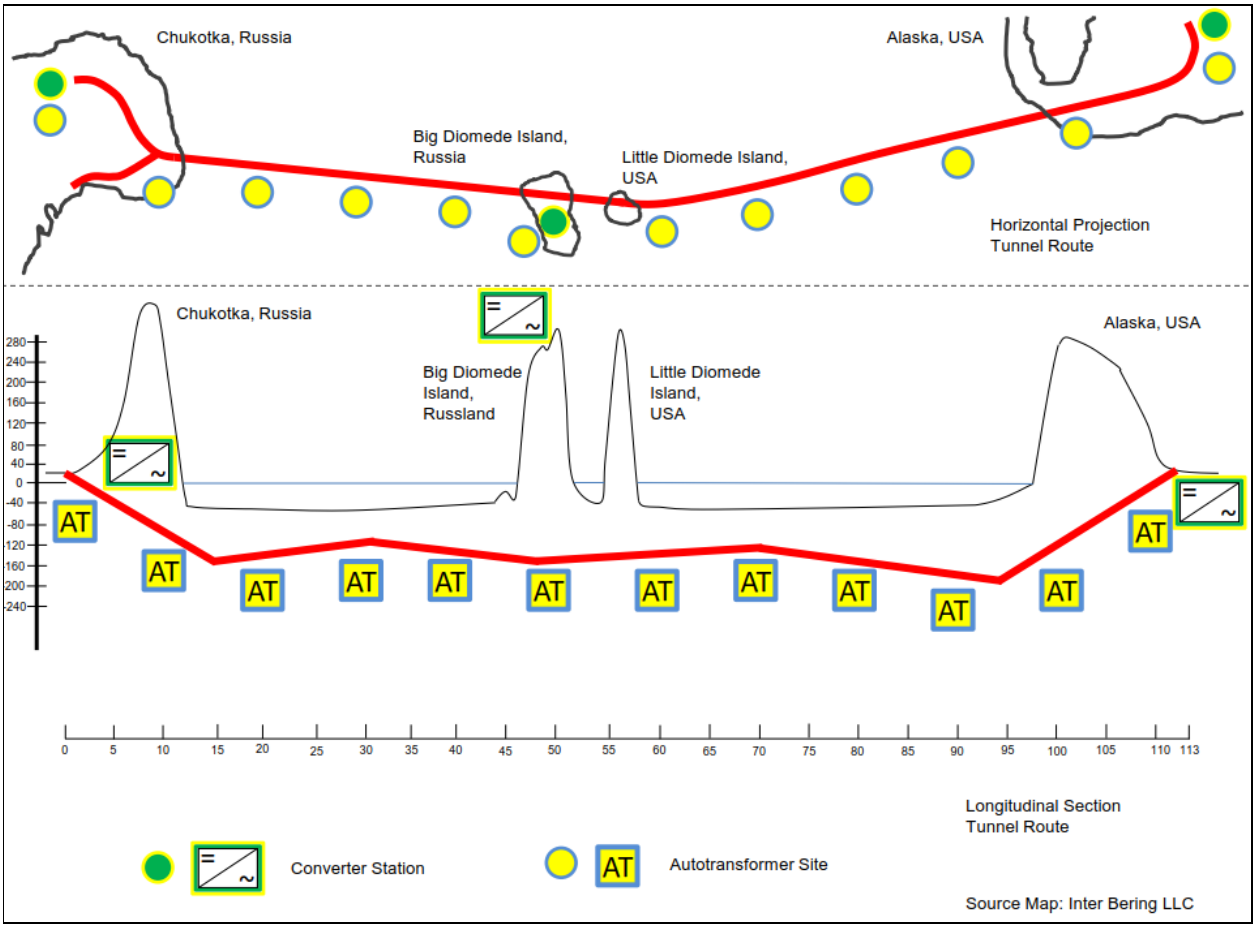


**Figure 5.6: Substation building plan – third floor**

### *5.2.9.3 Positioning of Energy Supply Facilities*

The locations of all three converter stations and 12 autotransformers are marked on the ground plot and the longitudinal section. The substations and converter stations are situated at the portals in Alaska and Chukotka. The third station is located on Big Diomede Island and is linked to an access shaft of the tunnel. Traction power supply from this favorable site is critical in order to keep voltage on a stable level. Moreover, as at the portals, emergency ventilation and exhaust facilities will be installed here which will be employed in case of fire in the tunnel. An evacuation shaft is another design feat characterizing the island's construction.

The autotransformers are spread along the track, one at every 10 km. The distance can vary though, according to an exact simulation to be carried out.



Source Map: Inter Bering LLC

Figure 5.7: Longitudinal section of the Bering Strait Tunnel displaying sites of converter stations and autotransformers

# 6 Summary

After surveying the political situation and the history of the tunnel a systemic analysis of the thesis' problem definition followed: “An Energy Concept for the Traction Power Supply of the Bering Strait Tunnel.” Hence, significant determinants influencing the energy system of the tunnel could be identified. Subsequently, the potential economic effectiveness has been explained. As a result of this analysis, the tunnel will be mainly used for the shipping of containers and subordinately for heavy cargo traffic. Passenger transport will play no role in this scenario since there is no economic reason at the moment.

The goods which are going to be moved through the tunnel are supposed to be shipped relatively fast in order to accommodate the demand of this means of transportation, being able to carry heavy finished goods quickly from A to B. Thus, the supposed train velocity of 100 km/h is an ambitious but realistic requirement. Inter Bering LLC made an assumption of 7 trains at 9.000 metric tons each, passing the tunnel per hour at the same time. This request could be verified. One issue still needs further study: the gauge change facility. This will either consist of a new developed automatic system for cargo trains similar to the Talgo system for passenger trains. The second option is rolling stock equipped with two sets of wheels at 1435 mm and 1520 mm track gauge. Though, the most likely third option is an efficient and large transshipment center.

With the results from the profitability assessment of 7 trains at 10,000 metric tons each crossing the tunnel per hour at a speed of 100 km/h, the required power and current at the contact line could be determined approximately. More accurate findings are to be established by means of a simulation. The required traction power (excluding auxiliary power) of 815.15 MVA for the entire tunnel and a necessary current of 3,261 A per train sets quite high demands for the tunnel energy concept. This result bears consequences for the construction of the contact line. Only a ceiling-mounted conductor bar is able to master such high amperage. The alternative of several parallel overhead lines is dismissed for reasons of inefficiency due to an increased maintenance effort.

Following the calculation the system components of the traction power supply scheme have been described. As the next step the selection criteria have been defined and explained. The alternative compositions of the components were given scores of 1 – 3. The final propositions entail nearby natural gas, tidal and wind power stations combined with methanation plants. In addition, more distant run-of-river, hydro and geothermal power stations are suggested. The electrical energy will be transmitted via 2 independent HVDC lines per power plant which lead directly into the three underground substations located at the tunnel portals and on Big Diomede Island. The latter is fed by several submarine cables from the power stations. On the substation sites the HVDC lines run straight into converters. The result after the conversion is traction power at 50 Hz and 25 kV. In order to keep voltage drops low along the track, an autotransformer system comprising 12 such devices is applied. The traction power supplies the locomotives (engines) through a ceiling-mounted conductor rail. Eventually, the electric motors of the locomotives transform the electric energy from the contact line into mechanical traction energy which generates the movement of the wheels and finally of the trains.

To assure the return circuit of the traction current a number of parallel return conductor cords will be installed inside the tunnel. The return conductor cords are connected to the rails every 300 meters. According to demand and profile at least four return circuit conductor cords are needed if normal cord size is used.

Auxiliary power plays an important role in the energy system of the Bering Tunnel. Without any basic information on which and how much electrical equipment will be installed in the tunnel it was impossible to determine demand for auxiliary power. Thus, the requested power was estimated at approximately 80 MVA with comparable numbers drawn from the auxiliary power in the Euro Tunnel.

In general, the layout of the traction power supply system seems feasible but quite ambitious due to the high load assumptions. It needs to be stressed that the same load assumptions as for the tunnel also apply for the feeder routes in Siberia and Alaska. Only if the entire new rail system is considered (as in the systemic analysis described) a rail “pipeline” between Eurasia and North America can be created.

Concluding, this study confirms that a Bering Strait Tunnel can be equipped with traction power facilities supplying the tunnel with energy, even under demanding conditions such as high load assumptions.

However, the risks for the construction of the tunnel are quite high. The current situation in world politics as of the rivalry between Russia and the US raises doubts on the realization of this project in the following decades. Only China has the potential to come forward and emerge as a leader for this endeavor. [22] From a financial point of view the current situation does not look much more promising. The worldwide financial and debt crises are still continuing without any significant improvement on the horizon. In addition to the political and economic challenges the technical feasibility raises questions regarding electricity generation and transmission covering extremely long distances. Moreover, programs for developing around 6,000 km of feeder routes need to be initiated in Russia, Alaska and Canada. These routes need to be built based on similar load assumptions as the tunnel. On the other hand, it is about time to explore new horizons and increase the capacity of infrastructure globally. A project such as the Bering Strait Tunnel has the potential to improve worldwide trade data. Further concepts regarding the realization of the tunnel are to be considered and tested. Some of them could revolutionize the world of transportation.

# 7 Future Advancements of the Bering Tunnel

In order for the reader to gain superficial knowledge on the general challenge of an electrification of the Bering Strait Tunnel this report outlines the most important key features. Questions are identified which must be subject to further investigation. More questions will follow. Some of the issues are being discussed in this chapter. An outlook into future developments completes the survey.

## 7.1 What Still Remains to Be Done

This study gives an overview of a viable design of the energy supply of the Bering Tunnel. Some of the constraints and impacts have already been stressed in the systemic analysis. Others have not been addressed yet but deserve further research.

The development of renewable energies, for instance energy storage, is advancing at a high rate. In terms of the energy supply to the Bering Tunnel it should be subject to verify whether and what kind of power station could be built on Big Diomede Island. This endeavor is likely rather expensive but would increase technical availability. This power station can be designed as a gas-fired power station combined with wind generators and a methanation facility. At a power rate of 1.5 MVA per unit [45], marine current generators are quite expendable at the moment. However, this report assumes more effective generators of this kind which also should be linked to the methanation device. All power plants on and around the island would be coupled making one virtual power station. An alternative would be a modern and safe MSR nuclear reactor

In the long run, the goal is to avoid long distance power transmission for the energy supply of the tunnel. Ideally, traction power should be generated as close to the consumer as possible, i.e. close to the tunnel. If this concept turns out to be not feasible in the next couple of years, more efficient means of energy transmission (for instance HVDC) need to be developed. Superconducting DC cables containing magnesium diborid [73] could be one option in this regard. To cope with the ambition of designing a high-voltage DC-grid, appropriate power switches need to be developed. This has been achieved [11][64] but they still need to stand the test in practice. Until production maturity of those power switches, DC should only be used as point-to-point transmission. With further development in the future the preference for long-distance power transmission for the Bering Tunnel could be well set.

Regarding the high currents in the tunnel a voltage increase should be considered. Voltage of 50 kV would be possible. Yet, such a change in demand implies a voltage change at a certain point. This could be achieved with a neutral section. The most notable advantage of this measure would be a reduction of amperage. A relief in the electrical protection system would be the consequence since short-circuits could be better detected that way. The higher the current on the contact line the more complicated to detect short-circuits.

This study suggests HVDC as the appropriate transmission method combined with static converters. However, this concept needs to be verified by a simulation in terms of voltage stability. Another issue to be examined by a dynamic simulation is the absence or presence of rotating mass for frequency stability in the power grid depending on the number of rotating generators, the composition of the grid and the substations. If DC is used as the main type of current in the grid the problem of frequency stability would be irrelevant.

For train operations the development of an efficient gauge change facility for freight trains similar to the Talgo system should be intensified. This way trains only needed to drive slowly through the facility without stopping apart from the quick exchange of the engines if the North American Route is not going to be electrified. Such a gauge change facility would save the lavish transfer station at the Alaska portal. This comparison should be subject to further economic analysis considering the rather inefficient transportation of only one container level on each cargo train as well as the delay of the transshipment. If the proposed transshipment station became reality it ought to be designed in an indoor fashion or underground. If an outdoor alternative is preferred the construction must be able to withstand the harsh local weather conditions of strong winds, low temperatures and ice.

Regarding the design of the energy facilities additional strategic space for further renewal and reconstruction or even extension should be well considered. One extra converter/transformer spot in each substation must be taken into account. Cable-runs should be designed using large bend radii for future bigger and more powerful cables.

One of the issues posing the highest risk in terms of costs and scheduling delays is geology. The tunnel tubes penetrate into permafrost which is not stable and moves at times. This requires a robust solution. The permafrost is one of the biggest challenges with the potential of compromising the entire project. Thus, a detailed geological survey needs to be carried out in the very beginning of the next planning stage.

Besides these descriptive constraints there are more radical ideas to be considered. Already there are trains carrying their own source of power: hydrogen. If fuel cell drives are the future of traction power there is no more need to discuss traction power supply with distant electricity generation and expensive installations. Time will tell if those systems are going to prevail in the world of heavy cargo shipping.

For a future increase of the tunnel's capacity a tunnel profile with more than one level ought to be studied. From a current perspective passenger traffic for business is economically not viable. Maybe, gradually there will be individual tourist trains allowed to squeeze into any available operational slots between cargo trains. But an enhancement of the tunnel will be aimed at freight trains. A tunnel profile with several levels is going to increase the energy demand significantly.

A feasible vision though would be the installation of an upper level for magnetic levitation trains (Maglev). The long detour in comparison to flying from Asia to North America can only be justified by higher speed. In April 2015 a Japanese Maglev train has reached a speed of 600 kilometers per hour. [37] How much energy was needed during the test is unknown though. Furthermore, this speed is still well below the competitive means of transport: commercial airplanes which travel at a speed of around 900 kilometers per hour and in beeline. However, travelling faster than regular planes could be made possible with an innovative means of transport such as the "hyperloop" envisioned by Elon Musk [74] with a top speed of 1200 kilometers per hour. Inter Bering LLC considers even faster transportation at speeds of 6400 km/h in a completely evacuated tube. [1] This would be revolutionary indeed, in particular, if such a system would be available for both passenger and cargo transport. There is no information on the potential energy demand of this system. In contrast to Musk's "hyperloop" this system consists only in theory. For the double-decker tunnel design Inter Bering LLC presumes a 15 m inner diameter. This profile appears to be rather ambitious and expensive considering the 7.76 m inner diameter of the recently inaugurated Gotthard Base Tunnel in Switzerland. [46]

Travelling several times faster than current planes would effectively alter the situation of transport. Further development of this technology should be well considered in the planning of the Bering Tunnel. Yet, this system would entail new magnetic feeder tracks in Asia and North America as for the railroad. Also, this system is expected to draw a lot of energy in addition to the already high power demands for the railroad resulting in more power plants, substations and transmission lines as well as converters. Important to consider is the fact that the competition does not rest. The development of future ships and airplanes can also bear surprises both in technology and pricing. Eventually, the anticipated market situation and the available financial resources will decide which transportation system(s) and which tunnel design will be chosen for further development. A larger profile will turn out to be way more expensive. Yet, in general, the tunnel is supposed to be designed in an innovation-favorable fashion.

It is to be studied whether the tunnel shall not only contain rail tracks but also energy, communication, water and oil pipelines. Inter Bering favors this option. Such a connection would link those lines between America and Eurasia (including Africa). This in turn would offer new opportunities for these businesses. However, containing such lines in the tunnel would be contrary to the notion of installing a minimum of sensitive infrastructure inside the tunnel. Conceivable in this instance is a fourth tube dedicated to the mentioned pipes and transmission lines possibly even including the HVDC line feeding the substation on Big Diomede Island.

This compilation of ideas is not supposed to be complete in any sense. In further studies this list will be extended.

## 7.2 Outlook

Inter Bering LLC expects the construction period for the tunnel only to last around 15 years. It is unknown to this point how long the construction of feeder routes is going to take. Due to the political disagreements between some of the concerned countries, the vague funding and unclear legal status, it can only be speculated on the beginning of the tunnel construction. Currently, any signed contracts are not expected before 2025 indicating firm commitments of the related parties and the start of serious project management planning. Despite of these adverse circumstances this project should not be dropped. On the contrary, further persuasive efforts ought to be invested in the project.

Regarding engineering this tunnel is rated feasible both in terms of the structure and the electric system. A tunnel project underneath the Bering Strait poses many challenges. Thus, it brings together several fields of engineering. With the anticipated long-term character for the realization to begin, many technological innovations are to be expected which will improve the tunnel design and offer new engineering opportunities.

This study represents thought-provoking impulses both for trying to improve existing systems and for venturing breaking new grounds together. This applies not only for engineers but also for politicians.

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# 9 Appendix

## 9.1 Table of Figures

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## 9.3 Appendix 1: Explanation of the Terms Related to the Systemic Analysis regarding the Traction Power Supply System

### 9.3.1 Safety

The tunnel must be safe. It will be designed according to current safety regulations. Not only precautions against accidents but also for more security against any potential terrorist attacks on the energy supply facilities will be part of the security and safety concepts. One aspect of the latter is the numerous redundancies dedicated to the power supply. For instance, the number of section isolators has an impact on the feeding points along the track and thus, it has influence on the energy concept. Moreover, the automation including numerous safeguard sensors shall be limited at a low level for easier maintenance. At this point, a compromise between surveillance and mastering of the system needs to be accepted. This scale indicates the level of required redundancy in terms of the energy supply system, its sensors and relevant control system.

### 9.3.2 Politics

Politics play an important role deciding on the construction of the tunnel in general as well as its design. This also has an impact on the energy concept of the tunnel.

### 9.3.3 Maintenance Concept

The Bering Tunnel needs to be designed around an efficient maintenance strategy. Preventive maintenance is a key element in the energy supply concept of the tunnel. In order to keep the maintenance effort at a minimum as few electrical devices as possible and only as many energy facilities as necessary shall stay inside the tunnel. This includes sensors and control systems. Parts of the traction power supply system need to be switched off during maintenance operations. This, in contrast, increases the number of necessary separators and switches. There must be a sensible compromise between operations and maintenance. Automation including the number of sensors in the tunnel should be minimized down to a prudent level. Otherwise, those devices need to be maintained as well. That increases the total maintenance effort. As in the Gotthard Base Tunnel, maintenance procedures are about to be conducted in a weekly eight hour window when no trains are operating in the tunnel. Maintenance operations must be carried out from all three maintenance centers at the same time and stick to a tight schedule. This recommendation is subject to scrutiny and should be investigated further. The more effective and efficient maintenance the safer and profitable is the tunnel.

### 9.3.4 Auxiliary Power

The exhaust, ventilation, illumination, drainage etc. also need to be supplied with energy. The concept of auxiliary power in the tunnel has direct impact on the overall energy concept. It is worth to study if electricity should be channeled off the traction power system via 1AC transformers inside the tunnel. In contrast to the latter chapter, this in turn would mean more energy devices in the tunnel, more maintenance and more potential safety issues. Routing cables with a redundant 3AC source from the tunnel portals into the tunnel would imply higher expense on cables and transformers at the portals. But this solution requires less electrical equipment inside the tunnel. The goal for the auxiliary power layout is also: only as much as necessary and as little electrical gear in the tunnel as possible.

### 9.3.5 Economic Viability and the Response from Competitors

A seemingly distant but far-ranging aspect is the response of the alternative carriers, for instance shipping traffic. The tunnel as well as the energy concept needs to be designed in an economic manner. On the other hand, reserves should be kept for times of higher demand when the capacity of the tunnel is going to be increased. Yet, energy supply shall not be the primary driver of the tunnel costs. The response from competitors is awaited with interest. Since the tunnel will grab only a small fraction from the global distribution market it is expected that this reaction will not be a drastic one. Maybe prices are going to be adjusted insignificantly. Though, the margins in transportation are low.

### 9.3.6 The Situation of the World Economy

The Bering Tunnel will serve the world economy. It is both fundament and consequence of the strong economic performance of Asia and North America. However, if the trade cycle is low there will be rather modest or no willingness for investment in such a tunnel. The global economy is the source for building the Bering Tunnel. A compromise solution, e.g. only one tube, due to slender financial resources and low motivation would impact the energy system of the tunnel as well. If the world economy is in a rather prosperous situation the persuasion of investors and decision makers will not be as tough.

### 9.3.7 Available Funds

Decisive data is reflected by life cycle costs (LCC). These include investments, renewal of certain installations as well as maintenance expenses. However, a sensible approach of life cycle duration must be determined. Moreover, this international project requires a fine definition of the interface between the different national sources. Or to put it simple: it needs to be clarified who pays what, how much and when. The funds should be ready before the project starts. Thus, a suggestion would be a “Bering Tunnel Investment Fund”. In terms of procurement of traction power supply equipment and planning not only costs but also qualitative factors should play an equally weighted role. In preparation of the expected cash flow, annuity scheduling for financing shall be organized in a very early stage of the project, as soon as the LCC are coarsely (30% accuracy) known.

### 9.3.8 Corruption

During the tendering process potential suppliers need to be able to take part in an objective and transparent procedure. The risk of interference of the tendering process by potential suppliers must be detected, reported and punished. Supplies and services which came about by corruption can cause substantial loss in quality. Besides tendering, corruption also can be a factor during acceptance and commissioning. The consequence of a finished traction power system affected by corruption is a safety risk. Moreover, the project can be delayed due to inadequate bureaucracy or red tape performed by corrupt officials. Transparency is an essential element in order to prevent compromised procedures and faulty facilities. However, this study presumes that corruption is a viable risk for the implementation of this prestigious project.

### 9.3.9 Development of Rail Infrastructure to and from the Bering Tunnel

The power supply for the Bering Tunnel is only one fraction of the overall energy concept. The elongated railway lines through Siberia are expected to be electrified while the railroad stretches in North America are probably not subject to any electrification in the near and far future. There is a direct reliance between the power supply of the tunnel and the open railroads leading to and from the tunnel. Trains with alternative engines driven by hydrogen already exist. Yet, fuel cell locomotives are presumed to be not ready for heavy cargo trains in the foreseeable future.

### 9.3.10 Cargo Logistics (Container Handling, Track Gauge Change)

Intermodal commercial transport shall be developed in the region but only in a train-to-train fashion. Vessels carrying material and other goods for the construction of the tunnel are going to be unloaded at both shores of the Bering Strait. Thus, offloading quays are to be built at the shores near the tunnel portals. However, future intermodal train-ship-train traffic is considered as ineffective. Yet, on most railroad tracks in North America and some in China double-decker trains are quite common where two containers are stacked on top of each other. Depending on the minimum clearance outline of the connecting railway lines and the tunnel profile a transfer station at the tunnel is a viable option. This station would be combined with a customs station. Even during a political rapprochement between Russia and the US there won’t be any free trade agreement between these countries in the medium term. Thus, customs stations on both sides of the tunnel are expected. A marshalling yard combined with a transfer station near the tunnel portals have an impact on the overall energy supply concept since energy and power demand are increasing.

### 9.3.11 Traction Power Installations

Due to the prominent traction power system of 25 kV and 50 Hz in Siberia and China it is reasonable to plan the tunnel’s traction power system based on this electric scheme. Thus, traction power installations, for instance insulators, are to be designed according to the selected traction power system. If 50 kV are selected as the traction voltage in the tunnel, larger insulators and wider safety clearance are the consequence making the tunnel larger and more expensive. This option would have an impact on the energy supply system. Moreover, a decision needs to be made if a regular overhead line or an overhead conductor rail is going to be selected as contact line. In addition, the concept of return circuit (booster transformers, autotransformers or several return conductor ropes) affects the energy concept.

### 9.3.12 Size of the Tunnel Perimeter

The dimension of the tunnel cross-section has a direct impact on energy supply. The smaller the tunnel perimeter the bigger the aerodynamic resistance and thus the more energy is needed to move a train. A larger dimension of the tunnel would be conducive in terms of energy demand. In turn, this would create higher costs for more material to be excavated.
The tunnel will be primarily used by freight trains. Due to the inferiority of passenger trains in terms of speed compared to airplanes only very few tourist trains are expected to transit the tunnel. Passenger trains will remain on the fringes as far as conventional passenger transport on rails is concerned. This is why future concepts of movement such as magnetic levitation trains (maglev) shall be mentioned in this report. Some models of the Bering Tunnel consider a vertically divided tunnel separated into several levels. The lower level is designated for heavy cargo traffic while the upper level bears a maglev train system. Since much time will pass before the commissioning of the tunnel becomes reality this vision should be considered in further planning. In this case spare space needs to be reserved for a wider diameter of the tunnel and additional electrical installations. The power demand for regular tunnel operations can be well double in this scenario. Moreover, the safety concept must be completely renewed if such a double-decker design is applied.

### 9.3.13 Transmission Lines

Power transmission is part of the energy system of the tunnel. Basically, there are two possible conceptions regarding energy transmission between the power stations and the tunnel portals: AC-lines of super high voltage of approx. 1.5 MV or HVDC-lines. Both systems can be installed on rods as overhead lines or through cables. HVDC cables are less prone to the severe climatic conditions in the area. While there is considerable capacitive load in AC cables, there is none if a DC system is selected. At the tunnel portals the HVDC lines are preferably connected to a static converter (SFC). Both the design of the converters and the layout of the switchgear depend on the type of electricity transmission. Two transmission lines in parallel, whereas one HVDC line and one 3AC super high voltage line would be one option to supply the tunnel and the industries as well as households along the route. Another option is to utilize two independent HVDC cables designated for supplying rail and civilian demand. The latter requires additional converter stations and substations along the track.

### 9.3.14 Geological Constraints

Depending on geology the return circuit will be carried out via ground or corresponding return conductors. Hence, geology affects the energy system of the tunnel in an explicit fashion. Geological surveys have shown several different materials in the perimeter of the tunnel. Thus, a routed return circuit to the substation is more likely and safer.

In terms of earthquake risk the Bering Strait is close but not situated precisely on the Pacific Ring of Fire where seismic action is usual. However, due to the significance of the transport link an earthquake-proof design of the tunnel is mandatory. This makes additional reinforcement necessary in order to stiffen the construction of the tunnel. One option would be the segmentation of reinforced parts of the tunnel linked by special joints. Additional bracing is also required to protect energy installations from seismic movement. Yet, putting much emphasis on the earthquake-proof layout of the tunnel will create considerable additional demand for funds.

Furthermore, geology determines the longitudinal profile. Freight trains can only run on low inclinations. Any ascent requires additional power. Thus, geological constraints have a direct impact on the energy system.

### 9.3.15 Regulations

The tunnel connects two countries with different guidelines concerning electrical railroad systems. For this project the same standards have to be applied. Two different systems in the same tunnel are no option. UIC norms can be helpful to solve this issue. Those yet unclear regulations on design will have a massive affect on the layout of the energy system.

### 9.3.16 Innovations

The tunnel is to reflect state of the art technology. In terms of energy supply this entails electricity generation, transmission, conversion and distribution. Possible modern transport systems for instance maglev trains create an additional energy demand. Such concepts need to be taken into account including appropriate space reserves.

However, innovations also involve alternative advancements which challenge the construction of the tunnel as a whole. Improved ship propulsion methods or new airplane concepts could allow faster, cheaper and more efficient transport of goods across the Pacific. Those would again compete with the Bering Strait Tunnel.

### 9.3.17 Operating the Tunnel: Train Speed and Train Weight

Basic data for the design of the energy supply system of the Bering Tunnel are the load specifications of the trains. Expected speed is one of them: a cruising speed of 100 km/h is expected. Train weights of 10,000 metric tons at speeds of 100 km per hour are input data for the calculation of the energy system. Those relatively high rates take into account a weight increase and faster acceleration of the trains. Such heavy freight trains are not common in Europe but no curiosity across China, Russia, Canada and the US (the four main participating countries in the tunnel).

The tunnel is not aimed at a possible competition towards existing shipping and airplane traffic across the Pacific. Rather, it shall close the gap between heavy crude materials and lightweight finished products which both are conveyed by ships or planes. The energy system is to perform at a high power level for years in the future. The dimensioning of the traction power system is carried out according to the highest possible load specification under realistic circumstances. This should reflect the worst case which is assumed to be the evacuation of a total number of ten trains in the two tubes at the same time. Train speed, train bulk and train acceleration are the fundamental constraints for the layout of the tunnel. The higher those numbers are the larger the dimensions of contact lines, converters, transformers, transmission lines, substations and power stations.

### 9.3.18 Control and Communication System

The control system is an essential element in the energy system. For instance, the control system of the autotransformers needs to be connected by wires which have to be laid along the entire tunnel. In fact, many kilometers of wires are necessary to realize the communication among electrical installations and control centers. Depending on the feeding system the control logic turns out to be more or less complex. Moreover, ducts sheltering high voltage cables supplying the substation on Big Diomede Island are to consider as a protective casing for control wires.

Due to the extreme span of the tunnel the control system must be designed in a redundant fashion.

Controls and servers operating the energy system of the tunnel are situated on both portals of the tunnel. For the control system the same notion as for all appliances in the tunnel is binding: the simpler the better, i.e. energy systems demanding less complex control systems are to be preferred. An important element of the control system is an effective radio system transmitting sensor data within the tunnel. This system must be planned redundantly as well. However, the more safety sensors are present in the tunnel the higher is the risk of failing sensors. For operational reasons too many failing sensors cannot be maintained and thus cannot be fixed in time, as in the Euro Tunnel. [71] The danger created by sensors on permanent malfunction is obvious.

### 9.3.19 Autotransformer Locations

Due to the large feeding expanse of 50-110 km, autotransformers are a necessity in this tunnel. They are to be placed in a distance of 10 km along the track inside the tunnel. Yet, this concept compromises the idea of installing only the minimum of electrical devices inside the tunnel. A substation on Big Diomede Island in the middle of the tunnel reduces the required number of autotransformers.
In theory, it is possible to place all autotransformers outside of the tunnel but the number and the length of the necessary cables is very inefficient. Moreover, it makes no sense physically since the impedance created by the extremely long cables would outweigh the aim of the autotransformers.

### 9.3.20 Economic Development of the Surroundings

By developing the infrastructure in the areas close to the tunnel and along the distributor railroads in China, Russia, Canada and the US (Alaska) the basis for future economic development is being set in these regions. Depending on the ambitions of future development more or less electrical branch connections are required. The more connections necessary along the track, the less efficient and less likely is a power transmission from the power stations to the substations at the tunnel via HVDC. The latter would implicate a higher number of switchgear and converter stations. Alternatively, two parallel transmission lines can be planned: one transmitting 50 Hz 3AC for households and industry, the other one HVDC aimed for traction power. A further option is the construction of virtual renewable power plants equipped with corresponding energy storage facilities in the new developed areas. This power generating system is an opportunity for local energy companies and enables communities to operate independently from central power stations. The construction of a nuclear power plant would be feasible and relatively safe if designed as a tested molten salt reactor (MSR). Here, the question of efficiency needs to be answered first. It makes sense if industries and settlements which demand both heat and electricity are going to be developed there along the railroad. If this is the case some MSRs could become a viable option.

### 9.3.21 Fire Safety and Evacuation

Fire safety measures include evacuation guidelines and emergency ventilation. Those also affect energy installations. Safety systems like these have to be installed in a redundant fashion. Sensors need to be reduced sensibly, though. The more sensors and control systems are installed inside the tunnel the more maintenance is required. Thus, safety is not increased with more monitoring systems. It can be even deteriorated if unfixed sensors send wrong data permanently.
Dividing the tunnel into several compartments, for instance every 10 km should be considered. The ventilation and fire distinguishing unit must be able to detect a fire reliably, distinguish it and exhaust smoke in high speed within such a compartment. In case of a fire these tunnel sections need to be separated from one another by fire safety gates breaking up the tunnel into compartments as in ships. Since this tunnel is situated beneath the ocean additional tunnel tubes for smoke evacuation need to be taken into account. There must be at least three smoke exhaust tubes with one to the Russian portal, one to the Alaska portal and one to Big Diomede Island. Ventilation, exhaust and distinguishing units are to be equipped with redundant and effective power supplies (see chapter auxiliary power 9.3.4).

### 9.3.22 Provisionary / Temporary Facilities

The construction of the tunnel requires energy supply. Further studies shall be launched examining if provisionary energy supply facilities need to be set up at the portals first or if the future permanent energy facilities shall be installed as a first stage in the project schedule. This would permit the auxiliary power supply for the tunnel construction to be installed in the beginning of the project. However, the latter option is rather inefficient. On the other hand, this is only a temporary situation and does not affect traction power supply sustainably. An economic and engineering study shall be carried out recommending the most feasible solution regarding power supply during construction.

### 9.3.23 Power Stations

The power plants represent the source of the energy supply. For the entire new railroad it makes sense to apply a mix of different $CO_2$-free power plants. Thus, base and peak loads can be better accommodated. Hydro and natural gas are the most likely resources for a reliable, sustainable and permanent energy supply of the tunnel. Nuclear MSR power stations would be feasible in combination with renewables but probably inefficient if used for traction power supply only.

A study carried out by Inter Bering illustrates a renewable power supply with several different water power systems. The report counts on run-of-river power stations in the big Siberian streams as well as tidal power plants at the East Siberian seaboard and the West Coast of Alaska. Additionally, geothermal power stations in Kamchatka and local virtual power stations combined with appropriate energy storage systems are possible options for electricity generation. The latter alternative is to be examined in relation to the development of electrical control and storage systems.

Both run-of-river and geothermal power stations qualify for the provision of base load. In order to break power peaks natural gas power stations are very feasible thanks to their quick start ability. Also possible are robust wind turbines linked to the natural gas power stations by methanation plants.

In terms of feeding the contact lines and auxiliary power, an additional substation on Big Diomede Island would be very beneficial. Local sources useful for additional energy harvest would be wind and marine current power combined with energy storage such as methanation.

Run-of-river power plants should be subject to an extensive environmental study. Depending on their design they are committed to run permanently. An interruption of the operation would have ecological consequences, for instance a wave running upstream endangering the neighboring flora and fauna. The downstream section of the river would suffer from lower water-levels. Though such power plants are going to be designed with a spillway next to the turbines all operational situations shall be considered in the environmental study. Every run-of-river power station shall consist of at least two turbines and generators as well as at least two independent transmission lines. This precaution reduces the risk of a complete outage of an entire power station of this kind causing large damage to the near environment and jeopardizing the power supply for the railroad. In times when the tunnel is closed and no additional energy is needed the electricity generated by run-of-river power stations shall be stored in energy storage devices.
Thorough environmental studies are also compulsory for all other tunnel related infrastructure including energy facilities: power stations, substations, converter stations, transmission lines etc.

The electricity generation in the named power stations can be designed in various ways. An AC generator produces 1AC power which can be used for traction power without further frequency conversion. Moreover, 3AC generators can create power that can be used for households and industries along transmission lines. However, this kind of current is subject to conversion to 1AC before it hits the contact lines. The third option entails the installation of DC generators. This would enable the transmission of HVDC without further frequency conversion. Placing converters right next to the generators would leave even more options on the table. Power stations can consist of a variety of generators. Feeding transmission lines of different kinds depends on the regional power demand and energy sales situation as well as concession, investment and maintenance costs. A 3AC transmission line parallel to the HVDC line should be subject to a further study.

The most feasible and economic option for each power station is going to be determined in the following research in the next planning phase.

### 9.3.24 Substations

The energy concept of traction power supply considers several different options. If the Russian and Alaskan high-voltage grids are going to be extended and connected a frequency conversion is essential. The Russian power grid is designed for 50 Hz, the US grid works at 60 Hz. This kind of conversion can be achieved by the interposition of an HVDC section between the two grids, e.g. cables through the tunnel or on the seabed.

However, it is very uncertain if the US railroad network is ever going to be electrified except for urban centers. It is well possible that the electrified section of the railroad ends at the Alaska portal or at the transfer station. Beyond that point the trains would run on Diesel to continue their journey through North America.

The most likely concept of tunnel substations intends the installation of a combined substation and converter station near each tunnel portal. In addition, one substation is going to be placed on Big Diomede Island. This enables voltage stability. Additional substations need to be installed along the open railroad stretch towards both tunnel portals.

As for all energy facilities there are several different options how to outline a substation. Air insulated switchgear (AIS) is technically mature and has low investment costs but in the Bering region it is at the mercy of the severe climate, if installed without protection. Encased gas insulated switchgear (GIS) is much smaller compared to an AIS system. An underground or encased AIS facility is conceivable but it will cover a relatively large area. If placed underground, the permafrost will again play an important role. There are solutions for this problem, though. Since such a design will be fairly expensive, space is of the essence. The subterranean structure can be designed as a rigid frame on piles or on adjustable foundations. All substations and converter stations will be placed outside of the Bering Tunnel close to its portals. Another substation (and converter station) is going to be installed on Big Diomede Island. It will be subject to another study whether that power feed will be generated by another power station on the island or by a high voltage cable running to the substation through the tunnel or on the seabed. However, the minimum requirement for the tunnel traction power supply will be three independent feeding points: one substation at the Western portal, one at the Eastern portal and one on Big Diomede Island.

### 9.3.25 Return Circuit: Booster Transformers or Several Return Conductors

The return circuit is an essential element in the traction power system. Without designated return installations the traction current would find its way through the rails into the tunnel shell resulting in an energized tunnel construction. In order to prevent this unacceptable condition there are several alternatives. If the return currents must be reduced to zero, booster transformers are an effective method. However, combined with autotransformers they increase the impedance along the rail track. Moreover, booster transformers would have to be put inside the tunnel which is against the concept of a tunnel on a minimum of electrical devices. Another option is the installation of several return conductors similar to the return circuit system in the Gotthard Base Tunnel. Thus, the largest part of the return current can be captured and efficiently guided outside the tunnel. This system is cheaper and simpler avoiding any additional electrical machinery in the tunnel.

### 9.3.26 Converter Technology: 3AC → 1AC or DC → 1AC

A further study is necessary for analyzing whether the electricity can be converted directly from HVDC lines into one phase traction power (DC → 1AC), or if an additional conversion level for altering DC into 3AC is necessary. If only HVDC is transmitted, additional converters combined with substations along the railroad are needed. If 1AC is used as transmission power, substations are sufficient for feeding the tunnel. Converters are not needed. The last scenario of a 3AC transmission also requires converters along the track.

### 9.3.27 Climate Conditions, Soil (Permafrost)

One of the biggest challenges during the construction of the Bering Tunnel is nature. The Bering Strait belongs to the Arctic climate zone. The permanently low temperatures in the area often come along with strong winds. This hampers work in the open areas of the construction site. Another problem is permafrost. It is hardly possible to manage it, only with lots of engineering effort. Permafrost needs to be tested on a regular basis of small intervals. The railroad tracks can be constructed using passive cooling similar to a Chinese design applied at the train line through Tibet. The section through permafrost remains stable so far. [75]

Buildings can be erected on pre-cast concrete piles. Due to the unpredictability of permafrost, important energy installations should be redundant and placed on separate piling enclosed in rigid frames. The most critical areas are located at the tunnel portals and at the crossover section between permafrost and rock. The tunnel needs to be protected from any movement compromising its statics. One option to do this has been explained in an earlier chapter: earthquake-proof design using total bracing and three variable foundations for each structure. Those foundations are subject to regular checks and adjustments. [20] The only passive alternative is to consider further redundant and dislodged energy facilities or to put everything underground. The latter solution requires planning several access ways through permafrost. All passage ways need to be secured. However, this implies high logistical, financial and maintenance efforts.

### 9.3.28 Minimum Clearance Outline

The minimum clearance may seem detached from energy issues. But again, the systems in Eurasia and North America differ from each other. In the US and Canada freight trains have a very large profile. The minimum clearance there allows for every rail car to carry two containers stapled on top of each other. Moreover, the railway construction is designed for those high loads, European rails are not.
Most of the North American trains are driven by Diesel engines. Few lines in China merge both worlds by having double-decker freight trains running on electrical energy. Stapled containers require a minimum clearance outline height of 6.50 m.

In Europe and Russia such large clearances exist only at very few railroad tracks. The highest clearance in the EU stands at 6.50 m, in Russia at 6.15 m. Furthermore, as stated earlier, many railroad tracks are not designed for additional weights.

This is why it makes economic sense to assign a minimum clearance to the tunnel of only one container height. It also saves excavation costs. A transfer station is to be established near the Alaska tunnel portal. Several functions are going to be managed here: container handling from 2 to 1 per car (or the other way around), track gauge change and customs. Alternatively, an intermodal system can be developed where freight trains from Eurasia end or start at the American portal. Trains which have been loaded with one additional container on top continue their onward journey on the American side or drive on westward with only one remaining row of containers.

A minimum clearance of only one container on each rail car reduces the demand for power. Thus, less powerful energy devices need to be installed compared to trains at the same length but double the number of containers.

Regarding track gauge the tunnel will be equipped with 1520 mm Russian broad gauge. This will be changed to 1435 mm standard gauge at the transfer station at the American portal.

### 9.3.29 Finance

Sufficient funds for this project are fundamental. The concept of the energy system also needs to comply with this very elementary constraint. Funds must be ready before the project starts. Other common finance traps must be avoided such as only indicating investment costs without expressing operational and maintenance expenses. Finance will be only covered if this sustainable approach is followed. If not, financial risks are increasing. Besides many more necessary clarifications which need to be managed previously to the start of the project, cost allocation between the participating countries must be definite and transparent. All involved states are obliged to deliver a certain share. The contributors are refunded according to their contribution share. Profit is made by transit fees for passing the tunnel.

## 9.4 Appendix 2: Traction Power Calculations

### 9.4.1 Calculation of Train Length:

$$l = 2 \text{ x } l_{Loc} + \text{number of cars x } l_{car} = 2 \text{ x } 20\text{m} + 230 \text{ x } 13.86\text{m} = \underline{\underline{3228\text{m}}}$$

### 9.4.2 Calculation of this train's weight:

$$m = 2 \text{ x } m_{Loc} + \text{number of cars x } m_{car} = 2 \text{ x } 150\text{t} + 230 \text{ x } 42\text{t} = \underline{\underline{9960\text{t}}}$$

### 9.4.3 Calculation of the Resistance of Rolling:

$$w_f = 2.5 + k(v + \Delta v)^2 \bullet 10^{-3}\frac{N}{kN}$$

with $k = 0.25$ for heavy freight trains

and $\Delta v = 45\frac{km}{h}$ common for threefold drag in Tunnels, normal $\Delta v = 10$ to $15\ \frac{km}{h}$ for open tracks

$$w_f = 2.5 + 0.25(100\frac{km}{h} + 45\frac{km}{h})^2 \bullet 10^{-3}\frac{N}{kN} = 7.8\frac{N}{kN}$$

$$\underline{\underline{w_f = 7.8\frac{N}{kN}}}$$

### 9.4.4 Load Case Considering Acceleration:

#### *9.4.4.1 Calculation of Traction:*

$$F_Z = F_s + F_f + F_a + F_b$$

Assumptions: from [34]

$F_b = 0$ an even and straight track is assumed

$m = 10,000,000$ kg

$g = 9.81\ \frac{m}{s2}$

$x = 1{,}2\%$ maximum slope, from longitudinal section

$\xi_{rot} = 1.1$ for mixed train compositions

$a = 0.05\frac{m}{s2}$ for heavy freight trains

$v = 100 \frac{km}{h} = 27.8 \frac{m}{s}$

$\eta_{Loc} = 0.85$ (85%) Level of efficiency of locomotive

$\eta_{tot} = 0.7$ (70%) Level of efficiency of the whole electrical system

$F_a = m \bullet \xi_{rot} \bullet a = 10{,}000{,}000 \text{ kg} \bullet 1.1 \bullet 0.05 \frac{m}{s2}$

$\underline{\underline{F_a = 550 \text{ kN}}}$

$Fs = m \bullet g \bullet x = 10{,}000{,}000 \text{ kg} \bullet 9.81 \frac{m}{s2} \bullet 0.012$

$\underline{\underline{Fs = 1177.2 \text{ kN}}}$

$F_f = w_f \bullet m \bullet g = 7{,}8 \frac{N}{kN} \bullet 10{,}000{,}000 \text{ kg} \bullet 9.81 \frac{m}{s2}$

$\underline{\underline{F_f = 765.18 \text{ kN}}}$

$F_Z = 550 \text{ kN} + 1177.2 \text{ kN} + 765.18 \text{ kN}$

$\underline{\underline{F_Z = 2{,}492.38 \text{ kN}}}$

### *9.4.4.2 Calculation of Traction Power and Current:*

$P_{tract} = F_Z \bullet v$

$P_{tract} = 2{,}492 \text{ kN} \bullet 27.8 \frac{m}{s}$

$\underline{\underline{P_{tract} = 69.288 \text{ MW}}}$

$P_{el} = \frac{1}{0{,}85} \bullet 69.288 \text{ MW}$

$\underline{\underline{P_{el} = 81.515 \text{ MVA}}}$ no reactive power!

$I_{train} = \frac{Pel}{U} = \frac{81{,}515 \, MVA}{0{,}025 \, MV}$

$\underline{\underline{I_{train} = 3{,}260.619 \text{ A}}}$

$P_{tot} = \frac{1}{0{,}7} \bullet P_{el} = \frac{1}{0{,}7} \bullet 81.515 \text{ MVA}$

$\underline{\underline{P_{tot} = 116.45 \text{ MVA}}}$

### 9.4.5 Load Case without Acceleration:

$$F_Z = F_s + F_f$$

$$F_Z = 1177.2\ \text{kN} + 765.18\ \text{kN}$$

$$\underline{\underline{F_Z = 1.942\ \text{MN}}}$$

$$P_{tract} = F_Z \bullet v$$

$$P_{tract} = 1{,}942\ \text{kN} \bullet 27.8\,\frac{m}{s}$$

$$\underline{\underline{P_{tract} = 53.988\ \text{MW}}}$$

$$P_{el} = \frac{1}{0{,}85} \bullet 53.988\ \text{MW}$$

$$\underline{\underline{P_{el} = 63.515\ \text{MVA}}} \qquad \text{no reactive power!}$$

$$I_{train} = \frac{Pel}{U} = \frac{63{,}515\ MVA}{0{,}025\ \text{MV}}$$

$$\underline{\underline{I_{train} = 2{,}540.612\ \text{A}}}$$

$$P_{tot} = \frac{1}{0{,}7} \bullet P_{el} = \frac{1}{0{,}7} \bullet 63.515\ \text{MVA}$$

$$\underline{\underline{P_{tot} = 90.736\ \text{MVA}}}$$

→ the critical load case is the one considering acceleration.

### 9.4.6 Calculation of Freight Handling each Day

Assumption: $m_a = 550$ mio t per year [6]

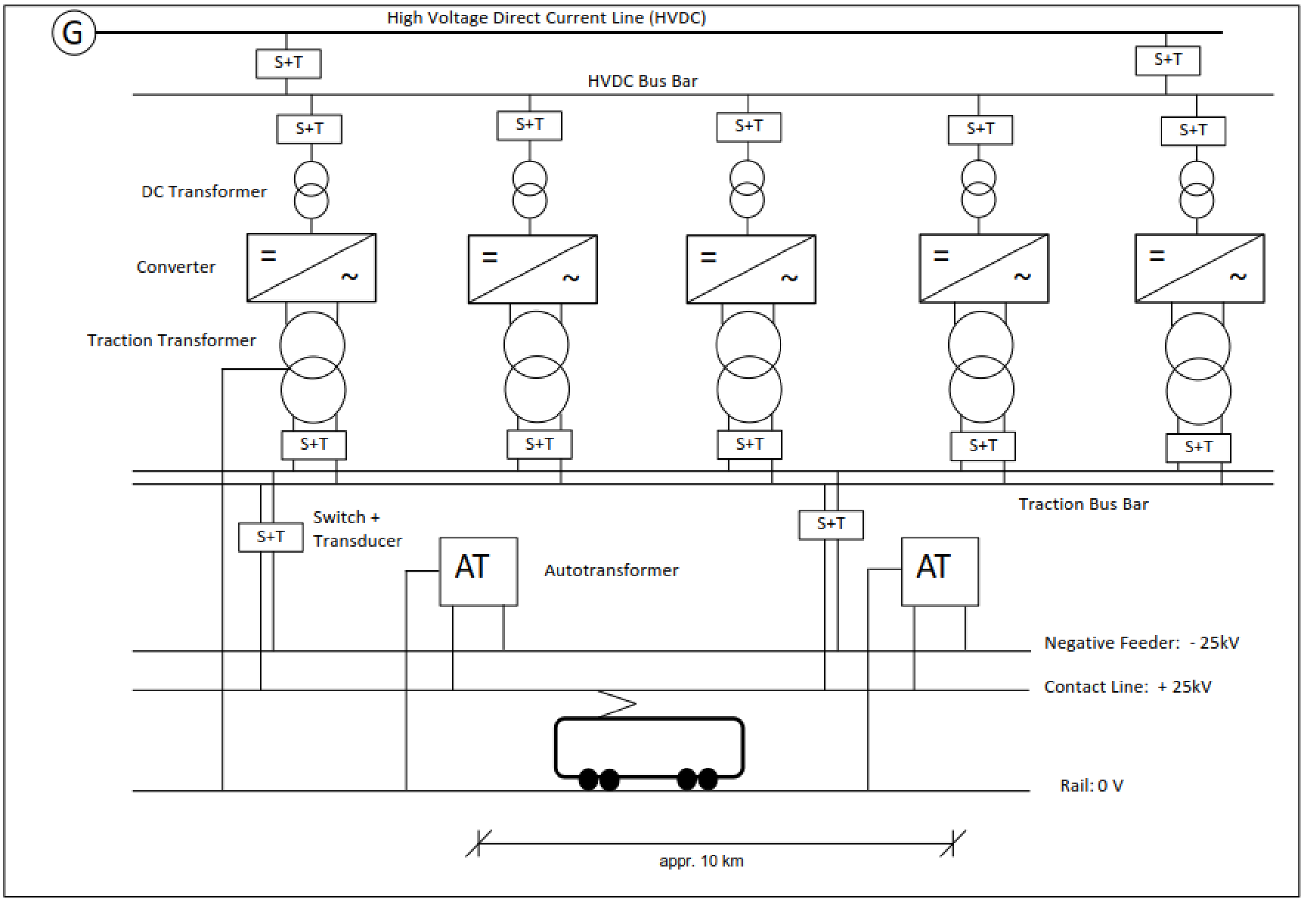
yield per day: $m_d = \frac{550\ mio\ t}{365} = 1.507$ mio t per day

yield per hour: $m_h = \frac{1{,}57\ \text{mio t}}{24} = 62{,}758$ t per hour

Splitting: 7 trains: $m_{Train} = \frac{62.758\ t}{7} = 8969.341$ t per train ~ 9,000 t per train

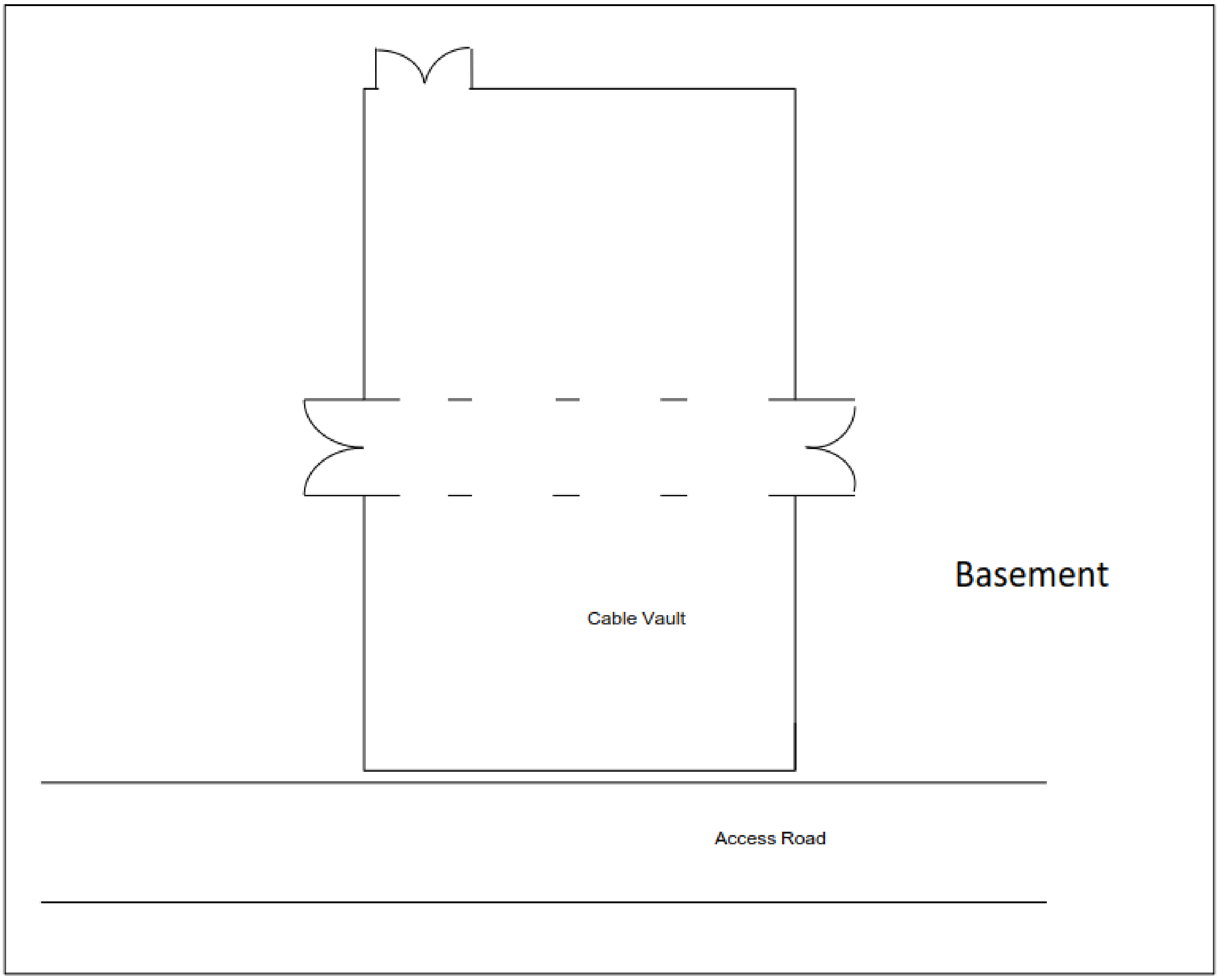
## 9.5 Appendix 3: Illustrations

### 9.5.1 Complete Electrical Diagram

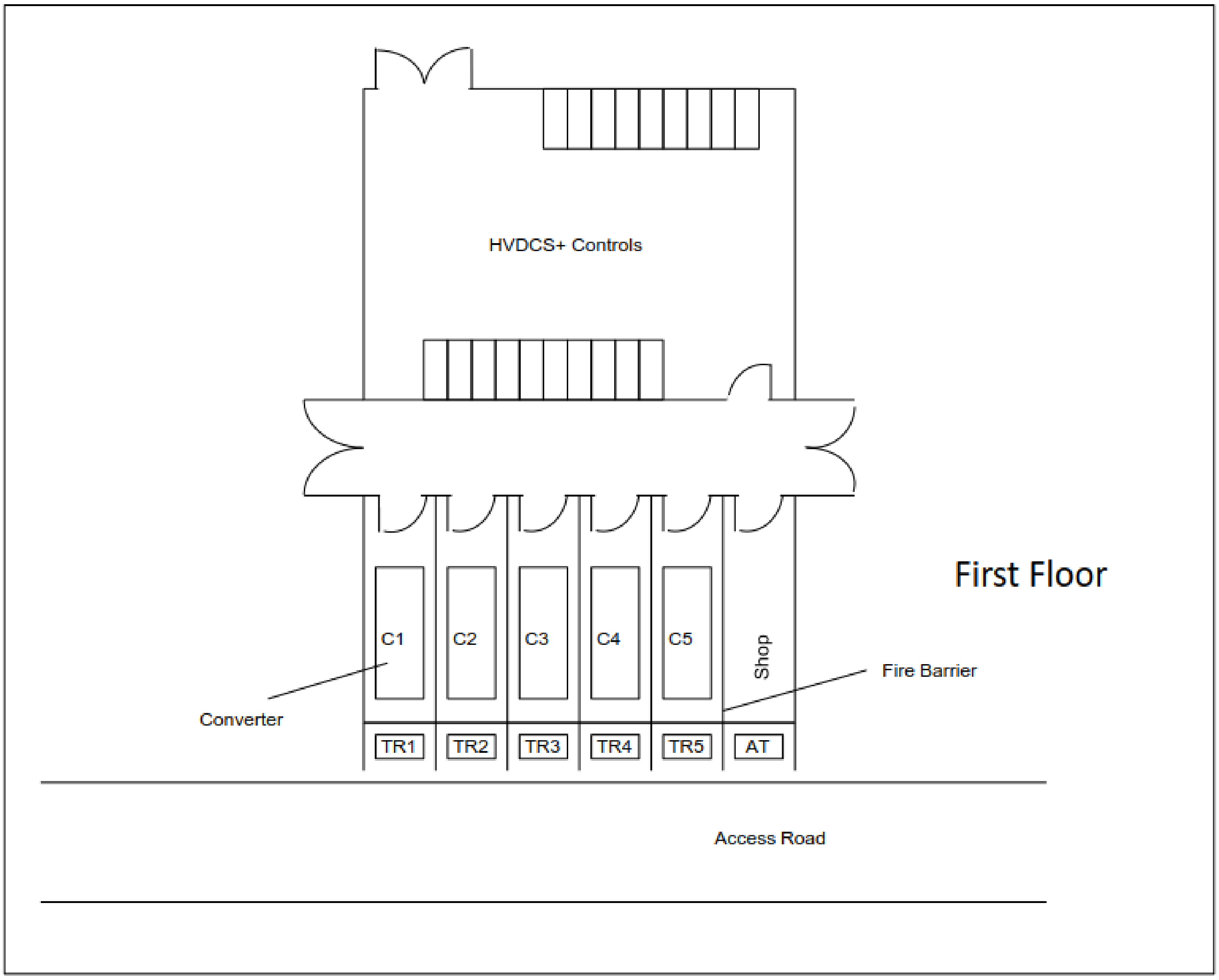


### 9.5.2 Sketches of Building Floor Plans

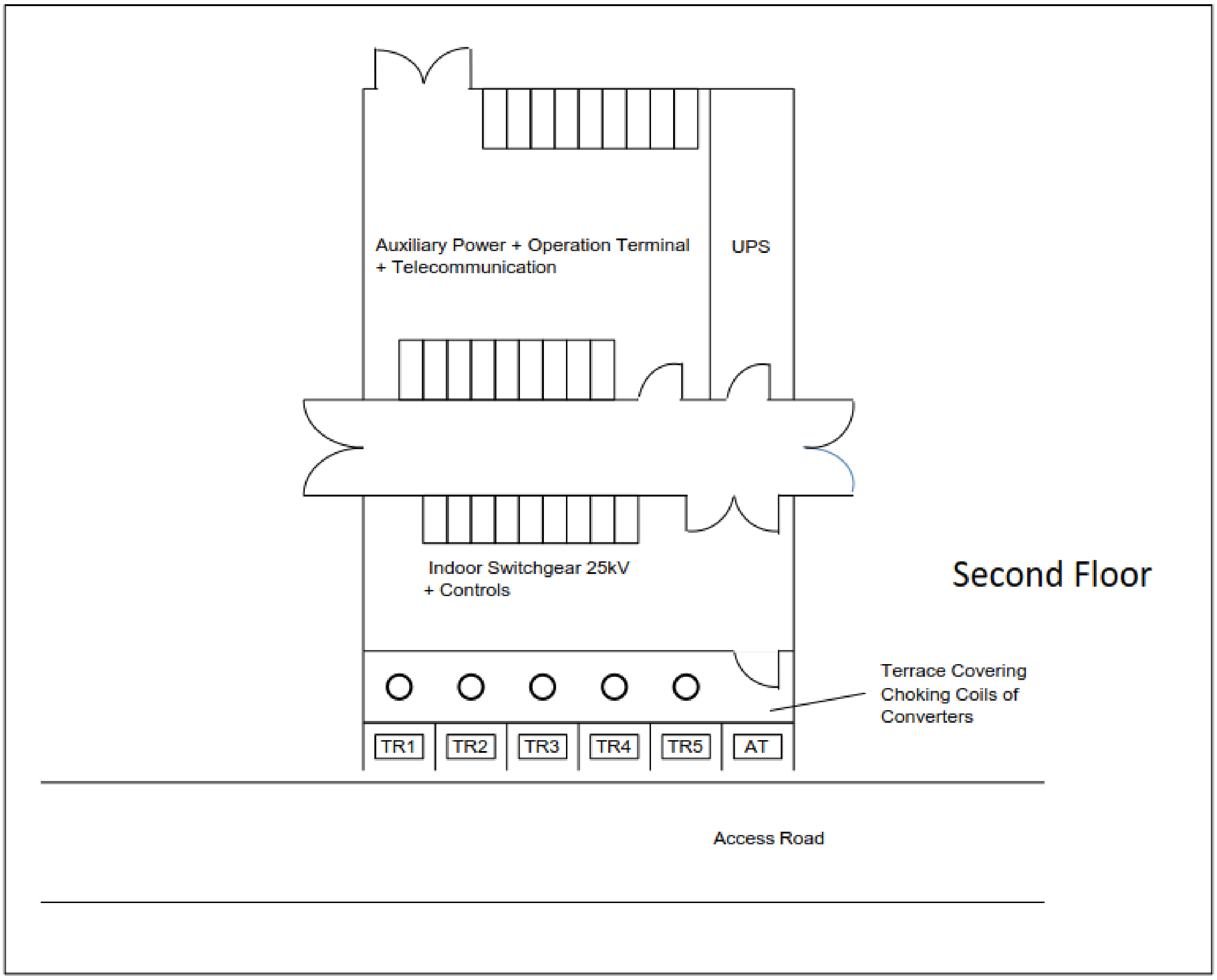
Basement



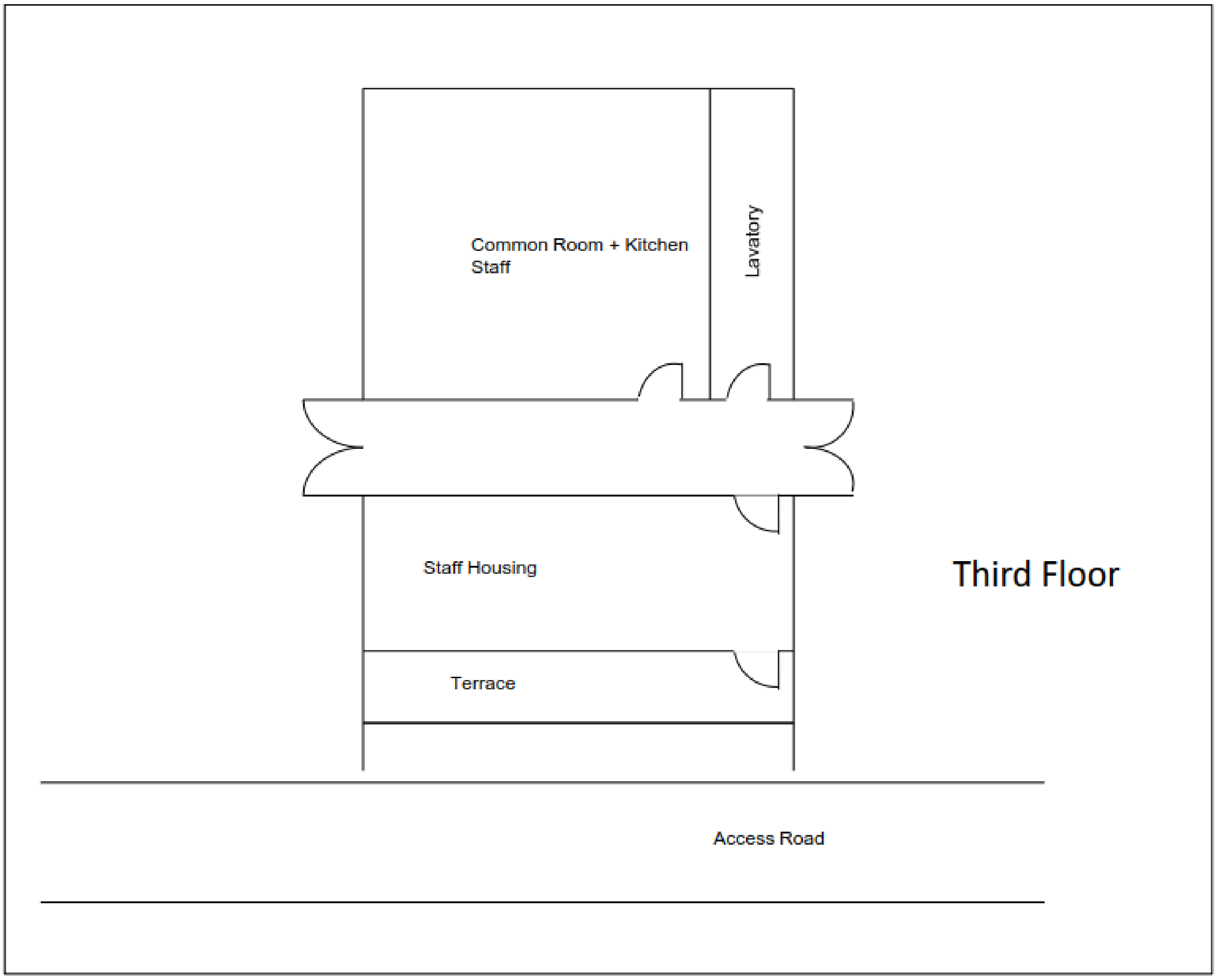
First Floor


HVDCS+ Controls
C1
C2
C3
C4
C5
Shop
First Floor
Fire Barrier
Converter
TR1
TR2
TR3
TR4
TR5
AT
Access Road

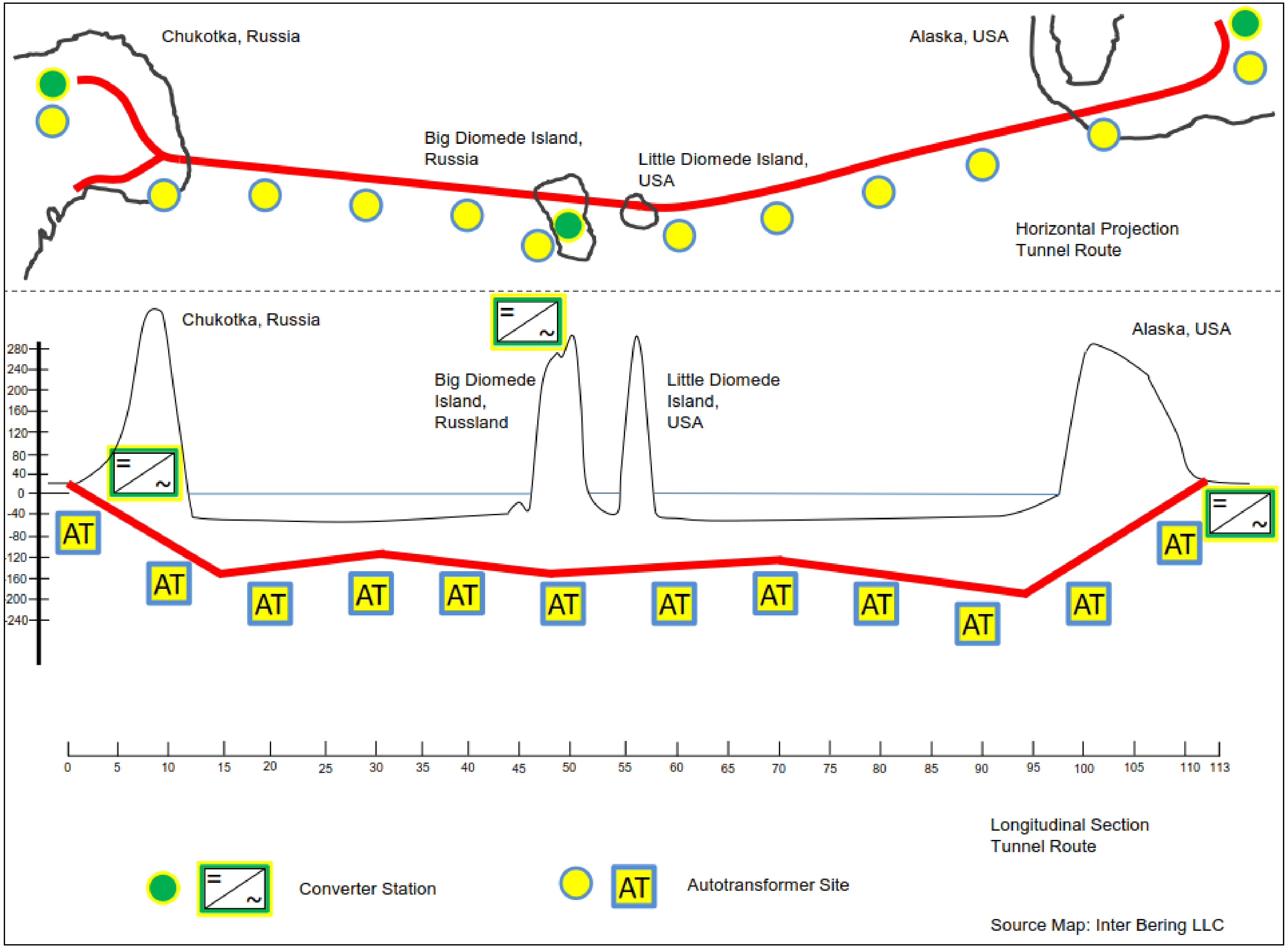
Second Floor



Third Floor


Common Room + Kitchen
Staff
Lavatory
Staff Housing
Terrace
Access Road
Third Floor

## 9.5.3 Tunnel Layout including Longitudinal Section and Cross Section



Source Map: Inter Bering LLC

### 9.5.4 Transfer Station at Alaska Portal