NORWEGIAN TUNNELLING SOCIETY

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Sustainability in Norwegian Tunnelling

SUSTAINABILITY IN NORWEGIAN TUNNELLING

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Preface

The Norwegian Tunnelling Society (NFF) is open to individuals, companies, institutions, and government services engaged in or associated with the construction industry where use of the underground and related work tasks and disciplines are central.

NFF has the tradition to present an English publication every year. In these publications we focus on different topics we think are relevant to share with our international friends and colleagues around the world. This year's publication is devoted to sustainability in Norwegian tunnelling.

The publication is targeted towards both an international and national audience, - both industry members, politicians and the readers interested in sustainability in general. We hope the reader will be inspired to participate in the work for improved sustainability in the tunnelling industry across the world, and hopefully help us to find even better solutions than described in this publication. We truly believe that UN Sustainability goal #17 "Partnerships for the goals" is essential to reach a more sustainable way to work and live.

The publication is written as a joint effort among the scientists, clients, contractors, consultants, and suppliers in the Norwegian tunnelling industry. It contains of a mix of professional papers and strategies shared from our member companies. We appreciate the willingness to share experience and thoughts through this written material. The authors are credited in front of each chapter. A special gratitude goes to the editorial committee:

Hrefna Run Vignisdottir, SINTEF Community
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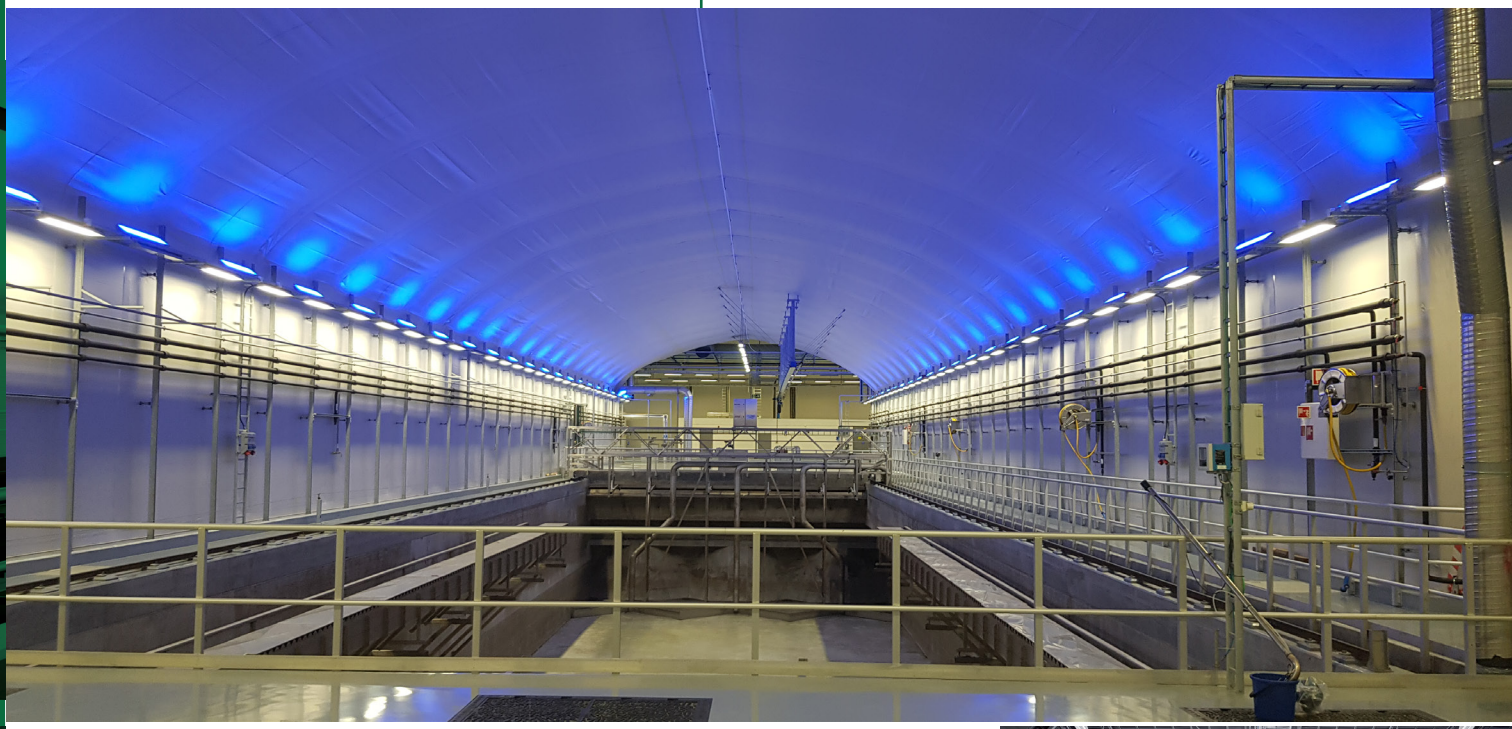

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1 Introduction

1.1 The objective and organization of the publication

The objective of this publication is to give the reader an insight in how we work with environmental sustainability in the Norwegian tunnelling industry in 2022. We have collected material from many of NFF's members and from other initiatives going on in the Norwegian marked today.

This publication is organized in two main parts where the first part focuses on how the Norwegian Tunnelling sector works towards increased sustainability while the second part presents how the different parts of the value chain work with their own domain for sustainability.

1.2 Content and delimitation of the publication

The use of underground solutions itself can in some perspectives be considered sustainable. It gives us a unique opportunity to save space overground, and it gives us the opportunity to reduce or rinse the emissions to both air and water. In Norway we have examples of underground solution for e.g., data centres, waste disposal, fish farming, storage of fuel, geothermal installations and so on. This is not included in this publication. We will refer to NFF's publication #15 and ITA's working group #15 for more information about this topic.

We are discussing the notion about life-cycle-assessments (LCA). However, we have not included any specifics about rehabilitation of tunnels. We believe that many of the topics discussed also refers to rehabilitation of tunnels, and we appreciate the fact that rehabilitation of older tunnels can be a sustainable solution in itself.

1.3 Historical background regarding sustainability

1.3.1 "Our Common Future"

In 1987 the World Commission on Environment and Development (WCED) released a publication called "Our Common Future". The work was sponsored by United Nations (UN) and chaired by Norway's Prime Minister Gro Harlem Brundtland. The report is also referred to as the Brundtland Report.

The report introduced the concept of sustainable development, as well as a description on how it could be reached. They attempted to explore the causes of environmental degradation. It included an understanding of the interconnections between social equity, economic growth, and environmental problems. Based on this understanding they developed policy solutions that integrated all three areas. The Brundtland Commission are recognized for the definition of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

In Norwegian perspective this marked the start of the work towards sustainability. The Norwegian industry is proactive and have since then actively put pressure on changes in regulations, construction processes, and material use. This work is ongoing and will hopefully always bring on more positive changes.

References:

https://www.britannica.com/topic/Brundtland-Report

https://en.wikipedia.org/wiki/Our_Common_Future

1.3.2 The UN Sustainable development goals

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a 15-year plan for peace and prosperity for people and the planet, now and into the future.

Today, progress is being made in many places, but, overall, action to meet the goals is not yet advancing at the speed or scale required. The 17 Sustainable Development Goals (SDGs) recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth. A prerequisite, is to handle climate change and to preserve our oceans and forests.

The SDGs build on decades of work by countries and the UN, from the start in June 1992, Earth Summit in Rio de Janeiro, Brazil, more than 178 countries adopted Agenda 21, a comprehensive plan of action to build a global partnership for sustainable development to improve human lives and protect the environment. The latest step in this development, so far, is the Glasgow Climate Pact signed in October/ November 2021 by every party at COP26 – representing almost 200 countries.

The SDGS includes 17 goals shown below. The 17 goals are divided into 169 sub-goals, and are supported by 232 indicators.

Today, the SDGs are often referred to in sustainability reports and strategic documents within the Norwegian Tunnelling and construction industry as it is in most larger and progressive companies. These are there often referred to in the document.

References:

https://sdgs.un.org/goals

https://ukcop26.org/wp-content/uploads/2021/11/COP26-Presidency-Outcomes-The-Climate-Pact.pdf

https://www.miljodirektoratet.no/globalassets/publikasjoner/m1681/m1681.pdf

https://no.wikipedia.org/wiki/Liste_over_Norges_milj%C3%B8vernministre

https://www.regjeringen.no/no/dokumenter/rapport_bkm2/id2507259/

1.4 The link from global and national goals to local activities

In Norway, 12 of the ministries are currently involved in achieving the SDG goals. The Ministry of Local Government and Regional Development is responsible for coordinating the common effort.

As for the crucial area of climate change, national follow-up of the Paris Agreement will constitute the main basis for action to fulfil SDG 13. Norway is committed to reducing emissions by at least 40 % (later increased to 50 %) by 2030, compared with the 1990 level. Norway is engaged in a dialogue on joint fulfilment of its 2030 commitment together with the EU.

There are some obstacles when trying to make a direct link from national goals to local activities. The obstacles can be summarized in how we measure improvement and a lack of a defined baseline.

While UN has done an important job with describing 169 sub-goals and 232 indicators, these are not as commonly known as the main goals. The quality of each indicator also varies. As an example; In total, the Norwegian Environment Agency reports on 30

Figure 1.4.1: United Nations' sustainable development goals.

indicators. Of these, 22 lack a described method in the UN STATS indicator handbook, 14 can be reported relatively well, two can be reported only qualitatively. Seven of the methods is too unclear, and for seven it is possible to report only by a different method than stated for the SDGs due to lack of or alternative data basis.

Within the topics we can measure, we struggle to find and agree upon a common baseline. When we have the goal to reduce the carbon footprint with a certain percentage from the level in 2015, we must ask ourselves; What was the level in 2015 within each area? The work with establishing a quantified baseline has started, and the baseline must be defined across many areas.

As with almost all other topics, the principle "what you measure is what you get" is definitely influenced the work with sustainability. It is so much easier to both discuss and follow up the areas that can be measured, such as the carbon footprint. This has to some extent made it natural to think about sustainability solely as the emission of CO_2.

As mentioned before there are 12 ministries involved in achieving the goals. There is not defined a clear responsibility down to each municipality. There is some discussion about the responsibility within each industry, but again, only when it comes to the carbon footprint.

Nevertheless, we register a growing interest and enthusiasm in taking part in this effort to improve sustainability. The people, the companies, and academia are not sitting idle waiting for baselines to be established, perfect indicators or other way to measure the improvement. This publication is a proof of that.

https://www.miljodirektoratet.no/globalassets/publikasjoner/m1681/m1681.pdf

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2 Methods and tools for sustainability measures

2.1 Life-cycle approach

The life-cycle approach in environmental management first came about in the 1960's to document environmental impact from packaging. Since then, the method of life cycle assessment (LCA) has been steadily growing as a method for accounting for emissions from a product, project, or a process with the goal of reducing emissions. The method is considered suitable for large infrastructure projects because it includes the whole life cycle of each product and process that need to be accounted for to avoid shifting environmental burden from one phase of the product life cycle to another [1].

Life cycle costing (LCC) is based on the same principle but is focused on evaluating the cost related to a project or a product throughout its lifetime. This would then consider investment costs, production cost and future cost during the use or maintenance of the final product. Using these two approaches allows for further evaluation of how emission reduction measures effect the cost throughout the lifetime of the construction/product, in our case of the tunnel.

The construction sector, and thereby the tunnelling industry, in Norway has embraced openness and share their experiences. The contractors wish to have a more predictable contract requirement and the road owners wish to enable early involvement in planning and designing projects. Using a standardized method for reporting on environmental impacts helps the sector to ensure evaluation of projects based on the same set of principles and it reduces uncertainties for both contractors and projects owners. This especially applies to tunnels which are highly dependent on rock types, water bearing joints and cracks etc. In 2018 the building and construction sector got a Norwegian standard (NS 3720) for calculating life cycle GHG emissions. The method in the standard can be used to calculate past, current, and future GHG emissions. PAS 2080 was similarly developed for carbon management in infrastructure projects [2].

In the construction sector LCA has been used to evaluate projects for over a decade. The first large project that used LCA and LCC to a large degree in the evaluation of the project was high speed rail investigation conducted 2010-2012. This particular project was very special because of the importance of tunnels in the project. Today, the use of LCA to evaluate construction projects has become common and even demanded by the project and infrastructure owners. Now the contractors, material producers, and the project owners are familiar with both the process and results from the LCA.

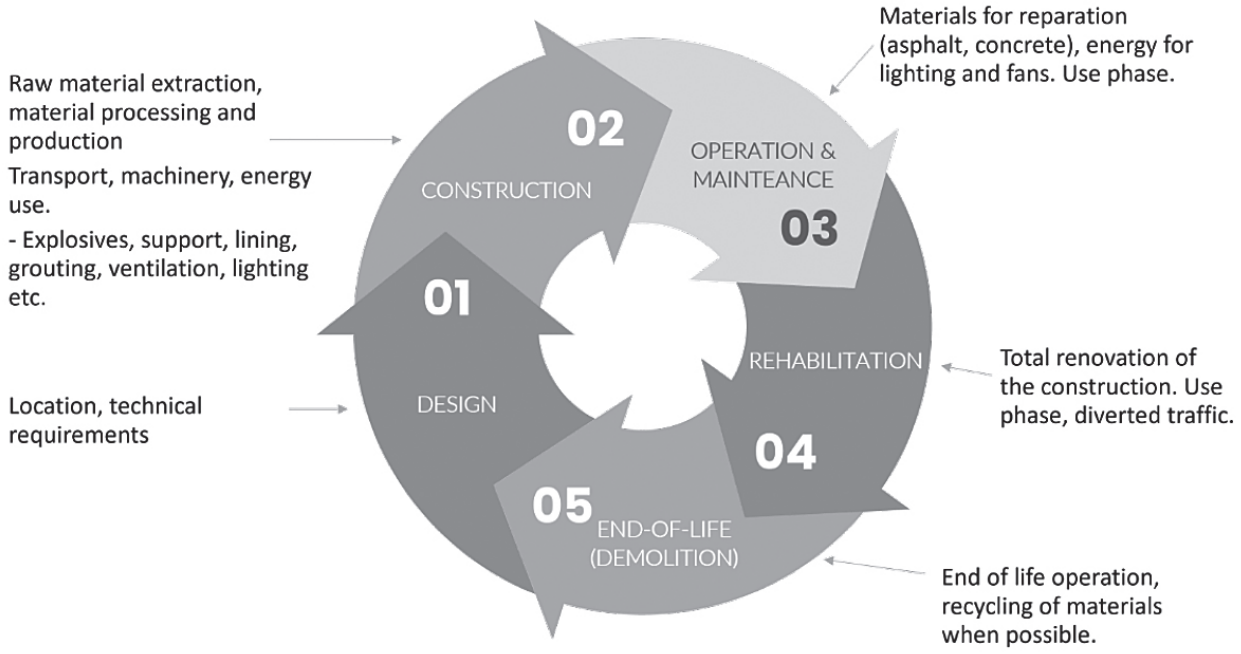

Figure 2.1.1: Life cycle of a tunnel, with main input in addition to transport and machinery.

The importance of tunnels in the environmental evaluation of projects in Norway should not be underestimated as the share of tunnels and bridges on Norwegian road and rail infrastructure is higher than the average share in Europe [3]. However, the life cycle of a tunnel is long and therefor the environmental impact has in the past often been neglected because of dominance of emissions during the use phase through both operation and maintenance, and from the traffic in the tunnels. Along with goals and ambition in the sector to reduce emissions, tunnels and constructions are getting increasing focus. As of today, several LCA studies have been conducted, and published, on Norwegian tunnels. The main processes included in these studies include the construction work, maintenance in form of structural maintenance and operation which includes lighting and cleaning and finally end-of-life, dismantling (see figure 2.1.1). The studies exclude traffic in the use phase as the focus here is to reduce emissions from the infrastructure itself.

The environmental impact from tunnel construction is to a large degree decided during the design phase of the project (phase 1 in the figure). After the design phase the choice of materials and energy sources are of course important factors to account for to minimize emissions. The construction phase (phase nr. 2 in the life-cycle figure) includes the tunnelling process, which is either drill and blast (D&B) or done by using tunnel boring machine (TBM). It also includes rock support, grouting, lining, drainage measures, and other general tunnelling operations. Phase 3 in the figure includes smaller maintenance tasks, lighting, fan operation and cleaning while phase 4 includes a more extensive rehabilitation of the tunnels. The final phase (nr. 5) includes dismantling and recycling of a tunnel after its lifetime of the materials, equipment that can be removed for reuse or recycling.

2.2 Tools and strategies for sustainability measures

2.2.1 CEEQUAL as a tool for improved sustainability

CEEQUAL is a recognised industry leader when it comes to sustainability assessment tools for infrastructure and civil engineering projects, and thereby a lot of tunnel projects. In Norway it was introduced to the market by several large contractors, in order to help clients, with a way to measure their sustainability efforts. It was introduced because it helps drive sustainability and performance across civil engineering projects of all types and enables validation of this performance against an internationally recognised benchmark.

CEEQUAL is a self-assessment process, carried out by a trained assessor. Using a manual and an online assessment platform, the assessor assesses and records the scores and the evidence for them. Completed sustainability assessments are externally verified by a verifier appointed by CEEQUAL. The result is a ratified CEEQUAL score and rating, and the certificate is awarded to all project partners. The assessment is divided in nine chapters; Project Strategy, Project Management, People & Communities, Land use & Landscape, Historic Environment, Ecology & Biodiversity, Water Environment, Physical Resources (Use & Management) and Transport.

The Green Building Council is organizing and promotes the use of CEEQUAL in Norway. It is an organization that helps Norwegian projects using the international assessment tool in a Norwegian context. It is now organized with the help of three important sponsors: The Norwegian Public Road Administration, Bane NOR and Nye veier. It is tight cooperation between The Green Building Council and Green Construction sector Network (In Norwegian: Nettverk for Grønn Anleggssektor).

Life cycle assessment is a part of the CEEQUAL certification scheme where the inclusion of LCA of the project in early phase and through to construction phase is one of the main criteria towards reduction of the environmental impact of construction products (projects). The method of how to perform the LCA is however not specified. In Norway GHG accounting is getting more and more common. Therefore, the largest project and infrastructure owners in Norway (NPRA, Bane NOR, NV) have developed tools and methods to perform LCA. At the same time, they have announced that all projects over a certain amount must perform life cycle assessment to account for GHG emissions, both before (a budget) and after (GHG accounting). Furthermore, the NPRA demand CEEQUAL certification, or compatible certification, for all projects over 500 million NOK (and evaluate if projects over 200 million should be certified) and Nye Veier demand it for all their projects from 2021 [8]. The tools to estimate emissions according to standards are therefore essential. Few of these tools and methods most used in Norway are listed below. These tools are used is in addition to a more elaborate LCA studies that use international and national software and databases (e.g., SimaPro, Gabi, EcoInvent).

Storåselva hydropower plant was awarded its certification in march 2018 and was thereby the first project in Norway to be implemented in accordance with the strict requirements for sustainability that

CEEQUAL sets in its certification scheme. The facility consists of approx. 2800 m inlet tunnel and 800 m outlet tunnel. The access to the power station takes place through a 320 m long access tunnel.

2.2.2 VegLCA and NV-GHG

One of the first tools developed in Norway is VegLCA which was developed by Asplan Viak for the NPRA [9]. The excel based tool is a middle and late phase tool that allows contractors and designers to estimate the total emissions from a project. At first the tool focused on road infrastructure (road, bridge, and tunnels) but later, a railway module was incorporated into the tool. NV-GHG is also an excel based early phase tool and these tools have been partially aligned when it comes to emission factors, calculation factors and system boundaries [10]. The process of more alignment of the different tools is ongoing, so is the further development of the tool itself, from excel based to a linking of LCA with BIM. The other Nordic countries have also been actively developing tools. In Sweden the most common tool was developed by the Swedish road authorities (Klimakalkyl) and in Denmark they have InfraLCA, which is a Danish version of VegLCA.

2.2.3 Nordic cooperation

NordFoU started as a cooperation between the national Nordic road administrations to start, finance and run R&D projects. From that the NordLCA project was initiated which has the main aim of sharing experiences and knowledge about life cycle analysis. The project was to improve calculation methods and tools to estimate and reduce climate impact. The project has evolved and now focuses more and more on how to effectively combine BIM systems and LCA for smoother and continuous reports on emissions during design and construction phase. A part of the results from the cooperation is a NordLCA guide for LCA (nordfou.org) of road and rail infrastructure [11]. The guide defines how to use LCA to evaluate GHG emissions from road and railway projects, from planning and through construction and maintenance. The aim of the guide is to narrow the room for interpretation and provide a more comparable result.

Figure 2.2.1: Storåselva Hydropower Plant the first Ceequal certified construction project in Norway.

2.2.4 EPD's in Norway

An EPD (Environmental Product Declaration) is a concise third-party verified and registered document with transparent and comparable information on products' environmental performance throughout the life cycle. Both the underlying LCA (Life-Cycle Assessment) and the EPD are always based on international standards. More than 1500 EPDs from over 220 companies are now published and freely available at EPD-Norway. NFF believes that the number of EPDs will further increase in the time to come. As an example, there are 17 EPDs registered just for explosives and ignition systems.

EPD's can aid in the reduction of emissions by allowing for comparison between different products environmental performance. This way the contractor and/or project owner can choose the products with best environmental performance. The different actors in the construction sector in Norway actively use EPD's in tenders, promotion of the products and in contracts. The producers in Norway have embraced the certification scheme and, together with the contractors, have developed product category rules for the Norwegian sector. The EPD's are then available for the industry to have local emission intensities for the projects in Norway.[12].

2.3 UN's Sustainabile Development Goals in strategy plans

UN's sustainable development goals (SDGs) are actively used to shape strategic work in the construction sector in Norway. These are used to shape the project portfolio and to prioritize efforts for improvement. Many companies select several of their most relevant SDGs that they can contribute to the most and focus on these in their strategic work. Norway's largest entrepreneurs all have strategies for at several SDGs, f.ex. NCC that focus on goals 7, 9, 11, 12 in addition to 13 (Climate action). Skanska focus on 5, 8, 9, 11, 12, 13 and 16. The wide use of the UN's SDGs in today's corporate environment is valuable for the work towards sustainability and allows recognizable pattern for international actors.

2.4 Circular Economy

The circular economy is based on the principles to eliminate waste and pollution through circulation of products and materials (without down-grading), and to regenerate nature. Adjusting to a more circular economy can help to reach international, regional and national sustainability targets, including several of the UN's sustainability goals under Agenda 2030. The basis for a more circular economy is to reduce the environmental problems that result from the extraction of virgin natural resources and the current production and consumption patterns.

Raw materials that are extracted and sold in a global market without the socio-economic costs from the resulting environmental problems they entail, are a significant reason for the lack of sustainability in the global economy. Another reason is a lack of global regulations or a lack of enforcement of such regulations. Through the EEA agreement, Norway is a part of a larger economy community with Europe. The EU's regulations for the circular economy constitute a central platform for Norway's contribution to solving a lack of sustainability in the world economy (Norwegian ministries, 2020).

For the construction sector an increased circularity in handling of masses and other heavy construction materials contributes greatly towards lower emissions and increased sustainability in the sector. Suppliers and contractors in Norway are expected to have strategies for increased circulation of materials and most already have internal strategies for to reduce extraction of virgin materials and for reuse of existing, available materials.

2.5 Methods and tools developed in Norway for risk analysis

Several tools and methods have been developed in Norway to assess risk to infrastructure, evaluate their resilience and to prioritize actions. The following is a short introduction of these tools and methods.

CIRAM (Critical Infrastructure Resilience Assessment Method) is a method that can be used to assess resilience of critical infrastructure and thereby contribute towards the work with climate change adaptation of the transport network in Norway. CIRAM presents a resilience curve that goes through 5 phases to adapt critical infrastructure to make it more resilient.

ROS-analysis (risk and vulnerability analysis) can help estimate the current risk to the structure. These analyses are mandatory.

VegROS is a mapping tool that maps current risk and vulnerability of the road network. It is not meant for assessing future possibilities.

MOTIV was developed by NPRA to model cost of operation and maintenance activities for national and county roads. It is meant to help with distributing fonds to the different regions and projects.

DeTECToR is a Decision-support Tools and guidance aimed at putting into practice the latest research and embedding climate change adaptation in operations and procurement.

NPRA often uses EFFEKT for cost-benefit analysis for new road construction projects and maintenance of existing infrastructure. EFFEKT does not account for climate change adaption.

In an uncertain future the use of cost-benefit tools could increase to see if the extra safety margins are worth putting in or if extensive maintenance later would be more beneficial.

This is important as budget constraints effect decisions for example after a weather event or unwanted incident, restoring the infrastructure to the same condition as before instead of making it robust against climate change.

References:

[1] G. Itskos et al., "Energy and the environment," Environ. Dev. Basic Princ. Hum. Act. Environ. Implic., pp. 363–452, May 2016.

[2] H. R. Vignisdóttir, T. Kristensen, T. Rise, and G. Kjellmark, "Veikart for Grønn Anleggssektor," Trondheim, 2021.

[3] C. Grossrieder, "Life-Cycle assessment of Future High- speed Rail in Norway," no. June, p. 75, 2011.

[4] A.-R. Korsmo Bergsdal, H., "Miljøbudsjett for Follobanen - Infrastruktur," 2011.

[5] L. Huang, R. A. Bohne, and A. Bruland, "Life cycle assessment of Norwegian road tunnel," Int. J. Life Cycle Assess., vol. 20, pp. 174–184, 2015.

[6] L. Huang, R. A. Bohne, A. Bruland, P. D. Jakobsen, and J. Lohne, "Environmental impact of drill and blast tunnelling: life cycle assessment," J. Clean. Prod., vol. 86, pp. 110–117, 2015.

[7] L. Huang, P. D. Jakobsen, R. A. Bohne, Y. Liu, A. Bruland, and C. J. Manquehual, "The environmental impact of rock support for road tunnels: The experience of Norway," Sci. Total Environ., vol. 712, p. 136421, 2020.

[8] R. Daler, "Nye Veier krever CEEQUAL-sertifisering - Anleggsmaskinen," 2021. [Online]. Available: https://anleggsmaskinen.no/2021/03/nye-veier-krever-ceequal-sertifisering/. [Accessed: 20-Dec-2021].

[9] J. Hammervold and O. Sandstrand-Dahlstrøm, "Documentation VegLCA v4.01." Statens Vegvesen (E. Norwegian Public Roads Administration), Oslo, p. 101, 2020.

[10] Ragnhild Stamer Ekerholt and Julie Gade Gørbitz, "CO_2-fotavtrykk | Nye Veier AS," V2.4, 01-Dec-2020. [Online]. Available: https://www.nyeveier.no/om-oss/co2-fotavtrykk/. [Accessed: 20-Dec-2021].

[11] B. Hamel, S. Knuuti, and Å. Lindgren, "Guide for LCA of Road and Rail Infrastructure," 2020.

[12] The Norwegian EPD Foundation, "The Norwegian EPD programme Programme operator The Norwegian EPD Foundation," Oslo.

3 Sustainable tunnelling

3.1 Norwegian practice for tunnelling

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Climate emissions and the extended use of resources in tunnelling are majorly related to the use of resources in such as concrete, steel and the handling of blasted rock in the construction process. For decades, the Scandinavian tunnelling practice has effectively minimized the use of such input factors by utilizing the self standing capacity of the rock mass as the bearing construction element combined with a drained structurerock mass. The support works need to be designed to handle the frequently changing ground conditions as these are encountered during the tunnelling progress, adjusting rock bolt patterns and sprayed concrete thickness according to the actual rock mass quality. Probe drilling ahead of tunnel face is an additional measure to identify and prepare for changing ground conditions whilst pre-excavation rock mass grouting is done to stem the water inflow. Hence the volume of concrete and steel is significantly lower than in tunnelling practices where a new engineering construction to a higher degree is designed within the rock mass [1][4]. In light of this, a continuous innovation process is going on, involving factors with high potential for optimization. The SUPERCON-project (described in chapter 3.8.6) is such an example. The TIGHT project is another one (described in chapter 3.8.6). Both projects aim to reduce the volume of concrete and cement in the secondary lining and rock grouting, respectively. The reduction of climate emissions is described in chapter 3.6.

A summed consequence of the existing practice is arcost and time efficient construction process (not low quality) compared to some other tunnel design methods. This adaptive approach is perhaps the most important positive sustainable factor made possible by the Scandinavian tunnelling practice. Low cost and high quality make it possible to choose tunnel as a construction element in infrastructure projects to a higher degree, thereby **significantly reducing the encroachment on nature**.

The main “sustainable drivers” can be grouped into the following topics:

- Construction design process
- Rock support
- Water and frost protection
- Rock mass grouting

3.1.1 Construction design process

The method of observation is adapted, based on an in-situ assessment of the rock mass, in principle following every single blast round. Rock support and blasting design are then targeted for the actual ground conditions, reducing the risk of overdoing the tunnel construction based on a theoretical design from the pre-construction design phase. Material resources and costs are thus kept to a minimum. A theoretical planning-based design, largely adapting the planned blasting system and rock support to in-situ construction is conservative in its nature.

A production logistic series of highly efficient equipment for high volume excavation optimized by digitalization makes it possible to excavate tunnels and caverns with high production rates, and thereby reducing the project’s cost. It is normal to excavate full-face in blasting rounds of 5-6 meters in favourable rock conditions still maintaining the integrity of the tunnel. Reduced blast rounds are limited to adverse ground conditions. The typical solution for water and frost protection applying a free standing inner lining consists of such as bolt-suspended vault of concrete or sprayed concrete leaving a void space between the tunnel concour and the inner lining. In recent years cast concrete for a secondary liner has been used in some, but few rail way projects, however the current trend is to identy alternative solutions that produce less carbon emission.

In adverse ground conditions, the blasting rounds could be reduced to e.g. 1-3 m, and possibly dividing the face if needed. In such rock mass, the construction process can be described as a fine-tuned process of finding the right combinations and approaches amongst the following:

- Probe drilline ahead of the tunnel face (15-30 m), single hole or fan of multiple holes
- Pre-excavation grouting of the rock mass
- Blasting length, alternatively with a face split
- Advance rock support with spiling bolts or pipe umbrella
- Face support with reinforced rebar ribs with sprayed concrete (RRS)

- Advance ground improvement and leakage prevention by rock mass grouting

These interleaved processes are updated for every new blasting round, adjusting the setup for each subprocess, as well as the combined system. Information about the rock mass ahead of the tunnel face, utilizing Measurement While Drilling (MWD)-data from exploratory probe drilling is an invaluable source of information (see figure 3.1.1), enabling adequate decisions on the utilization of the available tools at hand listed above [2]. Such a combined effort makes it possible to avoid a far more resource-demanding system of a full concrete lining or, when the rock cover is low, a cut-and-cover solution. An example of such a system is described in figure 3.1.2 and figure 3.1.3 from the Skillingsmyr tunnel in the railway-project UFP:Farriseidet-Porsgrunn [3]

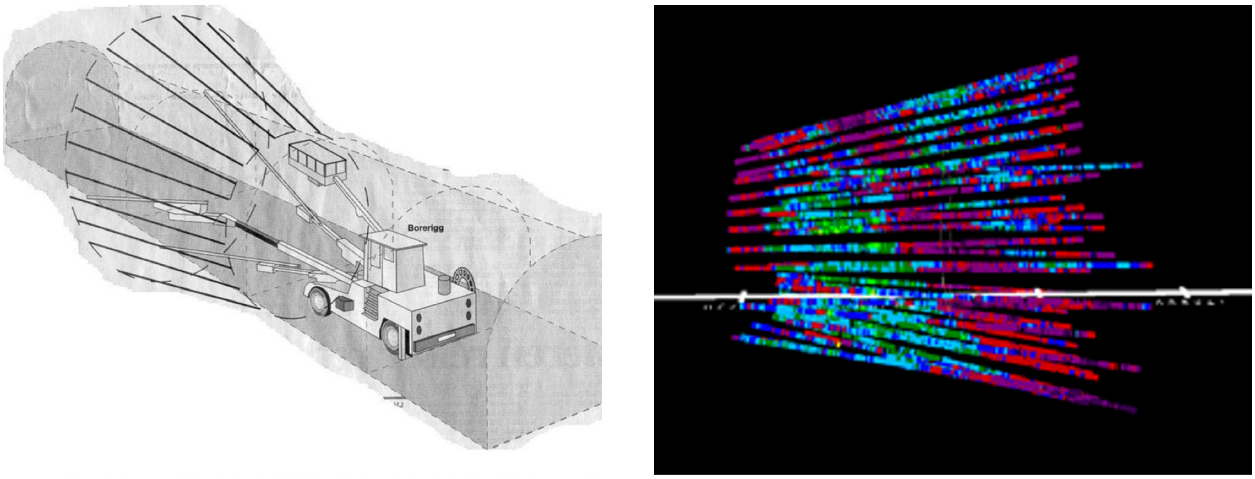


Figure 3.1.1. Left: Drilling holes for grouting in a fan around the tunnel contour. Right: MWD-data from probing/grouting holes give valuable advance decision-support information. Here: a dyke is some 5-10 m ahead.

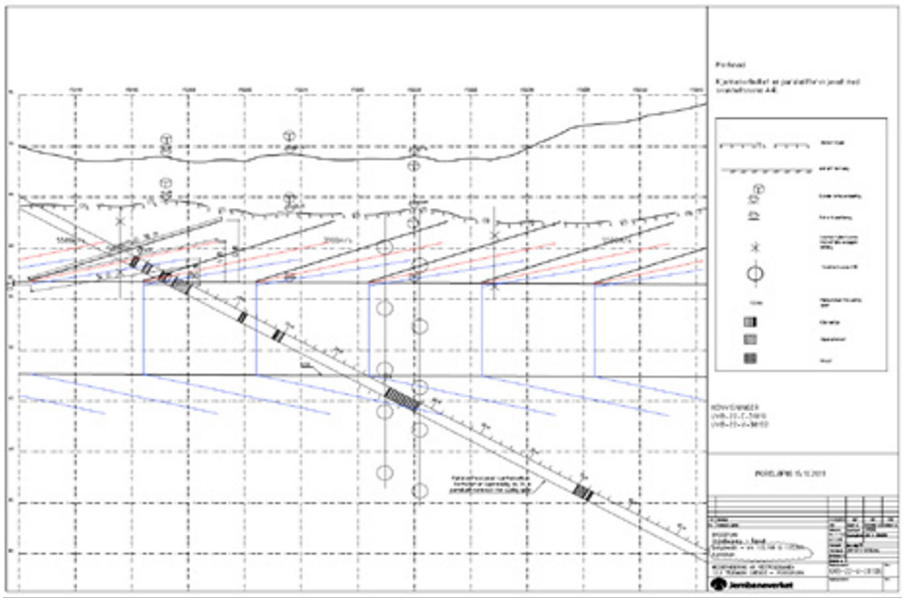


Figure 3.1.2. A combined approach of choosing the proper process for blasting, advance-support, face-support and ground stabilization makes it possible to excavate tunnels with rock cover down to a few meters with a cost-effective process. Probing holes in black, grouting fan with microfine-cement and low pressure in red, standard grouting fan in blue.

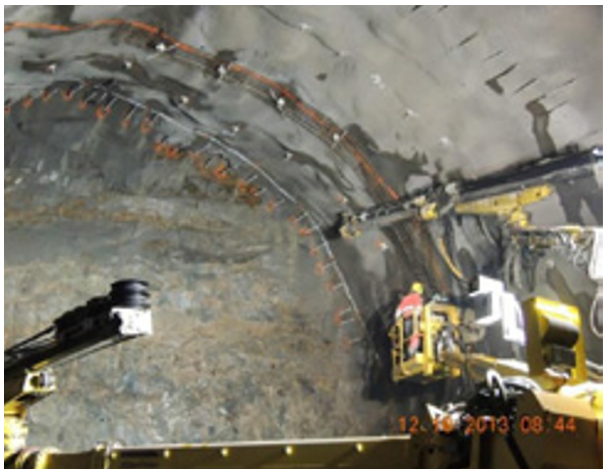
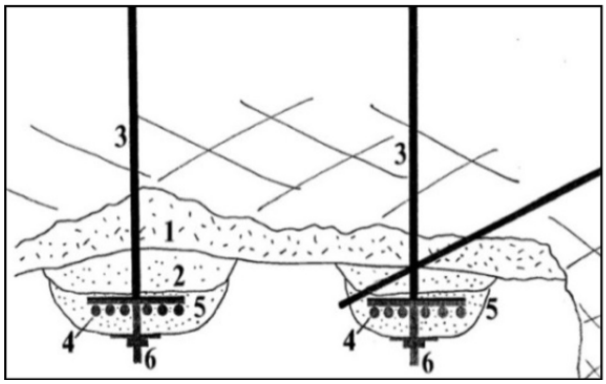


Figure 3.1.3. Left: Advance spiling bolts used to handle the zone described in figure 3.1.2. Right: RRS are installed on the face before continuing the blasting rounds.



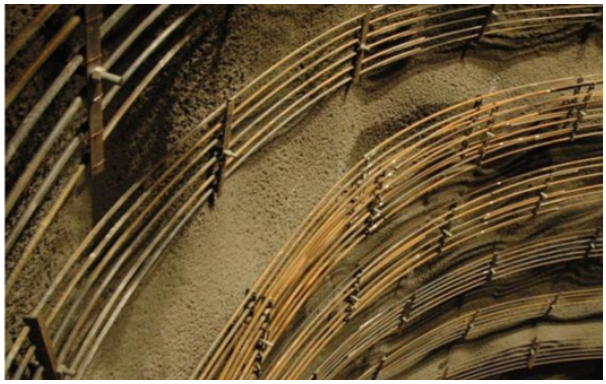


Figure 3.1.4. The construction principle of RRS [4].

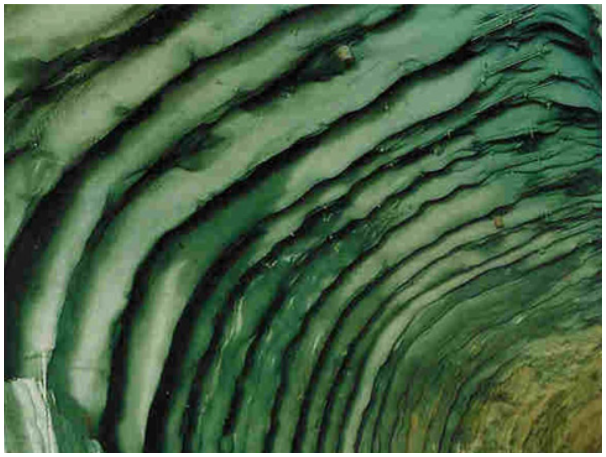


Figure 3.1.5. Constructed RRS in National theatre station [4].

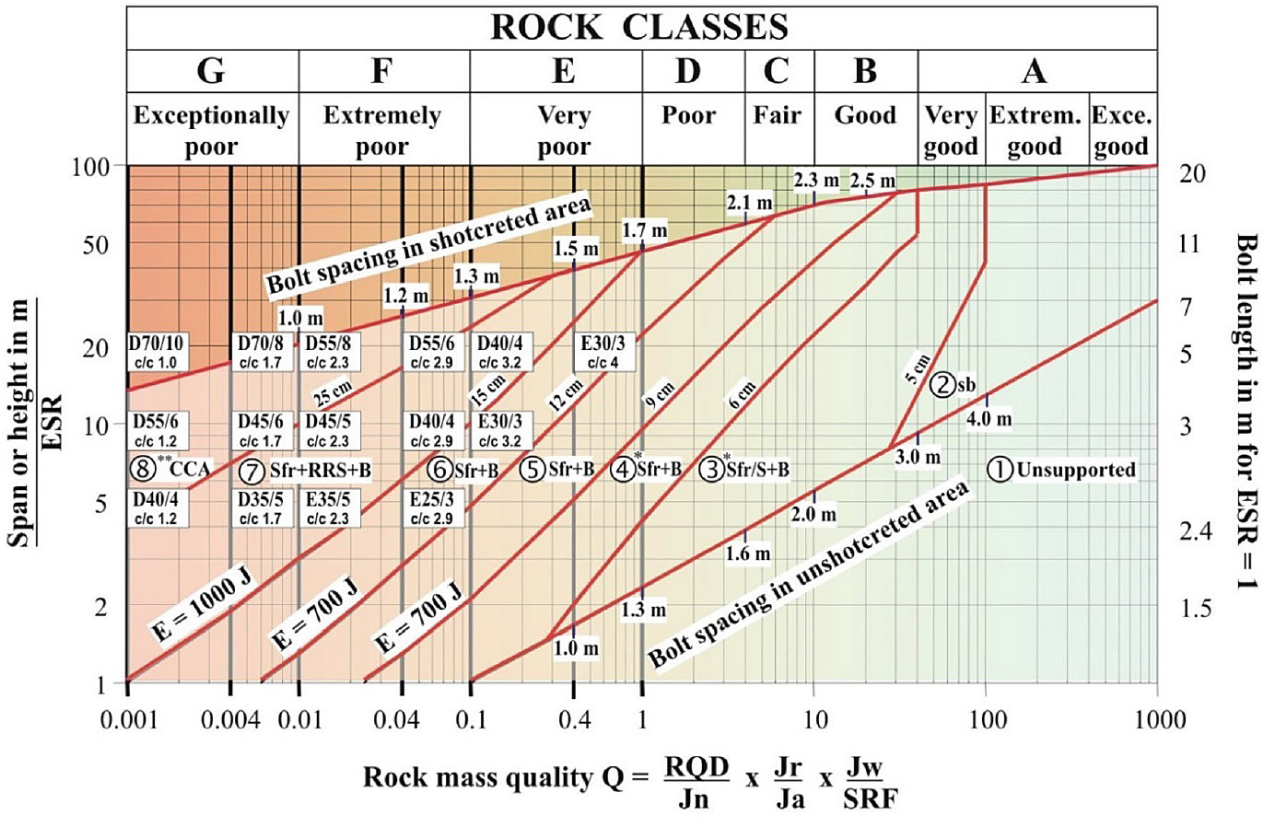
3.1.2 Rock support

Permanent support in Norwegian tunnelling is based on an in-situ assessment of the rock mass by trained face-engineers following scaling rock massof the tunnel contour from the last blast round (s). A typical assessment process can be described as:

- Assessing input parameters for the Q-system [4] and calculating the Q-value to address the rock mass quality

- Map the geology using digital tools
- Textual description of the rock mass
- Decide on a base support system using support classes described for intervals of Q-values
- Adapt the base support to local conditions, e.g., adding additional bolts targeting local zones, different bolting lengths, and adjustment in sprayed concretethickness.

In such a design process, the rock support is chosen based on the actual in-situ rock mass conditions and is not the outcome of a conservative planning-phase design process. Such an approach makes it possible to quickly adapt to the changing rock conditions. Even though such a process can be said to optimize the rock support to a higher degree than a planning phase approach, the process's subjectiveness still leads to conservative support decisions. Further utilization of new spatial and rich datasets from **lidar-scanning** the rock surface and **extensive MWD-logging** could be the way to optimize rock support decisions in future tunnelling.



REINFORCEMENT CATEGORIES

1) Unsupported
2) Spot bolting, **sb**
3) Systematic bolting, and unreinforced or fibre reinforced shotcrete, 5-6 cm), **Sfr/B+S**
4) Fibre reinforced shotcrete and bolting, 6-9 cm, **Sfr+B**
5) Fibre reinforced shotcrete and bolting, 9-12 cm, **Sfr (E700) +B**
6) Fibre reinforced shotcrete and bolting, 12-15 cm, **Sfr (E700) +B**
7) Fibre reinforced shotcrete > 15 cm + reinforced ribs of shotcrete and bolting, **Sfr (E1000) +RRS+B**
8) Cast concrete lining, **CCA** or **Sfr (E1000) +RRS+B**

The bolts are 20 or 25 mm in diameter

E) Energy absorbtion in fibre reinforced shotcrete at 25 mm bending during plate testing

D45/6 c/c 1.7 = RRS with totally 6 reinforcement bars in double layer in 45 cm thick ribs with centre to centre (c/c) spacing 1.7 m. Each box corresponds to Q-values on the left hand side of the box

Figure 3.1.6. Q-support system [4].

Huang et. al [5][6][7] describe the environmental impact of rock support for road tunnels in Norway. The main findings are:

- The sustainability potential varies significantly for different types of rock support and rock mass. Bolts contribute by a factor of 1/10 of concrete to emissions and energy consumption.
- In Norwegian tunnelling, the sprayed concrete counts for the major part of energy consumption compared to bolts.
- When the rock mass becomes poorer and the size of the cavern increase, the relative contribution from bolts increases.
- Improving the sprayed concrete method, such as reducing rebound and designing better mixtures, can have a significant positive effect.

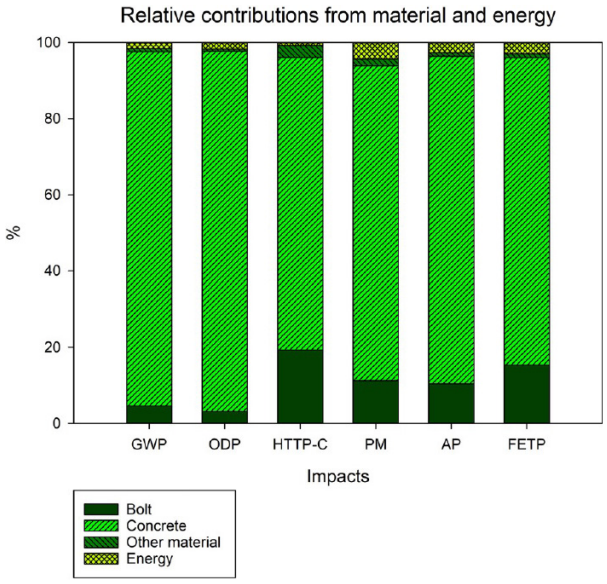


Figure 3.1.7. Relative contribution of material and energy for standard road-tunnel support [5].

3.1.3 Water and frost protection

Several tunnelling construction methods involve the construction of a cast concrete secondary lining on top of the temporary rock support, what we can call a double-shell solution [4]. The typical Norwegian design method is a single-shell method. Sprayed concrete combined with rock bolts, occasionally with additional support according to the actual rock mass quality such as RRS are used as the permanent support, reinforcing the rock mass with a single shell solution. A water and frost protection system is installed with bolts as a vaulted ceiling of watertight sheets of foam/membrane or membrane only covered by fire-resistant sprayed concrete or and pre-cast concrete elements. This solution employs much less concrete than fully lined tunnels [4]. There is a further potential to reduce the material resources even more. Extensive ongoing research is focusing on two promising ways to place the water & frost protection directly on the permanent sprayed concretesurface, thereby significantly reducing the necessary volume of excavated rock and the resources of concrete and steel:

- Sprayed watertight membrane directly on the permanent sprayed concrete support + a layer of fire-resistant sprayed concreteon top [8].
- Watertight shotcrete. In the SUPERCON project [9] (see chapter 3.8.6) the goal is to develop a sprayed concrete that is sufficiently watertight to be used as the permanent waterprotection.

References:

[1] A. Høien, B. Nilsen, R. Olsson. Main aspects of deformation and rock support in Norwegian road tunnels, Tunneling and Underground Space Technology 86 (2019) 262-278.

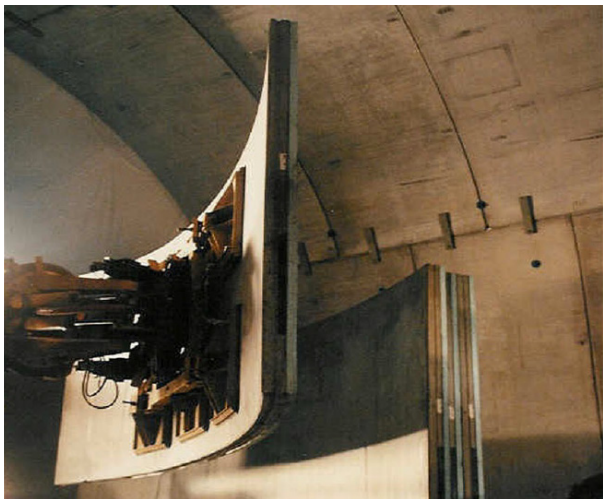


Figure 3.1.8. Vaulted ceiling of concrete elements [4].

[2] J. Chiu, T.F Hansen, T. Wetlesen. Norwegian tunnel excavation – Increasing digitalization in all operations. Geomechanics and Tunnelling, 2022.

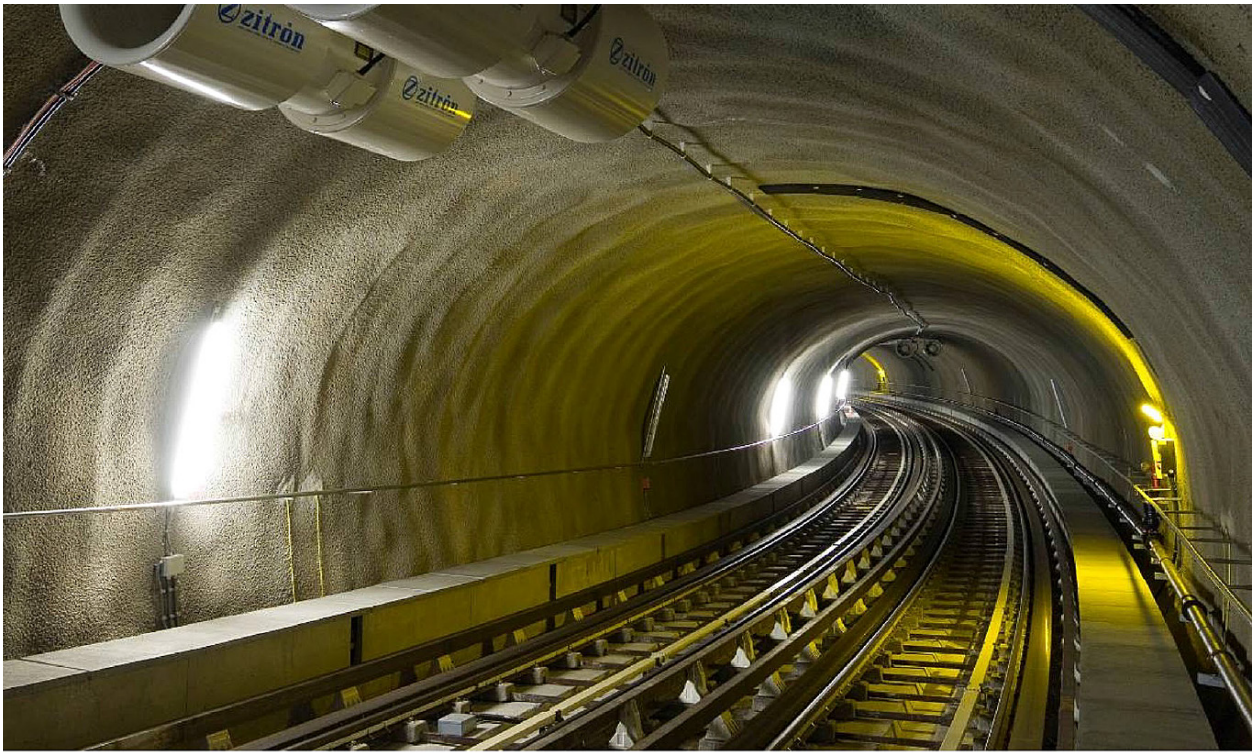
[3] T. F. Hansen. The railway project Farriseidet – Porsgrunn. 7 tunnels in total 15,3 km. Project status. Fjellsprengningsdagen, 2014. and rock mechanical / geological challenges.

[4] N. Barton. Minimizing the use of concrete in tunnels and caverns: comparing NATM and NMT, Innov. Infrastruct. Solut. (2017) 2:52

[5] L. Huang, R. A. Bohne, and A. Bruland, "Life cycle assessment of Norwegian road tunnel," Int. J. Life Cycle Assess., vol. 20, pp. 174–184, 2015.

[6] L. Huang, R. A. Bohne, A. Bruland, P. D. Jakobsen, and J. Lohne, "Environmental impact of drill and blast tunnelling: life cycle assessment," J. Clean. Prod., vol. 86, pp. 110–117, 2015.

[7] L. Huang, P. D. Jakobsen, R. A. Bohne, Y. Liu, A. Bruland, and C. J. Manquehual, "The environmental impact of rock support for road tunnels: The experience of Norway," Sci. Total Environ., vol. 712, p. 136421, 2020.



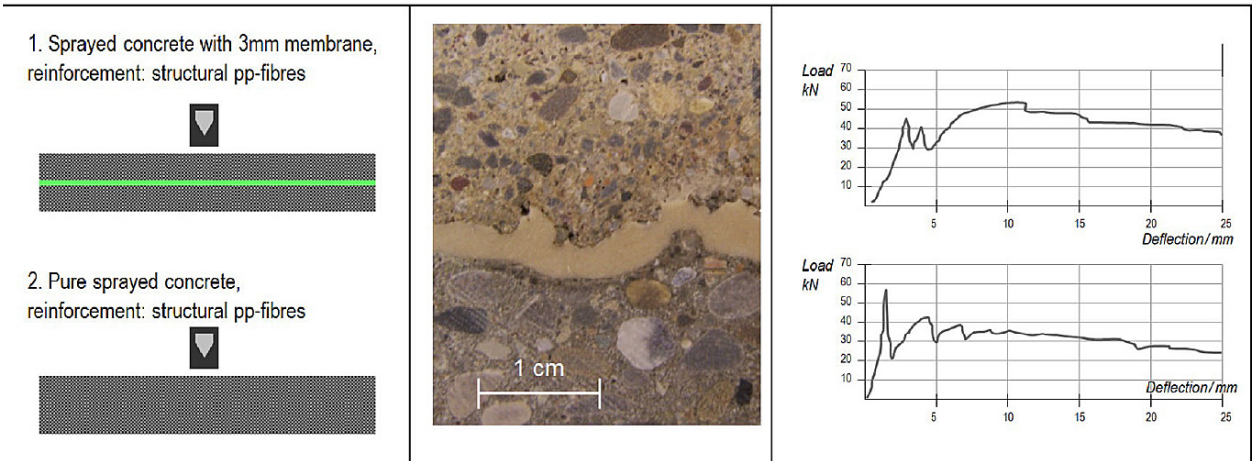


Figure 3.1.9. Tunnel with a watertight sprayed membrane [4].

[8] K.G. Holter. Permanent sprayed concrete tunnel linings waterproofed with bonded membranes. A review of the current state-of-the-art for hard rock conditions. World Tunnelling Congress, 2019.

[9] K.G. Holter, H. Strømsvik, E. Grøv. Material technology and spray-application development for waterproof and durable sprayed concrete linings. Goals and backgroun for the SUPERCON research project, Norway. Sprayed Concrete Conference, Alpbach, Austria, 2021.

3.1.4 Rock mass grouting

Helene Strømsvik, researcher, SINTEF Community

In the wake of the TIGHT research project (Grøv, et al., 2020), some media attention has been given to rock grouting on Norwegian tunnel projects. There are many indications that the tunnelling industry is at a crossroads where manual grouting processes are meeting digitalisation as well as increased requirements for control and reduction of the use of building materials, construction time and impact on the environment. In this transition period, it is important that the tunnelling industry maintains experience built up over many years of practical work while introducing expertise gained on recent projects and from new research. This applies to both methodology for performing grouting processes and choice of grout materials.

Both grouting equipment and software have undergone major developments in the past five years. This is only set to continue in the future. By utilising this potential, grouting can be continuously optimised to ensure that a tunnel with sufficient reduction in water ingress is obtained, without overuse of grout or construction time.

Choosing the correct grout

One of the keys to successful grouting is using the correct grout materials. There are many factors that are of great importance to the grout properties that influence on the achieved reduction in water ingress and consumption of grout and time. Research, both from the TIGHT project (Grøv, et al., 2020) and in Sweden, such as e.g. published by Håkansson et al. (1992) and Stille (2015), show that different types of cement-based grout vary significantly when it comes to both rheology and the ability to penetrate into small fractures. For example, two seemingly similar types of cement, from different suppliers, may behave very differently. Large variations also occur with the addition of plasticisers and accelerators, and in some cases the expected results are not achieved. In addition to this, every tunnel project is in many ways unique. Type of rock mass, overburden and fractures greatly impact the resources needed to meet the specific requirements. Therefore, in-depth knowledge of the products used and their properties are important, as is performing tests of the grout both before start-up and during the project. This ensures that projects will be better equipped to make the right changes if the grouting does not go as planned, both in terms of achieved reduction in water ingress and use of resources.

In the PhD study on the TIGHT project (Strømsvik, 2019), comparisons were made between grouting performed using ordinary portland cement (OPC) and micro-cement. In short, this showed significantly reduced amounts required when using micro-cement compared to OPC under otherwise relatively similar conditions. This was explained by shorter setting time and higher surface activity on smaller particles. This finding has also been confirmed by research performed in Sweden, e.g. in studies published by Håkansson et al. (1992) and Stille (2015). Since then, new micro-cement products have entered the marked with longer setting time. This emphasise that the focus should not be if it is OPC or micro-cement, but on the functional requirements of the material used for grouting.

Heated debate about grouting pressure

What recently has emerged as a heated debate in the tunnelling community is the grouting pressure. Grouting with the use of high grouting pressure with cement-based grouting is basically beneficial as faster penetration is achieved. Research has also shown that high pressure results in fewer filter cake formations and enhanced penetration into small fractures. Many in the Norwegian tunnelling industry are concerned that the practice of using lower grouting pressure, used in neighbouring Sweden, will spread to Norway. As a result, the debate about grouting pressure is often heated. What cannot be denied is that the grouting pressure applied on most Norwegian tunnelling projects is at a level where the local pressure from the grout in the fractures often exceeds the normal stress on the fractures, which causes hydraulic jacking of the fracture, an event that occurs more frequently than many may think. Hydraulic jacking of fractures is in most cases unwanted as it can result in uncontrolled spread of grout, which is not in line with the principle of pre-grouting, namely that a spread of grout must be achieved in as many fractures as possible immediately around the tunnel profile. There is further a risk of residual leaks from the small ungrouted fractures. In summary, hydraulic jacking might lead to unnecessary high consumption of grout, less penetration of grout in smaller fractures and backflow of grout

into the tunnel. In rock mass with clay filled fractures, hydraulic jacking may be beneficial. Simply put, there is no one-size-fits-all solution that is suitable for all conditions. The following is more important than for most other activities in tunnelling: grouting must be adapted and tailored to the local conditions.

If the Norwegian tunnelling industry is to maintain its use of high grouting pressure, it is important to introduce technology that can ensure that this is done in a safe and controlled manner, to avoid undesirable events during grouting as well as unnecessary use of resources. In order to put new knowledge into practice and to optimize the grouting procedures and materials, it is important that contracts allow a certain flexibility so that necessary adjustments can be made based on the local conditions and available products.

Real-time analysis during rock mass grouting
At the beginning of 2020, Logic Grouting, a three-year commercialisation project supported by NFR (KOMMERSFORSK19), was launched. Logic Grouting is managed by SINTEF with Bever Control as project partner and AMV and Bane NOR as external partners. Veidekke and Skanska contribute project data. The project develop a software with real-time analysis of the grouting process, including detection of hydraulic jacking during grouting. Combined with guidelines, this software will assist the operators to continuously adapt the grouting to the local conditions and thus reduce unnecessary use of grout and construction time.

Tunnels have different requirements for increased leakage depending on use and location. A tunnel that meets the requirements in regard to leakage most important goal as this safeguards the environment, overlying structures and infrastructure. But successful grouting should not only be judged on the basis of the reduction in leakage achieved, but factors such as budget and environment should also be addressed.

References:

HÅKANSSON, U., HÄSSLER, L. & STILLE, H. 1992. Rheological properties of microfine cement grouts. *Tunnelling and Underground Space Technology*, 7, 453-458.

GRØV, E., STRØMSVIK, H. & HAUGSAND, M. H. 2020. Sementbasert berginjeksjon. Sluttrapport fra prosjektet TIGHT. SINTEF

STILLE, H. 2015. *Rock Grouting – Theories and applications*, Stockholm, BeFo.

STRØMSVIK, H. 2019. *Assessment of High Pressure Pre-Excavation Rock Mass Grouting in Norwegian Tunnelling*. PhD, Norwegian University of Science and Technology.

3.2 Sustainability focus among infrastructure owners

Norwegian infrastructure owners (clients) are one of the main drivers of sustainable innovation through requirements for sustainability in contract and tender evaluation process. An example is the contract-requirement from Oslo municipality to only allow electric machinery with no direct emission of greenhouse gasses in construction projects for the municipality. Similar goals have been set by several of the largest municipalities in Norway e.g., Trondheim and Bergen (Offergaard, 2022; Trondheim Municipality, 2021; Strand, 2020). The three major clients in Norway, er described in chapters 3.2.1, 3.2.2 and 3.2.3.

References:

https://www.trondheim.kommune.no/aktuelt/nyhetssaker/2021/mobile-batteri-til-utslippsfrie-bygge--og-anleggsplasser/

https://www.bygg.no/her-kommer-bergen-kommunes-forste-utslippsfrie-byggeplasser/1446312!/

https://www.bygg.no/oslo-kommune-overgangen-til-utslippsfrie-bygge-plasser-skyter-fart/1487745!/

3.2.1 Sustainability for future construction projects in Bane NOR

Authors: Vibeke Tegneby, Anne Kathrine Kalager, Håvard Kjerkol, Elin Anita Walstad

The first steps
Since 1996, has the Norwegian National Rail Administration, now Bane NOR, earlier Jernbaneverket, implemented environmental requirements in the contracts for execution of new projects, in order to reduce or eliminate direct impact on the environment from the construction activities. These requirements were defined as limits for the execution of the work, in order to achieve control of emissions to air, to water and to soil, reduce or regulate the traffic in and out of the construction site, avoid reduction of pore pressure and of the ground water level, and reduce noise from the construction site, as some examples. For some projects, implementation of these requirements was a foundation of the approval from the governments to start the project.

In some cases, the achieved results were reported to the governments during the construction period and used as a verification of the effects of the requirements afterwards.

In 2009, Jernbaneverket agreed with the Ministry of Transportation and Communication to develop a template for an environmental account, which could be used to achieve control and an overview of the environmental impact related to the entire life circle of a railway system, including the construction phase. The Follo Line project were chosen as a pilot for this development.

The template for a greenhouse gas account were made as a cooperation with the National Road Authority, the Coastal Administration and Avinor (The Civil Aviation Administration) as a part of the preparation of the National Transport plan. The method used was in accordance with ISO 14040 and ISO 14044 (Life Cycle Assessment). In parallel, the Swedish infrastructure company, Trafikverket, and the infrastructure project Botniabanen (railway) developed a software for Product Category Rules for railway infrastructure projects, which gave a detailed account of the impact related to construction, operation, and maintenance of railway infrastructure. This was also used as a basement for the development of a greenhouse gas account for infrastructure projects.

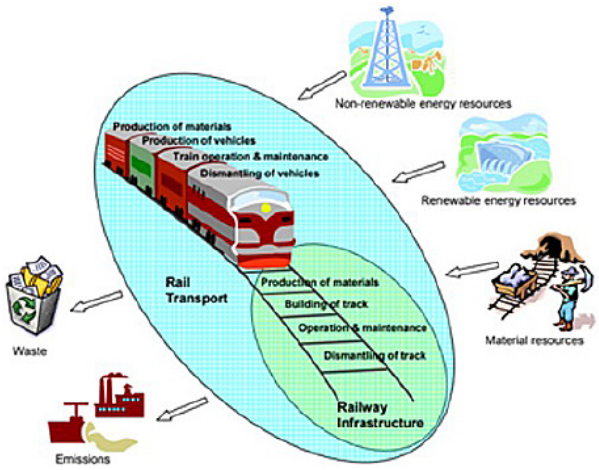


Figure 3.2.1. Life Cycle impact; The product categories from railway infrastructure and rail transport.

Jernbaneverket developed further a guideline for development and implementation of greenhouse gas budgets in upcoming projects. In 2012, the Follo Line project achieved the UIC Sustainability Award for the development of this guideline. In 2015, it was agreed within Jernbaneverket to implement greenhouse gas budgets as a requirement for all upcoming InterCity-projects.

Some examples of what has been achieved

Even though requirements for the environmental account were not implemented in neither the Invitation to tender nor in the contracts for the Follo Line project, there are examples of reduced emissions as a result of choices made before and during the construction period.

The assessment of the excavation methods for the main part of the 20 km long tunnel showed that the cost and schedule for the two excavation methods, four TBMs operating from one centrally located access point or drill and blast from seven different access points located along the tunnel section, many located within densely populated areas, were nearly similar. The main arguments for a decision of performing the excavation by four TBMs operating from one large rig-area were related to safety and environmental impact.

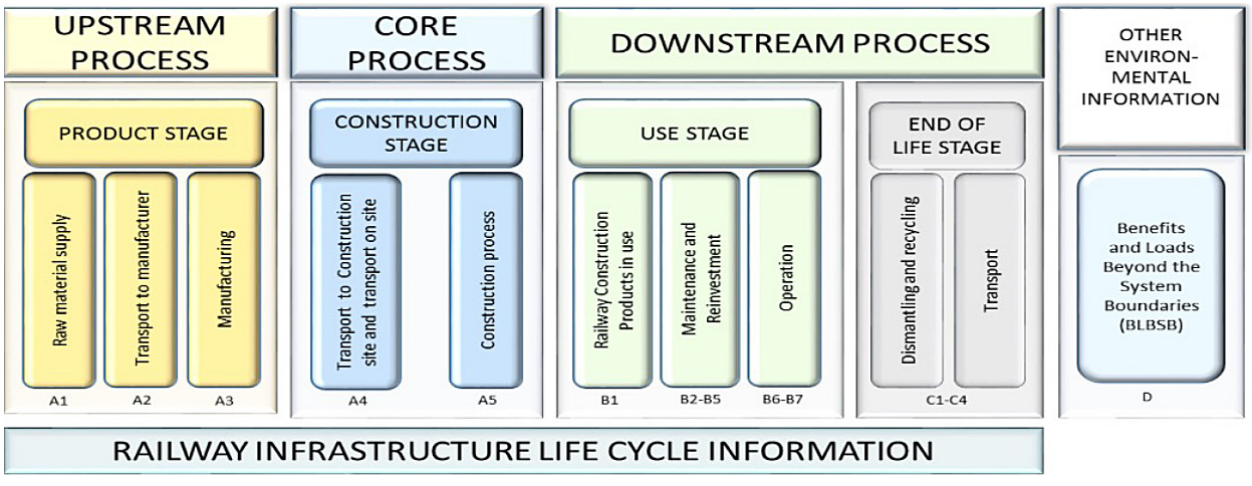


Figure 3.2.2. Life Cycle Assessment for Railway Infrastructure projects.

The site-area was located with direct access to the main road, E6. No transport on local roads were required. In addition, the area was large enough to house all the activities related to the tunnel construction, including reuse of the spoil, 9 million tons, production of the 141 000 segments for the lining and 20 000 invert elements, in addition to space for offices for company and the contractors and accommodation for the workers. The spoil was filled up in accordance with a specific procedure in order to be used as a basement for a future residential area.

The spoil was transported on electric conveyor belts all the way from the cutterheads of the four machines

Figure 3.2.3. One large rig-area, close to E6, where all the tunnel-related activities could be performed.

up to the area where the filling took place. This transport on conveyor belts, and this reuse of the spoil within the construction area, eliminated 360 000 vehicles from using the roads, compared to the alternative by excavating the tunnels by conventional drill and blast from seven different access points. By this decision, approximately 27 000 tons CO_2 were reduced. Safety is another area where benefits of reduced transport is documented.

All the temporary concrete slabs and other kinds of constructions at the site were crushed into different fractions. The concrete was sorted from the steel rebars, and it was reused within the construction site as filling material. Again, this activity contributed to an additional reduction of transport from site to different deposits, which also gave major safety and environmental benefits.

Figure 3.2.4. 9 million tons of spoil transported om conveyor belts.

In the majority of the large infrastructure projects in Bane NOR today, requirements regarding reduction of greenhouse gas emissions are given. In the Drammen – Kobbervikdalen project, which is a part of the InterCity network west of Oslo, a reduction of greenhouse gases of 36% has been reported as a result of the environmental requirements in the contracts.

Today, specific requirements regarding mitigations in order to reduce/ eliminate emissions of greenhouse gases are implemented as a standard for all upcoming constructions projects.

Bane NOR's awareness of UNs sustainability development goals (SDGs)

Bane NOR supports the work of the SDGs and has systematically related its own work on sustainability to the SDGs. It is well known that construction activities may have both positive and negative impacts in relation to the SDGs. Bane NOR is therefore making a systematic effort in order to minimise negative impacts, wherever possible, and by that contribute to achieving the goals. Together with the stakeholders, Bane NOR has prioritised five of the 17 SDGs, goal no 9, 11, 12, 13 and 17. These were chosen because they are the ones most closely related to Bane NOR's core activities, and are thus areas where specific efforts may have the greatest positive impact. Incorporating the SDGs is a useful compass in Bane NOR's work on sustainability.

Bane NOR also finds goal 5 (gender equality) and 8 (decent work and economic growth) fundamental for achieving the defined SDGs.

In addition, Bane NOR has prioritised ten material topics in order to contribute positively to sustainable development, to the SDGs, and at the same time support the company's long-term value creation.

Guidelines and requirements from the government, the company's specific strategic goals and implementation in projects

The government has high expectations for Bane NORs work with sustainability. White Paper No. 8 (2019-2020) - The state's direct ownership of companies – Sustainable value creation, sets out clear expectations for sustainable value creation in addition to legislations. Among other things, this are works to protect human rights and labor rights, reduction of climate- and environmental footprints, in addition to preventing financial crime, including corruption and money laundering.

As an initiative to meet the governments expectations, Bane NOR developed a road map for the company's work with sustainability" in 2021. With the vision "More on track leaves a smaller footprint", Bane NOR has high ambitions of becoming a role model within sustainable development within 2025.

The strategy is structured around the themes that have been assessed as the most important for strengthening Bane NOR within sustainability and contributing to a more sustainable society.

Bane NOR's most important contribution to greater sustainability – in society in general, and within the transport sector especially – is to strengthen support for rail transport in order to ensure that more people can travel by train. The transport sector is responsible for approximately 1/3 of the total greenhouse gas emissions in Norway, but only 0,3% of this comes from railway transport. Transferring transport to rail will then make the transport sector more sustainable, since rail transport require less energy and occupy less land in relation to capacity than any other means of transport. Transport on rails helps to achieve the defined SDGs.

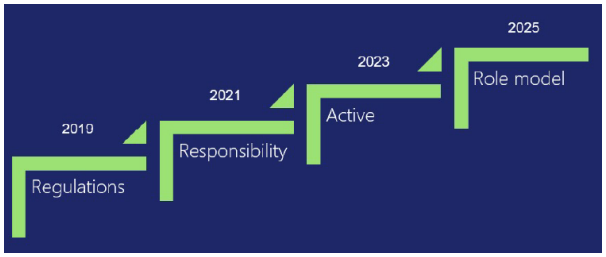


Figure 3.2.5. Bane NOR climbing the steps in order to become a role model within sustainable development.

Bane NOR believes that the most important factors that contribute to this, can be summarized through the following main goals for further work:

- Further developing rail's environmental advantages
- Ensuring punctuality and predictability
- Improving hub development and seamless travel

However, this prioritization does not mean that Bane NOR are not systemically working on the other themes defined as important, such as reducing ongoing and future activities' climate and environmental footprints, developing a sustainable supply chain and ensuring a good, expert working environment. Sustainability and long-term value creation need to balance social, environmental, and economic issues.

In 2003, Jernbaneverket (now Bane NOR) developed a software called Erex, which analyzes the trains' use and production of energy in different situations. The results of these analyzes are used to optimize the operation of the trains in order to reduce their need for energy. A reduction of 25 - 30% have been achieved, so far. Today, Erex have been adapted by the railway-organizations in eight other European countries, but Bane NOR in Norway is in charge of further development, maintenance, and education of the system.

Even so, it is important for Bane NOR to document that the railway's total environmental footprint and environmental advantage will persist both at the entrance to-, and after the green shift. Bane NOR has defined specific goals for how the railway can

become even more climate- and environmental-friendly.

Environmental issues are initially well regulated through laws and regulations. However, going forward, Bane NOR will also focus on three main areas to reduce the activities` creation of climate and environmental footprint:

1. Reduce greenhouse gas emissions, direct and indirect
   - Reduce direct climate emissions (from activities in Norway) by 40% within 2030
   - Reducing the indirect emissions from construction- and engineering activities, as this is identified as a main source to emissions.
2. Safeguard and enhance ecosystems
3. Promote a circular economy

To achieve the goal of becoming a "role model" within sustainability within 2025, Bane NOR will work closely with the suppliers in order to identify areas where reductions of emissions are possible. One tool is to set out functional requirements, including climate requirements related to the use of and production of concrete, steel, and aluminum, in addition to efficient mass handling, as a part of competitions, instead of giving specific requirements.

Today, most of Bane NOR's major infrastructure projects are carried out as turnkey contracts, and the contractor is then responsible for both design and construction. The suppliers are expected to come up with solutions to meet the overall goals and requirements. An example of this is the suppliers plan which describes mitigations to reduce carbon footprint, including direct and indirect CO_2 emission.

It is implemented as a standard for major projects to use climate budgets in order to identify large items and to work with emission reduction measures, in addition to accounts in order to document emission volume "as built". Experience shows considerable potential for reducing carbon footprints, using emission requirements, or reducing material consumption for larger material groups such as concrete, structural steel, and rebar, in addition to lime-cement piles.

Bane NOR is a partner in an ongoing innovation project called "KlimaGrunn", cooperating with the National Road Authority and Statsbygg, in order to reduce CO_2 emissions through soil- and clay stabilization. The project is funded by Innovation Norway, and the purpose of the project is to reduce the estimated overconsumption of limestone and cement by developing a method for documenting the achieved and necessary strength, stiffness, and homogeneity of the piles.

For Bane NOR, the results of the entire life cycle assessments, are important. Suitable mitigations will be implemented, as an ongoing process, within all the phases of the life cycle of the infrastructure, in order to reduce climate- and environmental footprints and achieving the goal of becoming a role model within sustainable development.

3.2.2 The Norwegian Public Roads Administration's work with sustainability

Gina V. Ytteborg

The Norwegian Public Roads Administration (NPRA), supports the UN sustainability goals by carrying out its social mandate in the best possible way. This includes respecting environmental boundaries, ensuring social justice and utilizing society's resources in a cost-effective manner. NPRA has a holistic approach to sustainability with particularly targeted follow-up of greenhouse gas reductions. Sustainability is included in the five top goals, and society has high expectations that NPRA as a public agency contributes to the UN's sustainability goals and shows how activities and delivery can contribute to goal achievement. All divisions are expected to promote sustainability as a strategic focus area and put energy into the work. Several of the divisions have established their own subject directors for climate and sustainability.

The sustainability work is now being structured across the agency. In addition, all new, major construction projects will be CEEQUAL certified. The construction division will also become ISO14001 certified, planned for 2023.

Much of the sustainability work is done through procurement and through training and awareness raising in the industry and of its own employees. Digitalization and analysis of data are important tools for promoting a sustainable road and transport sector. NPRA must also provide sustainable services for its customers. The agency is responsible for promoting sustainability in regulations and standards, which will affect the road sector and the construction industry as a whole.

Procurement

The Norwegian Public Roads Administration uses procurement as a strategic tool to promote sustainable and innovative solutions in, among other things, construction projects, operational contracts, ITS projects and internal operation of the business. The goal is to set requirements and expectations for the

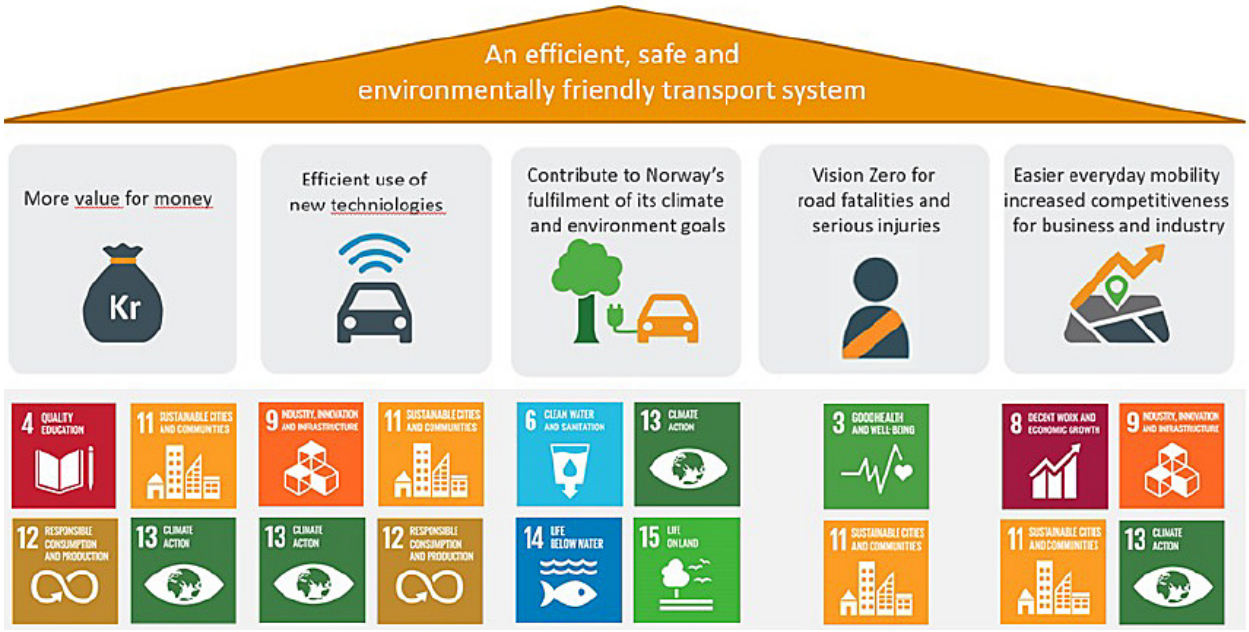


Figure 3.2.6. The relationship between selected sustainability goals and the NPRA top goals.

supplier industry to move the market to deliver sustainable solutions. Through strategic use of procurement and market dialogue, NPRA has drawn up development contracts that have been important for developing the Norwegian supplier industry. In 2021, the world's first hydrogen electric ferry was put into operation in Rogaland on national road 13 between Hjelmeland, Nesvik and Skipavik.

The transport sector plays an important role in reducing greenhouse gas emissions. NPRA has helped to limit greenhouse gas emissions, and reduced other negative environmental consequences through a procurement strategy where innovation and development in industry leads to a result where suppliers and the agency achieve climate goals together. When we as a developer and client challenge and set stricter requirements for the construction industry, we will accelerate the development of good solutions. One of the goals in the Climate Report states that the construction sites in the transport sector should be fossil-free by 2025. NPRA works with contractors and other stakeholders to find out what requirements can be set to produce more sustainable solutions, and how this can best be formulated in the competition documents for new road projects.

Emission path and emission calculations

The Norwegian Public Roads Administration aims to halve greenhouse gas emissions by 2030. The goal includes both direct and indirect emissions from small and large development projects, operation, maintenance, internal operation, and other services. Reductions in greenhouse gas emissions will be achieved through climate-conscious planning and land use, smart logistics and mass handling, low-emission technology, good material choices and less consumption.

An emission path will be established with a projection of the possibility of cuts, and management tools to ensure that we drive cost-effective greenhouse gas reductions. The emissions will be made visible as direct and indirect emissions.

In 2021, NPRA implemented a project that provides recommendations on how climate considerations can be better addressed in the early phase of the planning of new roads (concept choice studies and impact assessments). In collaboration with the other transport agencies and the Norwegian Environment Agency, work is also being done on further development and standardization of current methods for calculating greenhouse gas emissions from land use changes, as well as testing and implementing an indicator of impact on biodiversity from transport infrastructure.

Fossil-free construction sites

As part of the follow-up of the government's action plan for fossil-free construction sites, 5 pilot projects have been chosen with the aim of testing zero-emission technology.

The action plan is an addition to and a clarification of requirements that NPRA has worked on for a long time as part of climate and environmental considerations in the procurement regulations.

Extensive work has been done to map which work machines and vehicles with zero emissions are available on the market. In this connection, a number of meetings have been held with machine suppliers etc. In the dialogue, we clearly signal that we will demand this type of machine in the future. Part of the work is to find out whether machines for mines may be relevant for road construction, especially since these have come further in electrification than conventional machines.

As part of the safe use of the equipment, the safety aspects of using large battery packs in tunnels are also considered.

The lack of several types of large zero-emission machines means that we work with a market dialogue with the contractors and machine suppliers. We signal that we need to outline solutions that will quickly enable us to achieve the goal of a 50% cut in greenhouse gas emissions by 2030, and that we have a willingness to pay to achieve this goal.

In the current year, work has begun on obtaining an overview of power supply on NTP projects a little ahead of time. This is because restrictions on power supply can significantly increase the cost of projects based on cable and battery electrical machines. For this reason, we have also actively participated in the work on standards for emission-free building and construction sites where power supply plays a key role.

The work with zero-emission solutions in general is important to be able to assist the pilot projects with choosing solutions.

One of the projects, E39 Rogfast, aims specifically at piloting full scale emission free tunnel production.

Figure 3.2.7. The Rogfast subsea tunnelling project.

This project will become the world's longest and deepest tunnel below the sea. Tunnel production in general is very energy-intensive. Findings from life cycle analyzes made in VegLCA for E39 Rogfast in particular and what SINTEF has found, for tunnel production in general, show that greenhouse gas emissions from fuel (direct greenhouse gas emissions) from tunnel production are between 20-35% of the total greenhouse gas emissions. It is conceivable higher where the masses must be transported far to mass storage and landfill.

E39 Rogfast is a particularly good project for piloting a fossil-free construction site for several reasons in addition to being a tunnel project. Sustainability has been important from day one and E39 Rogfast was also previously a low emission pilot. Furthermore, E39 Rogfast is also of such a size that it can help reduce costs and risk when adapting zero-emission machines.

Through its history and requirements in the contract, E39 Rogfast has shown its willingness and ability to drive development and knowledge sharing within sustainable tunnel design and has taken great strides on the road to cutting greenhouse gas emissions from the tunnel operation itself.

Through the pilot, the project wants to test equipment at different maturity levels:

1. Innovation / first experience with extensive use of electrical work during the day / cable electrical work on stuff in connection with tunnel development

Tunnel production in itself is suitable work to perform using zero-emission technology due to already available electric power on stuff. It is therefore now being tested to set as a requirement in the contract that all static operations must be performed electrically in the day zone and cable electric (supplied by public power cable) in the tunnel.

This is the first time we are testing this production equipment.

2. R&D and risk assessment of large battery / battery electric vehicles and equipment in underground tunnels

Tunnels can be well suited for the use of battery-powered equipment and vehicles. But the dangers of fire in tunnels, extinguishing possibilities and safety for workers must be carefully considered. The project has identified this as a major challenge to further pave the way for and accelerate emission-free tunnel production. To achieve emission-free production of tunnels in general, it must be possible to set requirements for zero-emission machines in contracts.

As part of this work, E39 Rogfast sees it as necessary to assess the probability and consequence of incidents with battery technical equipment / machines separately in order to create the best possible knowledge base to be able to set such requirements. It will require significant investment to complete this part of the pilot as well. It is extremely important with good planning and risk assessment before an emission-free machine for mass transport is tested at the plant.

Mass handling

There is a desire to achieve better mass handling in the projects and in collaboration between projects. Handling of masses is area-intensive. Several projects are actively working on mass management plans and reuse of project-internal masses where they can be based on quality. It will replace the extraction of new masses and new terrain interventions in this connection. It will also help reduce the need for land use for permanent storage of surplus masses. To optimize this, it may require larger rig and construction areas in the projects to reduce the transport of masses. It is important where such extended areas are located in the zoning plan. Several projects receive good input from the contractors in this work. This is a main theme in the cross-sectoral project under the auspices of the Norwegian Environment Agency, in which several large state developers and agencies participate, including NPRA. The project submitted its first report in 2021 and will be able to proceed with more concrete measures and instruments in 2022 if ordering ministries request continuation.

3.2.3 Nye Veier

Marianne Simonsen Bjørkenes and Maarten Lohne van der Eynden

In 2021, Nye Veier adopted a business strategy and subsequently a climate strategy and an environmental strategy as well. The business strategy highlights climate and environment as one of four strategic areas for Nye Veier.

The climate strategy sets new climate goals for the company and specifies what needs to be done to achieve them. Nye Veier aims to reduce greenhouse gas emissions from construction by 50 percent and from operations by 75 percent by 2030, compared with the base year of 2005. Nye Veier includes climate requirements in its contracts and uses climate budgets and greenhouse gas accounts in its planning, construction and operations. In future, the company also aims to become a more diligent challenger and agent of change in the area of climate issues. An important part of this will be work on pilot projects for an emission-free future in the construction industry.

The environmental strategy has three environmental goals: We will reduce the negative impact on valuable land and biodiversity in our projects. We will increase reuse and circularity in our overall project portfolio. We will ensure that we reduce pollution and meet requirements. These objectives are to be achieved by reducing negative impacts, ensuring compliance and being a driving force for positive development in the industry. Several areas have been identified, including improved structure and increased quantification of environmental reporting, collaboration and R&D as well as further work with CEEQUAL.

Nye Veier takes clear responsibility for contributing to sustainable value creation. The company uses the GRI standard for sustainability reporting (Global Reporting Initiative). Areas related to the UN's Sustainable Development Goals have been selected. In the years ahead, the company will be producing reports on indicators, which show how Nye Veier affect the goals. Nye Veier particularly affects sustainable development goals for innovation and infrastructure, decent work and economic growth and halting climate change.

Holistic and life cycle perspectives are important for effective protection of the environment. All phases of the corporate governance model are applicable and important – from initial phase to operation. Tasks and room for manoeuvre differ in each phase, but a clear and important connection exists between the phases, between what has to be safeguarded, what has to be planned and the final result. The hierarchy of measures is an important starting point.

Nye Veier has several ongoing projects in the areas of sustainability, climate and the environment. These are both pilot projects and development projects. Some examples can be found below.

In 2018, Nye Veier decided that all new projects should be certified according to CEEQUAL and in 2020 that new projects should be certified as a 'whole project' and achieve the level of 'very good'. In the spring of 2022, certification is underway in various phases for approx. 17 of Nye Veier's projects.

Nye Veier has developed a set of indicators for its environmental impact. This set of indicators is now being tested. The purpose has been to quantify the environmental impact of various routes or sections at an overall level, using available baselines such as 3D centre lines, terrain models and public map layers. The indicators include area requirements, value requirements, barrier effects, audio-visual fields, road reuse and terrain change.

Nye Veier projects are prioritised according to socio-economic profitability which also includes non-priced factors. Today's methodology cannot, however, make visible and quantify non-priced environmental factors, but Nye Veier is working on developing a method for this.

Nye Veier reports environmental incidents in the projects – focusing on the construction phase. Incidents are classified in three categories; M1, M2 and M3, where M1 is environmental damage, M2 undesirable environmental incidents with minor or short-term consequences and M3 is minor environmental incidents and/or observations. Incidents may include multiple factors within the external environment, such as nature, pollution, noise, and both actual incidents and deviations from requirements.

Area accounts, nature accounts and quantification of non-priced environmental factors in socio-economic analysis are all topics that Nye Veier has worked on over the past year. The area accounts can be set up on several detailed levels, where the simplest level is permanent area requirements, and required area is distributed by category in NIBIO's AR5 map layer. The accounts are linked to fixed milestones such as the approved municipal partial plan, the approved zoning plan and the completed project.

Reuse of existing roads is increasingly relevant and is something that Nye Veier has been working on both at the general level and in several of the Nye Veier sections in the planning phase over the past year. Reuse can apply to both route and materials and can provide benefits in terms of e.g. costs, greenhouse gas emissions, land use, circular economy and pollution. Work is also underway to look at possible adjustments to road standards and manual requirements to ensure enhanced reuse.

3.3 Resilience

Author: Hrefna Run Vignisdottir, Phd., SINTEF AS

3.3.1 Impact of climate change on the Norwegian transport network

Climate changes are, and are going to, have considerable impact on the Norwegian transport network. The impact of climate changes on the transport network is mainly due to increased precipitation, increased freeze-thaw cycles, and extreme weather incidents. Figure 3.3.1 shows the main impact from climate change and relations between these. General increase in precipitation will increase the need for surface water management but it will also affect the need for water and frost protection (eg. Tunnels need more Drainage and pumping).

To face the challenges from climate change, society needs to plan for both extreme incidents that are unlikely but have large risks if it does happen, but we also need to prepare for the small gradual climate change that have lower impact individually but are very likely. This especially applies to increasing rain in Norway. Increase in precipitation affects the need for drainage and surface water management. The effects of increase in precipitation increase the risk of flood, landslides, and erosion.

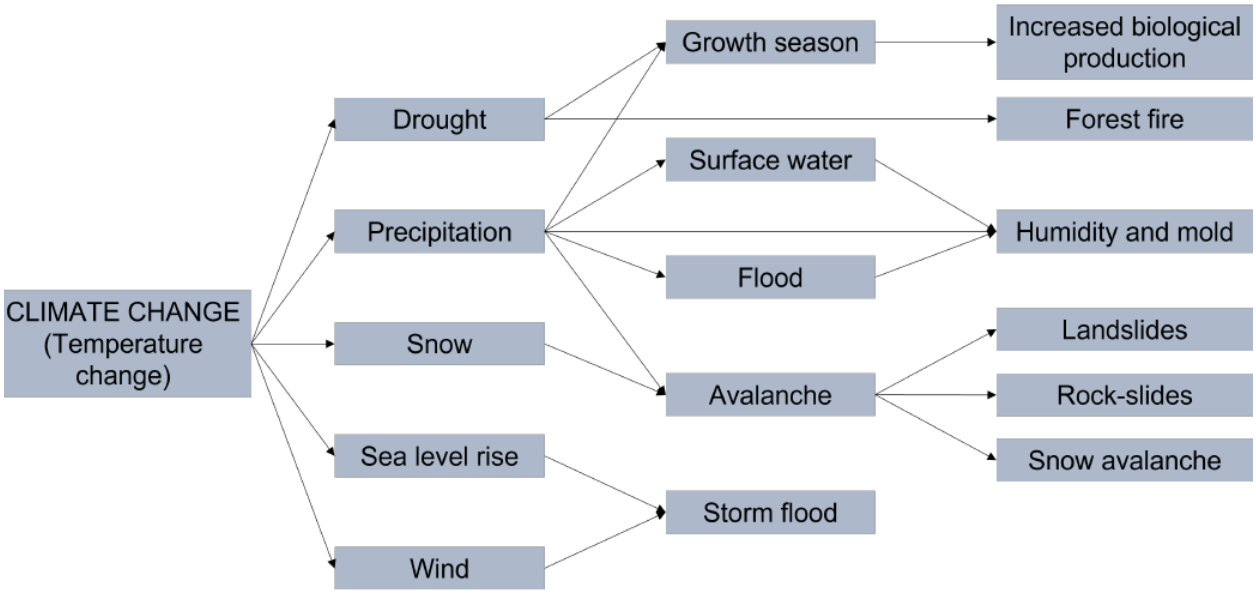


Figure 3.3.1. Climate change and relations to impact (Depina and Øien, 2021).

Tunnels

Tunnels are not safe from the consequences of climate change. Near the coast both flood and rising sea level pose risk to roads and construction, including landfilling and protective structures such as at the harbour and around coastal roads and subsea tunnels. The sea level rise in combination with increased frequency of storms are especially a threat for subsea tunnelling. Yet another challenge for coastal roads and tunnels located near the coast is the frequency of extreme weather where wave erosion together with saltwater intrusion can affect nearby soil structure and the infrastructure itself. Therefore, costal roads and sub-sea tunnel openings need to be evaluated carefully in future projects to make them more resilient against climate change and todays constructions can be assumed to need adaptation to face these challenges.

To correctly and efficiently design infrastructure to handle the water there is a need for projecting how today's situation might develop in Norway with regards to local flood size and frequency, the frequency of intense rain and location of smaller streams. This however is labour and data intensive work. Furthermore, higher sea level and increased rainfall might change the groundwater level and thereby reduce the strength of the soil beneath the road. As an adaption measure, reservoir pavements have been successfully developed which control the rate of run-off into the surrounding drainage systems.

Today the tunnel openings are designed for water level 150–300-year return-period but if we use scenario RCP 4.5 these tunnel openings will only handle 100–150-year return-period. As the design is recommended to hold for at least 200-year return-period these tunnels are at risk.

Adaptation for subsea tunnels is difficult so these should be monitored during high tide, wind, and air pressure to see how this can affect the tunnels. Otherwise, a protective construction, for example to break waves outside of the tunnel opening, increased erosion measures could be viable solutions. It is unlikely that overflooding the sub-sea tunnels will happen in the next 10-20 years. New construction should however account for rising sea level to account for climate change.

Bridges

Bridge operation and maintenance in a changed climate heavily involves changes in precipitation in the area. Erosion, because of increased water levels, is the main risk posing towards the safety and reliability of bridges. Erosion problems are often linked to materials like sand and silt but can happen in riverbed with other materials. The velocity of water increases erosion and there is a need for better knowledge about erosion near transport constructions. This requires better quality in estimation on water flow, and the condition of riverbeds, also upstream from infrastructure. Erosion is however not the only risk to bridges. With heavy rainfall or precipitation in general there is an increased risk of floods that can cause trees or other debris to crash into the bridge but more importantly also ice and snow avalanches in the waterway.

Other factors such as thermal gradients can create uneven internal stresses in the bridge deck, giving rise to curling or warping in concrete pavements, damage to bridge expansion joints and to steel bridge decks if the asphalt has been removed for maintenance.

Finally, de-icing materials effect bridges and tunnel opening in a significant way by destabilizing the soil around, damaging vegetation and causing erosion of the materials in the structure itself. There is therefore a good reason to focus on robust bridge design but also on the surrounding area with regards to potential flood paths, landslides, or formation of ice dams upstream from the infrastructure.

Roads

The road and railway track itself are also affected by climate change. For the existing infrastructure condition monitoring and preventive maintenance is very important to be able to adapt the system before a weather event occurs. The main impact from a changing climate on the road is through increased precipitation and thereby a need for an effective drainage system. In this regard, local extreme rain projections and the general increase in precipitation should be monitored by the road owner.

Asphalt is the part of the road that is the most dependant on temperature where the material stiffness depends on it. The increased fluctuation in temperature and a larger range of temperature challenges the asphalt industry to provide a more flexible asphalt to withstand the changes in climate. The base and subbase are to a larger degree affected by water content and frost. However, modelling the development of rutting under the influence of a wetter and milder climate shows that a positive effect from less frost is stronger than the negative effect of more moisture. Less frost is not only positive though as in some regions the slightly warmer climate can result the frost to linger at a sensitive level in the construction. For national and county roads, the anticipated effect of climate change will give a reduction of rutting of approximately 0,2 mm/ year, or a corresponding 13 - 16 % longer service life. This saves annually about 150-200 mill NOK of maintenance costs.

3.3.2 Adaptation

Many factors affect the risk to infrastructure and the need for adaptation of the infrastructure. Generally, during planning road and rail infrastructure it is important to choose good solutions that are resilient against increased precipitation, fluctuation in temperature and the occurrence of extreme weather events.

Surface water management

Decisions during early planning regarding the best place to cross waterways and ensure good drainage and measures to reduce erosion are important. In a changing climate in Norway, drainage and surface water management is of utmost importance. Safe and stable stream crossings can additionally accommodate wildlife and protect stream health, while reducing expensive erosion and structural damage to infrastructure.

First step for effective drainage is to protect natural drainage systems and paths. The new road construction, after carefully choosing the route, must have correctly dimensioned culverts for the climate now and into the future. The Norwegian Public Road Authorities (NPRA) have tested several individual drainage areas to see if they are able to handle current and future surface water in their area. The results of the case studies showed high variation between how areas have been designed to handle surface water. According to the tests, 70% of the drainage areas could not handle half of the water amount that is recommended in the guidelines. This strengthens the need to adapt the drainage systems to an overall increase in precipitation and individual days with heavy rainfall. This problem becomes even more prominent in an increasingly urbanized society. Areas without natural drainage is increasing challenge and Norwegian cities and urban road owners will especially need to increase the capacity of the drainage system.

Floods and landslides

One of the consequences of climate change on the road and rail network is the increasing risk of landslides. The frequency of closed roads and accidents because of landslides can be assumed to increase if no adaptation measures are put into place. Landslides here also includes rockslides, mudslide or any material that can slide or fall into the road and pose a risk to people or infrastructure.

Today the risk factors affecting the likelihood of landslides include precipitation, snow melting, temperature change, earthquakes and crack widening from tree roots. In a changing climate the risk increases with extreme rainfall, changes in soil moisture and snow melting frequency. That is, having snow accumulate and then melt in heavy rain in areas where snow cap used to be more stable and only melted once a year. These changes to the climate can increase risk of landslides in previously low-risk areas.

The budget for preventive actions, monitoring and ensuring road safety from rockslides is likely to

increase. A recent rockfall into a double laned road in the south of Norway, a group of experts recommended that all rock-slopes in Norway should be re-evaluated to see if they fulfil the standards for protection measures. It is difficult to estimate how rockslides could developed is a changing climate. Rocks and cliffs at risk need long time to adjust before active movement subsides. The increased fluctuation around 0°C in many areas in Norway will only aggravate the situation. Experts have predicted that rockslides are likely to increase by 5-10% towards 2050.

National register for vulnerability and impact can improve quality of adaptation measures. Analytical model for landslide risk, independent of landslide history in the area, is under development. Today's model needs to include early warning system that include currently unknown areas that, with increased precipitation for example, are more likely to be at risk. Prioritization plan for new land slide protection and protection adaptation to meet challenges due to changing climate should be included in cost-benefit analysis of the road/rail section.

The future risk of snow avalanches is likely to increase up in the mountains and in northern Norway, especially towards 2050. After that, as the temperature increases even more the risk should go down again. The main adaption is similar to land- and mudslides where mapping of at-risk areas is useful and careful selection of route for new roads is important.

Erosion

Many factors affect the risk of erosion for example water velocity and the state of vegetation. Reduction in vegetation due to higher temperatures and drought during summer, and/or higher wind speeds could increase erosion processes on embankments and near tunnel entrance, leading damage to the infrastructure. Guidelines for erosion protection is regularly updated. The guide recently increased the safety factor for floods for erosion safety. It was adjusted up to 200-year floods. Erosion is not only an issue, but it can also pose a risk in through smaller erosions that cause blockage in water paths and the drainage system.

One of the most important measures to reduce the risk of erosion is to reduce the water velocity. This can be achieved by for example widening the water paths or creating step-dams. Step-dams can also be aesthetically pleasing and good for wildlife. Sprayed concrete has earlier been used to reduce the risk of erosion, but the effects are uncertain. It can reduce erosion through binding together stones and materials and by that avoid single stones to be eroded from the embankment. But it can also increase pressure differences when water gets behind the concrete and cause instability of embankments.

Construction projects

The effects of climate change should be considered as an integrated part of the planning and development of road and rail projects. However, for infrastructure in Norway with expected service life less than 30 years it is recommended to use updated observations rather than climate projections for decision support. For new construction projects, water management is of high importance and evaluation early in the design process should be a basis for all planning. Surface water plans should also be scaled for increased precipitation in the future. Flood analysis and mapping of vulnerable areas gives a good basis for route selection. Material selection also need to consider a warmer climate and the increasing fluctuation in some areas around 0°C. Structural design parameters should continually be updated for and improved to account for the effects of climate change.

During design phase and material selection the friction layer has a lifetime that suggest that the best option is to use current climate information (temperature and precipitation while the base and subbase have somewhat longer lifetime and should therefore account for climate change projections to a larger extent.

Adaptation measures for infrastructure includes

1. Stone blocks, against wave, floods, and winds
2. Wider water passage and or step-dams, to fight erosion
3. Risk analysis should to a greater extent include bridge- and geotechnical aspects in the surrounding area
4. Change anti-and de-icing strategies near critical infrastructure

Effects on operation and maintenance

Planned maintenance and operation tasks are obligated to be planned according to updated road/rail norms and include climate change factors. This means that if a road needs acute reparations, e.g., after a weather event, climate factors are not necessarily accounted for, and it leaves the infrastructure in just as vulnerable towards the climate change impacts as before.

The effects of climate change are likely increasing the consequences of road maintenance backlog that exists Norway and will generally require higher

priority and funds for maintenance activities and monitoring of drainage systems such as ditches, culverts, pipes, and pumps. Therefore, closing the maintenance gap is essential. Critical points in the road network need to be mapped and priority given to stretches that are at higher risk from climate change impacts.

Maintenance contracts should therefore be structured in a way that makes it clear that preventive actions before a known weather event is more beneficial than reacting after the fact. But it should also be noted that repairing or renovating exiting constructions should consider the remaining service life of the infrastructure. This implies that if the service life of the road is estimated to be only 10 – 20 years it should be enough to account for current trends in weather rather than projected climate change.

3.3.3 Conclusion

To summarize, the main consequences of climate change on the Norwegian transport network are from flood, erosion, landslides, rock fall, avalanches, droughts, and higher temperatures. These will lead to deterioration of transport infrastructure such as tunnels, increased operation and maintenance activities and need for risk assessment tools and general management.

Continuous monitoring of landslides, weather and infrastructure conditions is important. The data gathering should preferably be automatic and open for infrastructure owners so they can learn from each other. Continuous monitoring would contribute to a more effective maintenance planning through a better prioritizing of measures. A more effective and correctly timed maintenance should decrease the constructions vulnerability and the use of resources. This would limit further effect on the climate.

During early planning of new infrastructure projects and, renewal of older infrastructure, a careful evaluation of route is vital. The route affects not only the use of resources during construction but during the whole life-cycle of the infrastructure. This is both because of planned and acute maintenance, and winter maintenance. General maintenance includes structural maintenance and maintenance for effective drainage and safety for the infrastructure users (visibility).

References:

Klimaloven. (2017) Lov om klimamål (LOV-2017-06-16-60). Retrieved from https://lovdata.no/dokument/NL/lov/2017-06-16-60

Miljøverndepartement. (2013). Klimatilpasning I Norge (Meld. St.nr. 33(2012-2013)). Available at: http://www.regjeringen.no/nb/dep/md/dok/regpubl/stmeld/2012-2013/meld-st-33-20122013.html?id=725930

Hoegh-Guldberg et. al., 2018. Impacts of 1.5°C Global Warming on Natural and Human Systems. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. In Press.

IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

I. Hanssen-Bauer et al., 2017

All reports available at: https://klimaservicesenter.no

Miljødirektoratet, Veileder: Klimatilpasning i infrastruktur og samferdselsektoren

Ivan Depina and Knut Øien, 2021. Raport 27: Klima-Resilient Infrastruktur.

Last updated: 20.02.2020. Avvailable at https://www.miljodirektoratet.no/myndigheter/klimaarbeid/klimatilpasning/klimatilpasning-i-sektorer/infrastruktur-og-samferdsel/

Nation Public Road Authorities reports (with links)

1. Klima og transport
2. Erosjonsskader ved Middøla bru
3. RV362 Bitu bru – Pilotprosjekt erosjonssikring
4. Erosjonssikring av bruer i Telemark
5. Veger utsatte for stigende havnivå og stormflow
6. Skred og flom på veg
7. Beredskapsplan for driftskontraktene
8. Sikring av veger mot steinskred
9. Tilstandsutvikling på vegnettet

3.4 Tunnels from a landscape perspective

Marius Fiskevold, Sweco

3.4.1 Introduction

In a mountainous country like Norway, tunnels are one of the most important tools for preserving existing and creating new landscapes. This applies to such different sectors and infrastructure as hydropower, water supply, railways and road construction. With the tunnel, valuable parts of the earth's surface can be kept free of infrastructure. On the one hand, this contributes to a significant reduction in irreversible interventions. On the other hand, the preserved surface of the earth contributes to the continuation of ecological contexts, cultural heritage, recreational areas and visual character.

This article takes a closer look at the various benefits that the use of tunnels offers from a landscape perspective. We will define what landscape is and the expectations a country like Norway has committed itself to by approving the Council of Europe's Landscape Convention. We will then look at the connection between the use of tunnels, tunnel length and different landscape qualities on a current road project in the Norwegian national road network. In this context the tunnel is not limited to being a technical element, but functions primarily as a tool for managing existing landscapes in a sustainable way.

3.4.2 Council of Europe Landscape Convention

As early as 2001, Norway ratified the Council of Europe Landscape Convention (European Landscape Convention).

The Council of Europe Landscape Convention is the result of a political initiative that points out that the link between technological development, financial power and supranational decision-making arenas has led to increasing pressure on nature and nature-based life forms:

Landscape must become a mainstream political concern, since it plays an important role in the well-being of Europeans who are no longer prepared to tolerate the alteration of their surroundings by technological and economic developments in which they had no say. Landscape is the concern of all and lends itself to democratic treatment, particularly at local and regional level.[i]

The Landscape Convention recognises and emphasises the close connection between nature and each person's ability to identify with life processes and the characteristics of nature in a given area. Landscapes are therefore not exclusively linked to a specific space, a specific time, a specific culture, a specific nation, a specific minority or another category that for one reason or another seems more exclusive than inclusive. Landscapes arise in all places where mankind gives nature value as part of a certain way of life and identity.

The Landscape Convention itself refers to a number of conventions, including conservation of endangered species and cultural heritage. The concept of landscape in this way provides a platform where both individual qualities, such as ecology and cultural heritage, but also the connection between them, are emphasised in a decisive way.

We will look at the ways in which this multifaceted view of nature was handled in several phases of the E39 Mandal – Lyngdal east road project. We will also look at the way in which a technical solution, such as a tunnel, was used to safeguard valuable landscapes in this area.

3.4.3 The E39 Mandal – Lyngdal East project

The E39 Mandal – Lyngdal east road project runs approx. 25 kilometres from Mandalselva in Lindesnes Municipality to Herdal in Lyngdal Municipality [Fig. 01]. This section is part of the main E39 connection between Kristiansand and Stavanger. Planning and construction are undertaken by the state-owned road company Nye Veier.

The project has been through two planning phases since 2018. Both in the initial area zoning plan and in the final detailed zoning plan, the use of tunnels has been an important tool for safeguarding landscapes sustainably. The arguments for the choice of tunnel can be found both in the area zoning plan's impact assessment and in the subsequent optimisation of the chosen alternative. Optimisation was an important part of the detailed zoning plan.

3.4.4 Impact assessment (area zoning plan)

Impact assessment, socio-economic analysis and landscape quality

All Norwegian road projects of a certain size have to include an impact assessment. The impact assessment must set out the advantages and disadvantages of a project for society and the environment.

On government road projects, the socio-economic analysis forms the core of the impact assessment. In Norway, this socio-economic analysis is divided into two parts. On the one hand, it sets out impact in terms of monetary value. On the other hand, it contains effects that are graded along a value scale. These effects are divided into different subject areas. The value scale shows whether a project has a

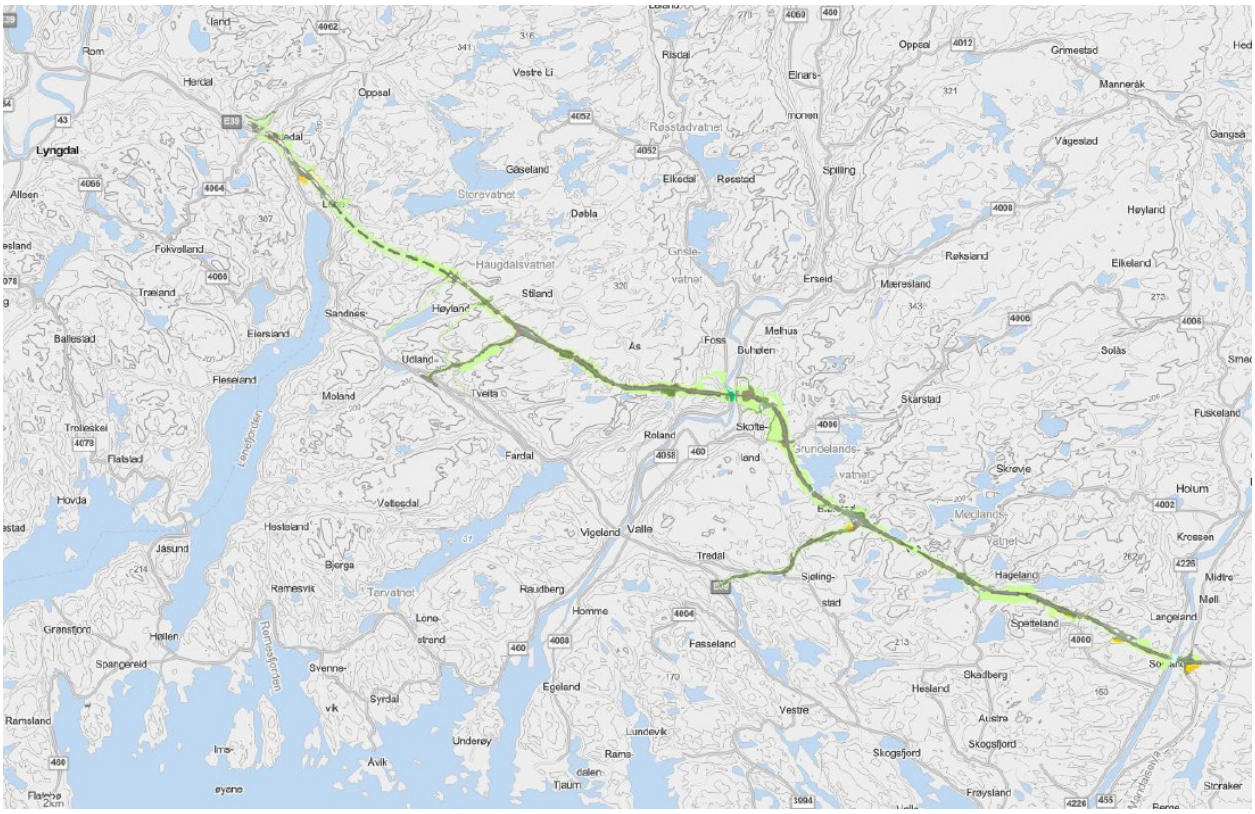


Figure 3.4.1. – Project area. The figure shows the E39 Mandal-Lyngdal East road project.

positive or negative impact on each separate area.

The societal values that are not addressed can also be called landscape qualities. The Norwegian Public Roads Administration's Handbook V712 (p.112) shows how the various subject areas each contribute to the landscape as a whole[ii]. This connection is again set out in the Landscape Convention (see Table 1).

The Norwegian Public Roads Administration's Handbook shows in great detail how each individual subject area should be examined. However, it becomes vaguer when each individual area has to be put together into a whole. It is in this context that the concept of landscape invites the various technical voices into a joint conversation.

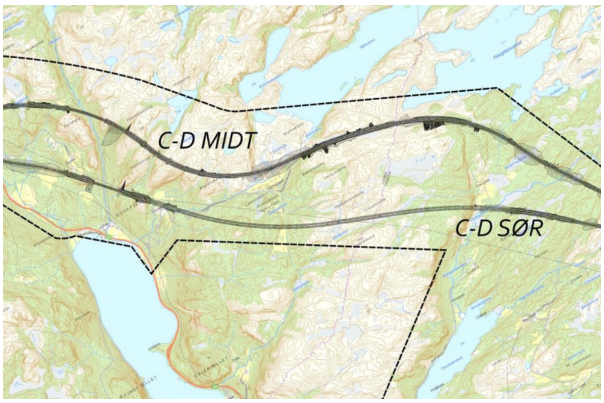


Figure 3.4.2. – Alternatives. The figures show the tunnel alternative (C-D Sr) and the road on the surface alternative (C-D Mid).

The landscape qualities of tunnel and external alternatives assessed

On the E39 Mandal – Lyngdal East project, many different alternatives were studied on different parts of the section. One of these sections was located between the municipalities of Lindesnes and Lyngdal [Fig. 02]. There were two alternatives. In the northern alternative, the road was taken through pristine nature and partly through very steep terrain. In the southern alternative, the road was taken through an approximately three-kilometre-long tunnel. The assessments show marked differences between the road on the surface and the tunnel alternatives.

The extensive landscape interventions, especially the intersection south of Haugdalsvatnet and the large intersections and embankments between Grummedal and Optedal, would have meant major barriers for wildlife, hiking trails and roads [Fig. 03]. Also, in the hillside north of Lenefjorden, the road on the surface alternative included deep cuts. This

Theme	Landscape quality/reference to convention
Visual character	'The spatial and visual landscape'
Recreation, urban and rural life	'The landscape as people perceive and use it'
Nature diversity	**'The ecological landscape'** • Convention on the Conservation of European Wildlife and Natural Habitats (Berne, 19 September 1979) • Convention on Biological Diversity (Rio, 5 June 1992), Convention Concerning the Protection of the World Cultural and Natural Heritage (Paris, 16 November 1972)
Cultural heritage	**'The culture-historical landscape'** • Convention for the Protection of the Architectural Heritage of Europe (Granada, 3 October 1985) • European Convention for the Protection of the Archaeological Heritage (Revised) (Valletta, 16 January 1992)
Natural resources	'The production landscape'
• European Charter of Local Self-Government (Strasbourg, 15 October 1985) • The Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (Aarhus, 25 June 1998), • European Outline Convention on Transfrontier Cooperation between Territorial Communities or Authorities (Madrid, 21 May 1980)	

Table 3.4.1. The table demonstrates the way in which the concept of landscape can be understood as a collection of different qualities. Each of these qualities is enshrined in a number of international conventions. The concept of landscape rests in its entirety on conventions related to democracy and participation. The table is an extended version of the layout shown in V712.

meant that the extensive landscape interventions for the road would be very exposed [Fig. 04]. The project consistently went across the area's many ridges and cut these off. The road left unsightly interventions and fundamentally violated the character of the landscape. The surface alternative meant that a large transport facility and noise source would be introduced in the large and largely untouched landscape defined by the heaths around Storevatnet and Haugdalsvatnet lakes. The area was also defined as a regionally important recreation area and was close to a government-guaranteed recreation area.

The long tunnel, on the other hand, would maintain existing routes for wildlife migration, large outdoor areas and provide a significantly less exposed corridor in the hillside north-east of Lenefjorden. The tunnel also maintained the conservation area and landscape in the mainly untouched landscape formed by the heaths around Storevatnet and Haugdalsvatnet lakes [Fig. 05]. As an additional benefit, it would provide an improved situation in relation to the current main road along Lenefjorden.

Figure 3.4.3. – Grummedal 2018.06.29-120.01. The figure shows the steep terrain at Grummedal. The road on the surface alternative is taken through the cliff on the far right of the picture.

Landscape qualities are affected by many disciplines

We see here how an element, such as a tunnel, ensures interdisciplinary landscape qualities in the given development area. Although different subject areas represent different aspects of a common and

Figure 3.4.4. – Lenefjorden 2018.06.29-035.014. The figure shows Lenefjorden, Lene farm and the hillside beyond. The road on the surface alternative was planned to go over the top of the hillside, while the tunnel alternative was planned to go through the middle of the hillside.

Figure 3.4.5. – Haugdalsvannet 2018.06.29-160.01. The figure shows the pristine landscape by Haugdalsvannet lake. The use of tunnels maintained the character of the landscape.

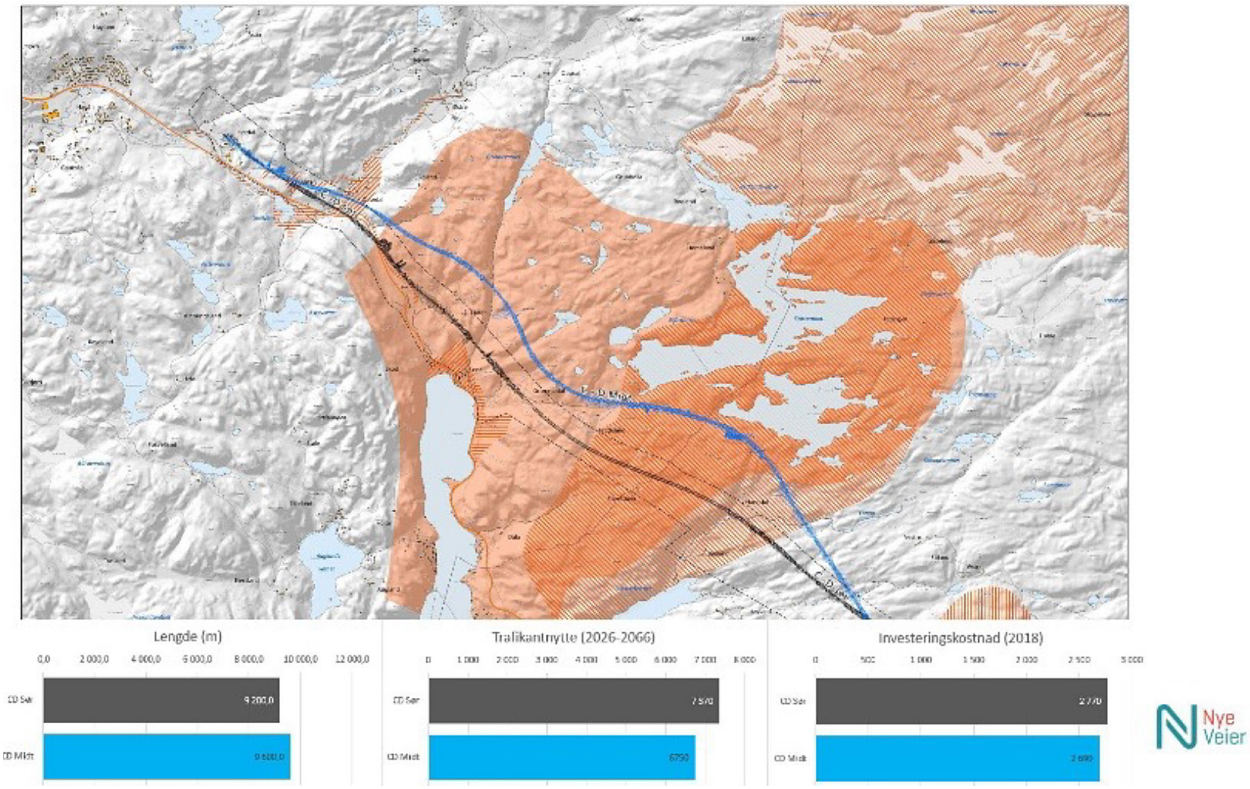


Figure 3.4.6. – Compilation of values. The figure shows a comparison of landscape qualities, road length and investment costs. Orange denotes landscape qualities with great or very great value. Where several hatched areas overlap, the values are great for multiple subject areas.

shared landscape, the comparison also shows how the different areas strengthen and complement each other.

If we look a little beyond the academic dividing lines, we will also find arguments that support the link between tunnels and landscape qualities among technical subjects and disciplines that are not usually associated with the landscape. For example, if we look at the priced consequences, short, straight road corridors without extensive relocation of materials generally ensures low investment costs and excellent net benefits. With extensive landscape intervention (high embankments and intersections),

however, tunnels are both able to reduce investment costs and increase road user benefits. Travel length and time will be shorter. And especially emissions related to fuel consumption are significantly reduced [Fig. 06].

Another aspect is winter maintenance. The external alternative was planned to run through a poorly vegetated plateau. Large lakes north of this alternative could in winter mean harsh weather conditions. Snowdrifts and large amounts of snow could be avoided by choosing the tunnel alternative.

3.4.5 Optimisation of road within the selected corridor (detailed zoning plan)

Extended tunnel under Grummedal

The multidisciplinary link between the use of tunnels and landscape quality was developed further in the subsequent detailed zoning plan. The road corridor had been chosen, in this case the tunnel alternative, but it had not yet been sufficiently detailed.

As the impact assessment revealed, it was not the tunnel itself, but the tunnel seen in the context of the area in which the road was located that determined whether it made sense to propose such a project or not. Many cost elements are, of course, associated with the construction, operation and maintenance of tunnels. But external roads are not cost-free either. Especially when they run through areas such as the ones proposed here. The costs of the external road will often exceed the costs associated with the tunnel. Tunnels also often provide more predictable construction. These factors, combined with an assessment of the landscape qualities in the area, were decisive for the tunnel alternative in the next planning phase not only being retained, but also extended approx. 500 metres. The extension of the tunnel helped to preserve an entire farm. This contributed to fewer negative effects for various important habitats and significant landscape encroachment on the hillside north of the farm. Large visual effects, extensive safety measures and major construction challenges were also avoided [Fig. 07].

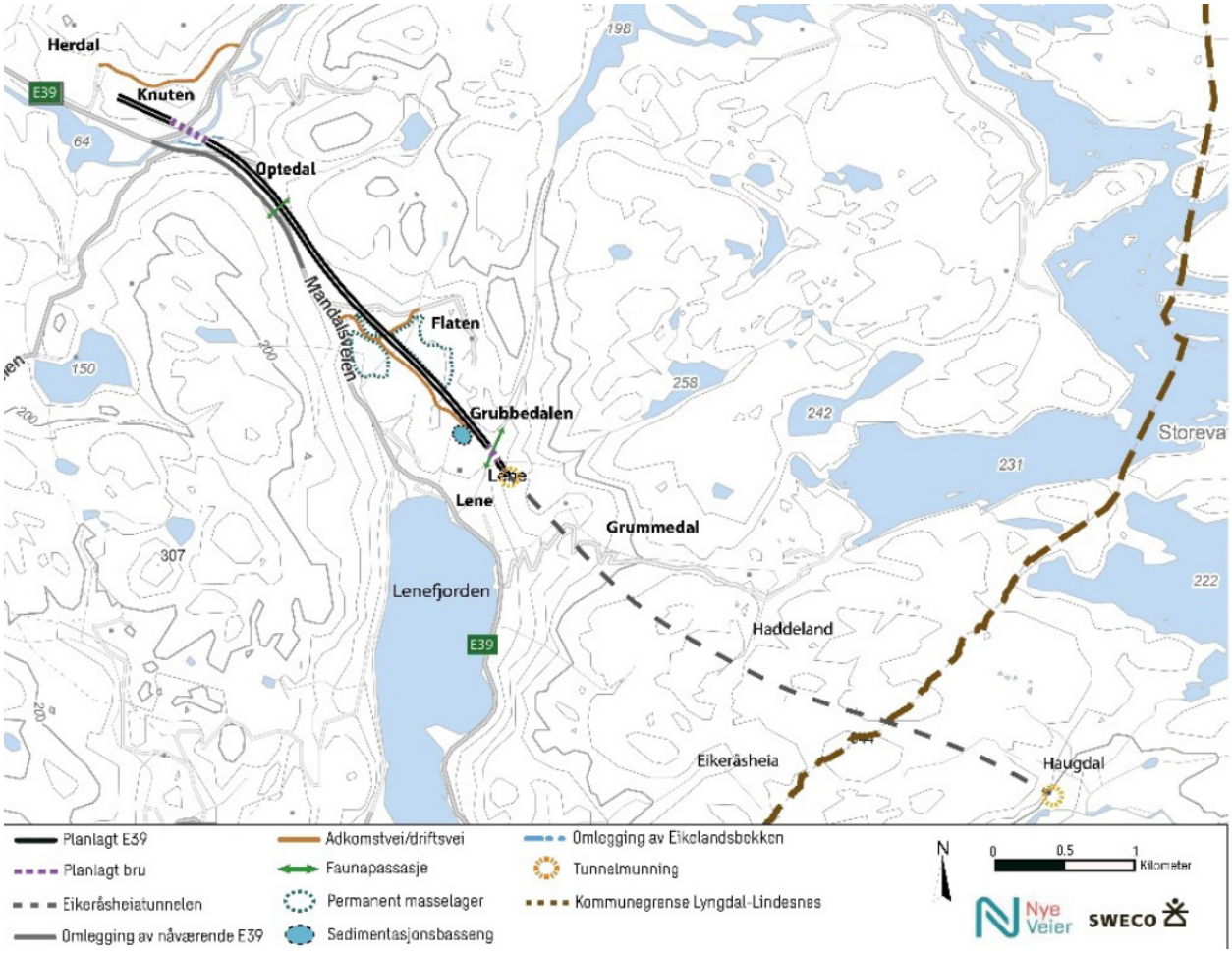


Figure 3.4.7. – Project and extended tunnel. The figure shows the project in Lyngdal Municipality. Between the Grummedal and Lene farms, the tunnel was extended approx. 500 metres in the detailed zoning plan.

Surplus materials from the tunnel create a new landscape

Tunnels basically provide large surpluses of rock material. Although the tunnel itself may appear to be a positive element, the landfills generated by the rock can lead to major negative effects on the landscape. On the E39 Mandal-Lyngdal East project, great emphasis was placed on regarding the stone blasted from the construction of the tunnel as a resource. This was also in line with national interests. The *Kortreist Stein* project (described in chapter 3.8.3), a sub-project in connection with the area zoning plan, systematised much of the knowledge about the local stone as a building material[iii].

In both the area and detailed zoning plans, a great deal of work was put into achieving a balance of materials on the project. The surplus materials from the tunnel and the surplus materials from the many rock cuttings were placed along the road corridor. In this way, large landfills east of the tunnel were avoided [Fig. 08]. To the west, surplus materials were used for landscape formation [Fig. 09]. The landscape formation was based on the area's landscape and recreated the existing character of the landscape in a new shape. For example, a gap between the planned road and existing terrain was filled in. At the bottom of the road, the gradient of the road was reduced to 1:8. In addition to recreating the gradient with a new surface, the areas could then potentially be used as new cultivation areas [Fig. 10]. The road runs through a number of plots of land with surface soil. But by collecting and reconstructing these on top of the blast stone landfills, it will be possible to use the areas for new agricultural production once the project has been completed.

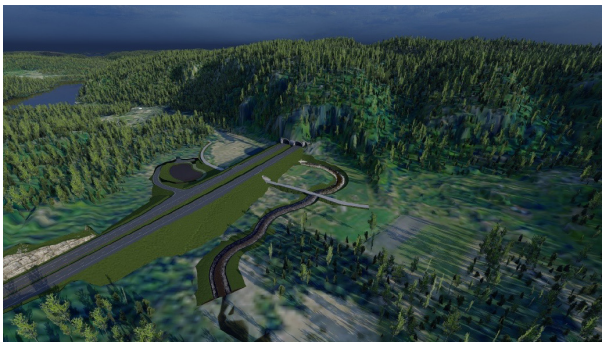


Figure 3.4.8. – Tunnel portal (Haugdal). The figure shows the planned landscape around the tunnel portal to the east (Haugdal).

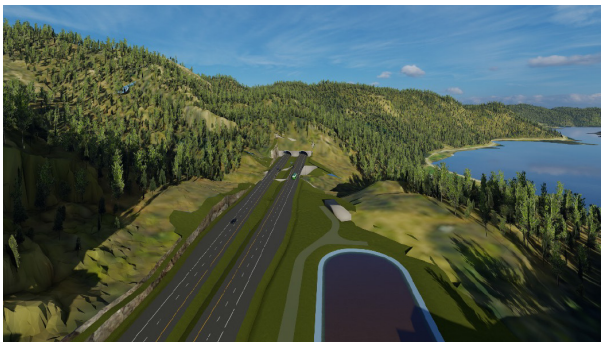


Figure 3.4.9. – Tunnel portal West (Lene). The figure shows the planned landscape around the tunnel portal to the west (Lene).

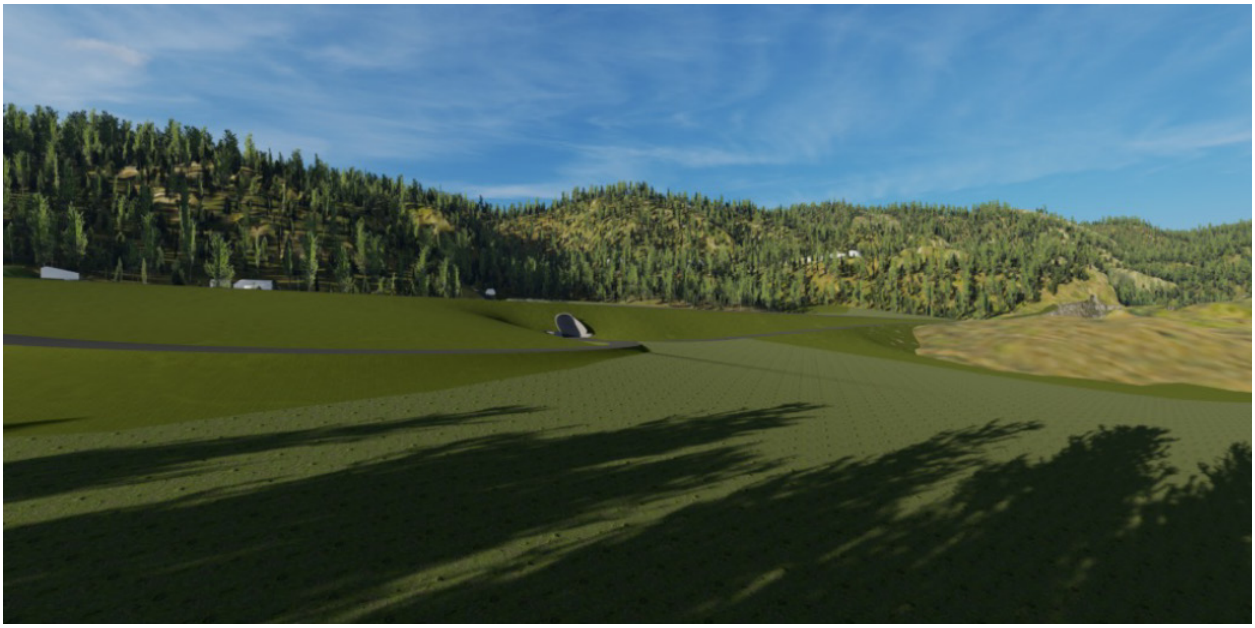


Figure 3.4.10. – Flaten. The figure shows planned areas for re-establishment of arable land at Flaten.

3.4.6 Environmental indicators

Tunnels are usually good for continuing or developing landscape qualities. This is also true on a more general level. On behalf of Nye Veier, Sweco Norge AS has prepared a draft of indicators that allow the monitoring of different environmental qualities throughout the phases of a road project. The indicator represents a simplified version of the complexity of an environmentally assessed value. The indicators do not represent a complete situational survey or mapping. To a greater extent, the indicators show whether the given road project is developing in a positive or negative direction.

In the area zoning plan for E39 Mandal-Lyngdal East, the environmental indicator system was also used as one of the project's key performance indicators (KPI)[iv]. The figure below shows the detailed area zoning plan (DRP), optimised area zoning plan (ORP) and optimal landscape alternative (good landscape adaptation, long passage options etc.) assessed for the entire project. The indicator system uses six indicators. On the E39 Mandal-Lyngdal East project, we saw how the use of tunnels generally had a positive effect on all the indicators (see figure below). The tunnel resulted in significantly fewer irreversible interventions (landscape change), reduced surface area used for road purposes (land use), reduced loss of landscape values at national and international level (value) and more crossing options along the road corridor (barrier effect). The visibility of and noise from the road will also be reduced, even if this is not shown due to the way the audio visual field is calculated in the indicator system.

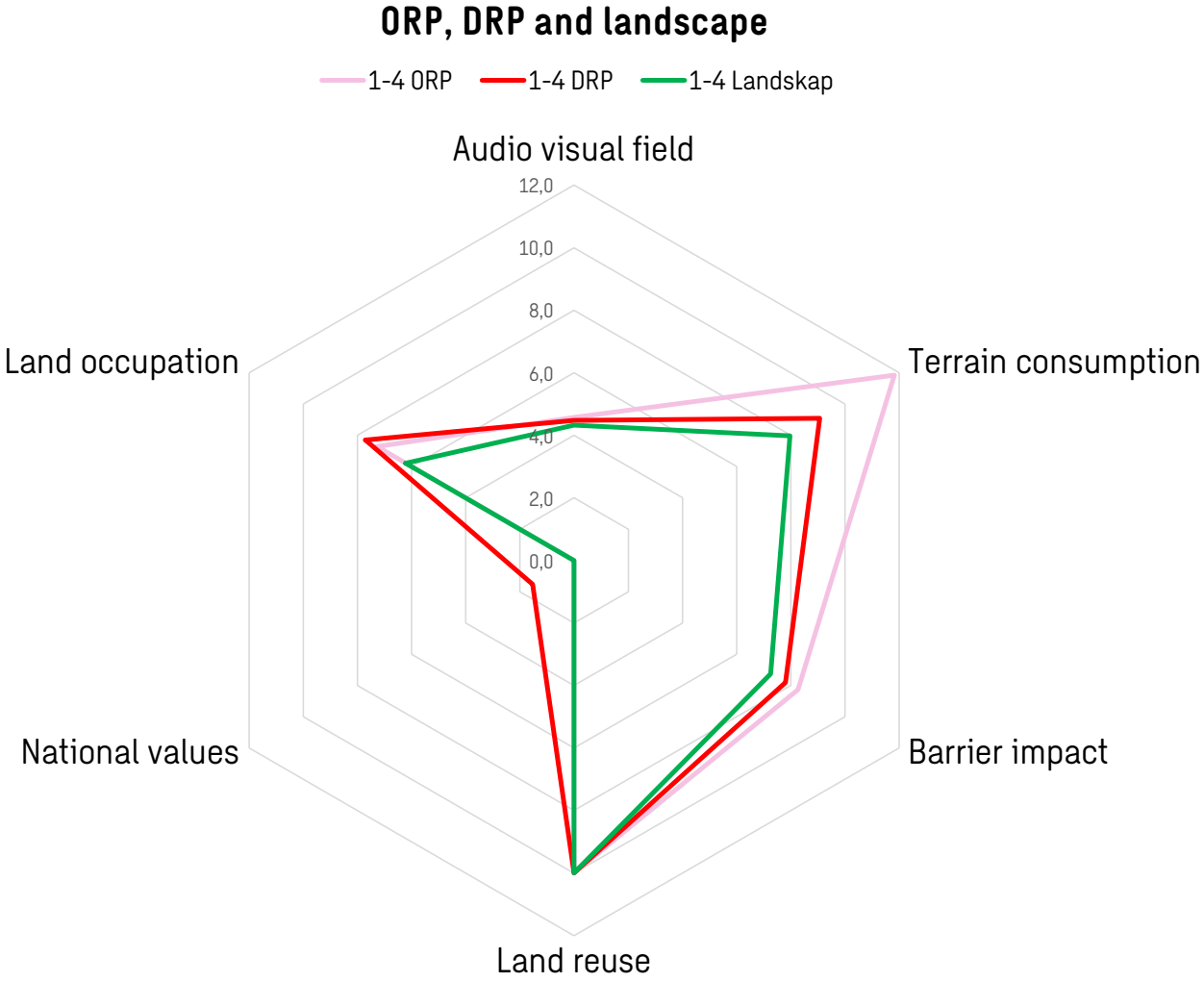


Figure 3.4.11. – Environmental indicators. The figure below shows detailed zoning plan (DRP), optimised area zoning plan (ORP) and optimum landscape alternatives (good terrain adaptation, long passage options etc.) for the entire project. All values are related to a scale between 0 (poor quality) and 10 (good quality).

3.4.7 Greenhouse gas budget

A greenhouse gas budget was also prepared as part of the project. The project's estimated emission of greenhouse gases shows how the use of tunnels can contribute to maintaining landscape qualities once it has been decided that a project is to be implemented. Tunnels and similar structures that require large amounts of steel and concrete are traditionally perceived as climate barriers on transport projects. If we include several aspects in the calculation, we see, how emissions related to the use of steel and concrete also have to be related to the use of natural elements such as bogs and forests. A comprehensive survey of bog depths was performed on the project. This survey showed that the bog depths in the project area were generally greater than the model assumed. The planned road would affect large areas of high-quality forest. Emissions related to land use were therefore considerably higher than emissions related to the project's use of steel and concrete. More tunnel would therefore reduce the use of bogs and forests and lower greenhouse gas emissions.

3.4.8 Landscape qualities come and go in the planning arena

This article highlights how a construction element, such as a tunnel, can contribute to managing and developing landscapes in a sustainable way. If this perspective is to be taken seriously in decision-making processes on current cost-focused projects, it is, however, not enough to point to big visions such as the UN's Sustainable Development Goals or international climate agreements. As many of us experience almost daily, most decisions are still made at a more trivial project level.

In such a context, good decisions are related to the ability to take care of both one given technical subject area and the whole of the project at the same time. With today's specialised expertise and models, we all too rarely seize this opportunity. Whether an element such as a tunnel ends up as a good landscape project or not is far too seldom determined by the area itself and a little too often by the use and design of the various *calculation models*.

A more sustainable and forward looking alternative does not necessarily lie in rejecting well-developed methods or models. But concepts such as landscape give everyone an opportunity to influence the overall end result of the project. Landscape then becomes not only an area in which something takes place, but also an arena in which dialogue between different operators takes place. Different disciplines will then be able to work towards a common goal, whether the project is a greenhouse gas budget, a cost-benefit analysis or a tunnel plan. By coordinating different interests, opening up to unexpected solutions and seeing new aspects of our own subject, we can ensure that the results of any project will provide highly valued landscapes for future generations.

References:

[i] Council of Europe (20.10.2000:4): *Explanatory Report to the European Landscape Convention*. Florence

[ii] Norwegian Public Roads Administration (2018): *Håndbok V712 Konsekvensanalyser*. Report. Oslo.

[iii] Rise, Torn, Allonge Checklist & Randers, Ida (red) (2019): *Korrigering stein. OneDrive regulatorisk* (2016-2019). SINTEF

[iv] SecFlix Gorge AS (2021.09.13): *Identifikator III*. Report. Oslo.

3.5 Biodiversity

3.5.1 Introduction

When building infrastructure in untouched nature, it is inevitable to influence the life of smaller and bigger animals and insects both on land and in water. Many of these creatures adapt easily and find a new way of living next to the new structure, on the other hand, there are species that are more vulnerable and need special care.

The most important global cooperation to keep biodiversity is the UN Convention on Biological Diversity. The Convention was signed by 150 heads of state in Rio de Janeiro in 1992 and covers the protection and sustainable use of all biological diversity.

On behalf of the Ministry of the Environment in Norway, the Directorate for Nature Management has prepared a national plan for biodiversity monitoring. The report is a summary presentation with proposals for monitoring biological diversity, mainly based on DN report 1995-7 Strategy for monitoring biological diversity and study for DN 1997-7 Monitoring of biological diversity in eight habitat types. Environmental protection policy for sustainable development, provides recommendations for biological monitoring diversity in Norway's main ecosystems; forests, bogs and wetlands, cultural landscapes, mountains, freshwater, coastal, ocean, as well as arctic ecosystems.

A total of seven ministries have joined forces to coordinate all mapping and monitoring that is relevant to biological diversity and to establish new

registration activities where the knowledge base is too poor. The first part of the program period is devoted to mapping, while monitoring will be more in focus in the last part of the period.

Many projects have taken measures to take care of vulnerable species; e.g., a special type of dragonflies close to Os, a black fly close to Drøbak, a rare salamander in Kjose have all initiated special structures or other type of initiatives to save the biodiversity. In the chapter below, you will get to know a special type of owl, getting their own tunnel to keep the breeding area calm and safe, given as an example to what extent we need to take care of the nature.

https://www.fn.no/tema/klima-og-miljoe/naturmangfold

https://www.vegvesen.no/fag/fokusomrader/miljo-og-omgivelser/naturmangfold/naturmangfold-loven/kartllegging-av-biologisk-mangfold/

https://www.miljodirektoratet.no/globalassets/publikasjoner/dirnat2/attachment/46/rapport-1998-1.pdf

3.5.2 Norwegian drill and blast tunnelling in ka-hoots with endangered species

Anita Nesthus
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Normally, drill and blast tunneling will ruffle a good few feathers during the building of a large infrastructure project. This, however, has not been the case at the spectacular Northern Island Road (Nordøyvegen). Here, the feathers of the nationally, critically endangered species Eurasian eagle-owl (Bubo bubo) have been taken into special consideration already on the early planning stages of the huge road project.

A tunnel owl for me!

The Northern Island road project consists of connecting five islands on the west coast of Ålesund in Norway with the mainland by road. The road project contains three large bridges, 2.7 km road on sea fill, 15.6 km of subsea tunnels, crossing three fjords, and one environmental tunnel, also known as the owl-tunnel. One of these five islands is Fjørtofta, inhabited by 110 people, and a few documented, nesting Eurasian eagle-owls. Thus, this island came to receive its very own owl-tunnel, Burbergtunnelen. The name is derived from "bur" supposedly from the sound that the owl makes as it sits on its nest, (burr-buuurr) and “berg” one of the several Norwegian words for mountain.

Figure 3.5.1. Burberg tunnel, aka. “The owl tunnel” in progress in November 2019.

Owls and zoningplans

"Is it really there? I mean, has anybody ever really seen it?" or "Today we made some nice owl-soup after the shift" are just some of the reflections and jokes made in good humor by the tunnel workers on Fjørtofta island. Because, as it often will to people who are not trained as environmentalists, building a complete 170-meter-long tunnel for a small animal that you probably might never see, seems somewhat silly. So here is why it is not, are you owl ears? The Eurasian eagle-owl is critically endangered in Norway, due to several threats including power lines, wind power, human interference of their habitat and most crucial, land changes. Therefore, it was decided to give extra weight to biodiversity in early risk assessments during the zoning plan work of the spectacular Northern Island road project. The consideration for biodiversity and especially the breeding area for the Eurasian eagle-owl had a high priority through the planning work. The challenge was to find a solution for Fjørtofta which the County Governor accepted. Consideration for the owls was weighed very heavily in the choice of solution. A supplementary impact assessment was carried out, and a consultant carried out a survey of and assessed the consequences in relation to route selection, etc. The compromise result was that the project was to include the “owl tunnel” and ensured the isolation of transformers on electric poles on the island prior to start-up. The requirement in the registration plan also included requirements for start-up time. If nesting was to be registered with the owls in Ramsberget, it should not be crushed or carried out similar noisy activity in area during the period March 15 to July 15.

A local ornithologist who had been monitoring the owl population during the last 10 years was consulted by the County Governor and by Statens

Figure 3.5.2. The building and construction area by the Fjørtoftfjord tunnel seen from the east. Ramsberget to the left in the picture. If nesting was to be registered with the owls in Ramsberget, it should not be crushed or carried out similar noisy activity in area during the period March 15 to July 15.

Vegvesen in connection with mapping and follow-up of the owls on the island. When Statens Vegvesen had to implement a regulatory change in 2020 for the establishment of a permanent landfill at Fjørtofta Nord, it was again discussed what consequence this would have for the owls and their nesting. Again, the consideration for the owls was highly emphasized and described. Great emphasis was placed on terrain formation and adaptation of measures. This was done to reduce the risk of

negative impact on the owl's functional area, as well as giving the measure a good landscape adaptation for society otherwise. The tunnel masses were decreased from the original 300,000 m3 to just under 200,000 m3 at Fjørtofta north to meet the need for adaptation locally. In addition, it was done damage reduction measures in the form of the establishment of embankments and rapid restoration of the area. With these harm-reducing measures, the project would be able to state that the risk of harm to biodiversity were reduced to approve levels.

References:

Hubro. (n.d.). https://www.wwf.no/dyreleksikon/hubro.

Fv. 659 Deponi Fjørtofta nord Fjørtofta, Ålesund Municipality Plan ID-202001065

PLANOMTALE MED KONSEKVENSUTGREIING (KU) 2021

REGULERINGSPLAN Fv 659 Nordøyvegen Fjørtofta Haram municipality 2013

3.6 Emissions

Tunnel construction, operation, and maintenance activities have many very different processes and materials. These activities result in a large variation of emissions from GHG and particulate matter (dust) to emissions to water bodies. The following section will present emissions to air (GHG and other emissions) and emissions to water.

3.6.1 Greenhouse gasses

The most common method to estimate GHG emissions in Norway is the earlier described method of life cycle assessment. GHG budgets and accounting is today often required by the project owners and preferred by the contractors in relations to their own targets and CEEQUAL certification of projects. Therefore, the number of LCA studies on road and rail infrastructure has been steadily increasing but these studies still vary considerably [1]. LCA studies on tunnels first had impact on the Norwegian infrastructure decisions in 2011 in relations to the Highspeed train project conducted by Bane NOR on behalf of the Norwegian government. Since then, several studies have been performed.

The LCA studies performed have shown that tunnels significantly affect the overall emission profile of a construction project, whether it is road or rail infrastructure project. This is mainly due to the construction phase of the tunnels, often the source of around 50 – 60 % of the GHG emissions, which are material and energy intense. The processes resulting in these emissions are mainly from consumption of concreate (cement) during casting and tunnel lining process, the second main source is rock support, and finally it is the tunnelling process [2, 3].

Regarding emissions from material consumption the main measures to limit emissions is leaner construction and more efficient use of energy. Material consumption during casting and tunnel lining has improved in recent years mainly through a positive development of cement products that can emit less GHGs today. However, this is only a part of the solution. As the use of cement products continue there is a need for carbon capture & storage (CCS) to limit GHG emissions. Without carbon CCS it will not be possible to reach the climate goals and at the same time continue the use of cement and concrete products.

Regarding the most common tunnelling process in Norway which is drill and blast (D&B), the environmental impact from the process is mainly from the loading and hauling process (36 %), secondly from ventilation (31 %) while drilling and blasting is third

biggest contributor (29 %). The overall main sources of emissions are from explosives, diesel, and electricity [6]. Therefore, it is natural that the design of the tunnels with regards to size and length highly affects the emission profile of the tunnel. This was found to be because of increased drilling, blasting, and need for ventilation. Lizhen et al. [3] found that GHG emissions per meter standard Norwegian road tunnel, with a 100-year lifetime was 10.7 t CO_2 eq. while per meter of road with shorter lifespan, can be estimated to emit 2,2 t CO_2 eq. during construction, maintenance and rehabilitation [4]. It is therefore important to analyse emissions from tunnels and apply reduction measures where they have the biggest impact. Cross-section is important in that regard as it highly affects the energy and material need in the construction process. As an example, a tunnel with a 120 m2 cross section is estimated to emit as much as 1.4 tonnes of CO_2 while a smaller cross section of 20 m2 emits only 0.4 tonnes of CO_2. Ventilation and transport because of increased length of a tunnel is also an important source of emissions. The main measures to reduce transport and ventilation was found to be tunnelling from both sides [3,5,6].

Tunnel construction uses considerable amount of electricity and an increasing emphasis on electric machinery will further increase it. Norwegian studies have shown that the electricity source is an important factor and needs careful considerations. Earlier studies have compared results using Norwegian to European electricity mix. However, today it is important to consistently use European electricity mix because the systems are inherently connected. If projects are not in a place that allows for grid connection, it is important to include emissions from the site-specific power source.

From the Norwegians studies and reports it is found that the main opportunities for GHG emission reduction is through more effective use of explosives, leaner design, and improvement in concrete materials with less emission intensities. The Norwegian construction sector uses LCA to evaluate the effects of the different measures for emission reduction and have developed several tools for this purpose (see in section about methods and tools) [7,8].

References:

[1] E. Hoxha, H.R. Vignisdottir, D.M. Barbieri, F. Wang, R.A. Bohne, T. Kristensen, A. Passer “Life cycle assessment of roads: Exploring research trends and harmonization challenges” Science of the total Environment, vol. 759, pp 143506-, 2021.

[2] A.-R. Korsmo Bergsdal, H., “Miljøbudsjett for Follobanen - Infrastruktur,” 2011.

[3] L. Huang, R. A. Bohne, and A. Bruland, “Life cycle assessment of Norwegian road tunnel,” Int. J. Life Cycle Assess., vol. 20, pp. 174–184, 2015.

[4] F. Gschösser and H. Wallbaum, “Life cycle assessment of representative Swiss road pavements for national roads with an accompanying life cycle cost”, Environmental Science and Technology, vol. 47 (15), pp. 8453-8461, 2013.

[5] L. Huang, R. A. Bohne, A. Bruland, P. D. Jakobsen, and J. Lohne, “Environmental impact of drill and blast tunnelling: life cycle assessment,” J. Clean. Prod., vol. 86, pp. 110–117, 2015.

[6] L. Huang, P. D. Jakobsen, R. A. Bohne, Y. Liu, A. Bruland, and C. J. Manquehual, “The environmental impact of rock support for road tunnels: The experience of Norway,” Sci. Total Environ., vol. 712, p. 136421, 2020.

[7] J. Hammervold and O. Sandstrand-Dahlstrøm, “Documentation VegLCA v4.01.” Statens Vegvesen (E. Norwegian Public Roads Administration), Oslo, p. 101, 2020.

[8] Ragnhild Stamer Ekerholt and Julie Gade Gørbitz, “CO_2-fotavtrykk | Nye Veier AS,” V2.4, 01-Dec-2020. [Online]. Available: https://www.nyeveier.no/om-oss/co2-fotavtrykk/. [Accessed: 20-Dec-2021].

3.6.2 Carbon capture & storage – A major step towards carbon neutral concrete structures

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HeidelbergCement

Longship

In December 2020, the Norwegian parliament adopted the “Longship” project – the government’s investment in full-scale demonstration of capture,

Figure 3.6.1. The Brevik cement plant.

transport and permanent storage of CO_2. Norcem is involved in the capturing part of the project at the Brevik cement plant, while transport by ship from Brevik to the interim storage facility in Øygarden, further transportation in the pipeline out to the Aurora Field and final injection and storage in the bedrock will be carried out by Northern Lights.

Brevik Capture Facility

An amine-based capture facility will be built at Norcem in Brevik. When the capture facility is completed in 2024, it will have a capacity of approx. 400,000 tons of CO_2 per year, which corresponds to approx. 50 % of the emissions at the factory. The reason for this is that the capturing process is highly energy-intensive and the actual capturing part is designed in such a way as to utilize the existing residual heat and surplus energy from the process in order to operate the capturing facility. The available energy volume will be able to capture approx. 55 tons of CO_2 per hour, which corresponds to approx. 400,000 tons per year.

Zero Vision

To be able to reach national and international goals of GHG emission reduction it is important to reduce emissions from the cement industry. Reaching the goal of net zero CO_2 emissions requires several challenging measures shown in figure 3.6.2.

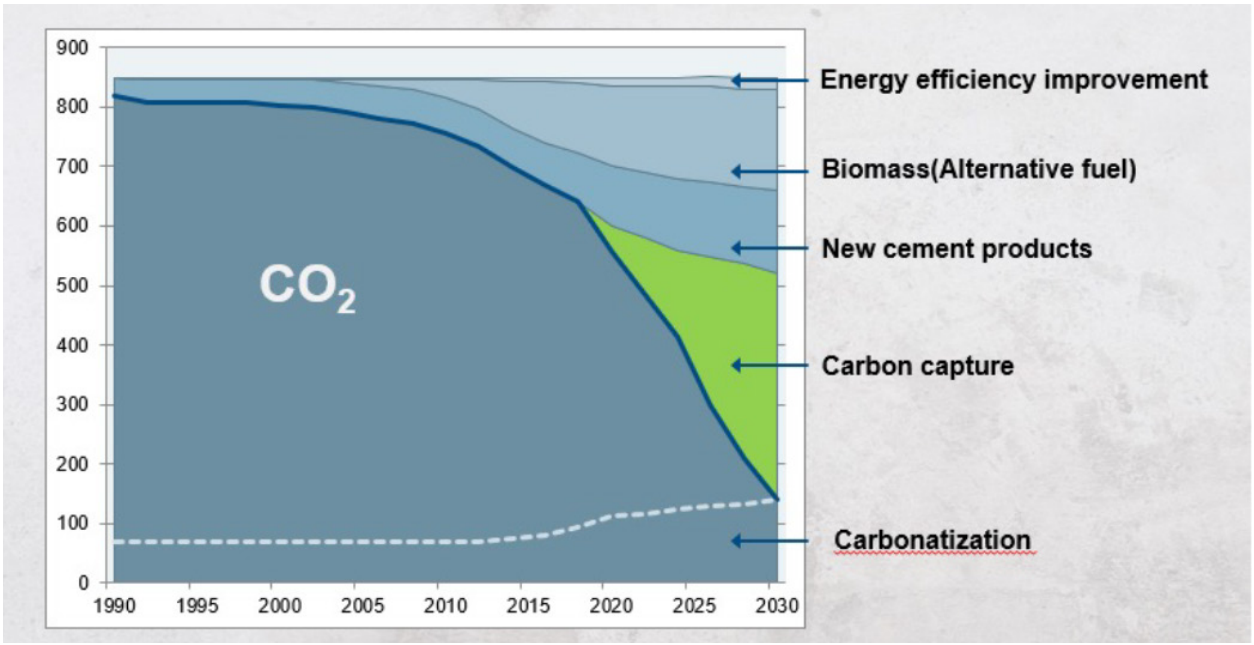


Figure 3.6.2. Norcem Zero Vision.

At the Brevik plant the work to reduce CO_2 emissions has been ongoing over many years, where the use of alternative fuels and the use of substitute materials have been the most important instruments in this context.

Fuels account for approximately 40% of the total emissions and the replacement of coal with alternative bio-based fuels has made a major contribution to reducing the total CO_2 emissions. At present, the plant has replaced approximately 80% of its coal with alternative fuels, approximately half of which are bio-based. The reduction in CO_2 as a result of alternative fuels amounts to around 120,000 tons of CO_2 per year.

Mixed cements where parts of the cement clinker have been replaced by substitute materials such as fly ash from coal-fired power plants or granulated pig iron slag have become more and more common. Norcem started developing their products with substitute materials to reduce both emissions and costs as far back as in the 1980s with this type of cement. With the current level of substitutes, the Brevik plant has reduced CO_2 emissions related to the cement supplied to the Norwegian market by more than 200,000 tons per year compared to a solution with pure Portland cements.

Effect on the environmental profile of the cement

The impact of the different reduction measures on the environmental profile of the cement is illustrated in figure 3.6.3. below.

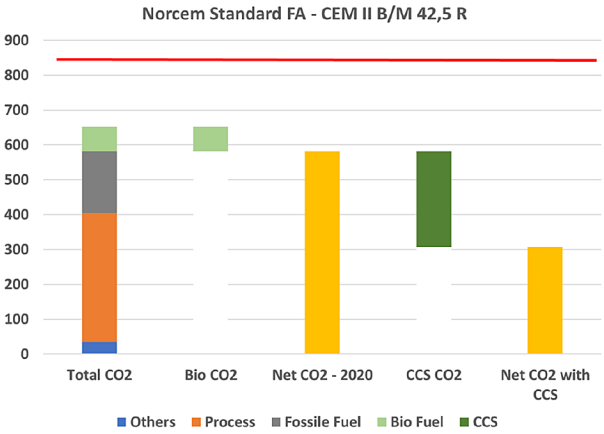


Figure 3.6.3. CO2 Norcem standard.

Today's principal product from the cement plant in Brevik is Standard FA cement.

The red line represents the level if a pure Portland cement had been delivered. The total emissions allocated to this cement mainly derive from the production of the clinker proportion in the cement. In the case of the clinker, the process-related emissions from the expulsion of CO_2 from raw materials account for approximately 60% of the emissions, while emissions from the fuels account for almost 40%. Through the use of bio-based alternative fuels, emissions for this cement have been reduced by approximately 10%. Through carbon capture (CCS), emissions will be reduced by almost another 50%, so that net emissions will be at a level of 300 kg of CO_2 per ton of cement in the case of the Standard FA cement.

Impact on the concrete footprint

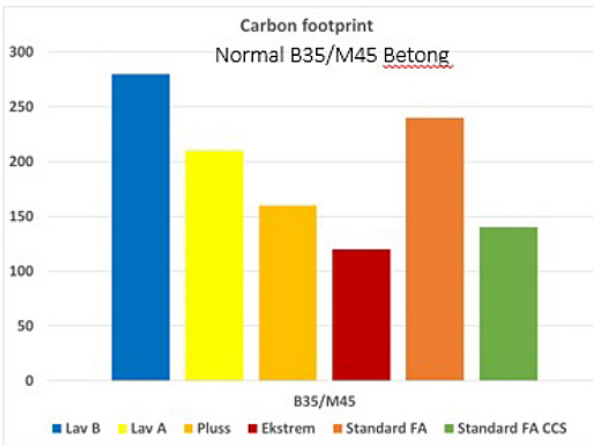
Over many years, the Norwegian concrete industry has developed a management tool to classify the environmental profile of various concrete solutions. This is described in the Norwegian Concrete Association's Publication No. 37 Low-carbon concrete. Four different levels for low-carbon concrete are described here with specific values for CO_2 emissions per m3 of concrete.

Low carbon B: is a level that most concrete producers can achieve through relatively simple technically prescribed measures. This level has gradually progressed to become the most commonly supplied concrete in the Norwegian market.

Low carbon A: is a level where a number of technically prescribed measures must be taken in order to achieve the specified emission levels. These may include measures such as the addition of additional fly ash or silica dust. This is a level that is not normally available for everyone, but most concrete producers will be able to offer this type of low-carbon concrete.

Low-carbon Plus and Low-carbon Extreme: are levels that are not normally available, but which can be achieved through special measures. This requires very special binder compositions that are not generally available throughout the market and supply options are checked out on a case-by-case basis. Low-carbon concrete in these levels will also be concretes with completely different usage characteristics than normal and extra measures must often be taken in the construction phase in order to achieve good results.

Figure 3.6.4 below shows how a typical Normal concrete and Low carbon concrete of Standard FA produced in the south-east of the country will be in comparison to the class limits in NB 37.



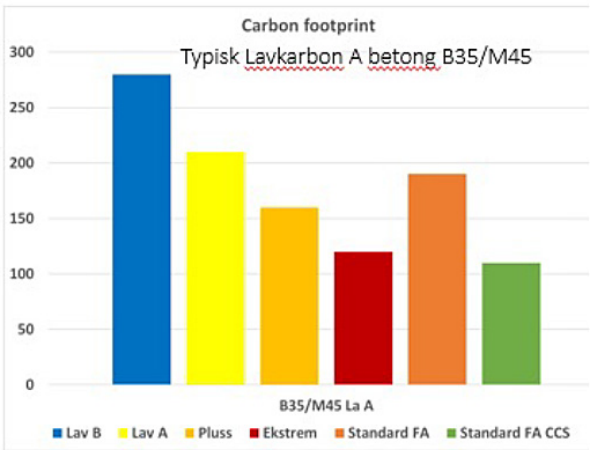


Figure 3.6.4. The carbon footprint for normal concrete and low carbo concrete.

Through carbon capture, the normal Standard FA cement will achieve such a low CO_2 emission that Low Carbon Plus will be able to be produced with perfectly normal concrete grades/prescriptions and Low Carbon Extreme will be able to be produced with some additional prescribed measures that will result in a concrete with completely normal usage characteristics.

This means that carbon capture & storage will contribute to concrete as a building material being perceived as the most environmentally friendly solution in the majority of construction projects.

3.6.3 Other emissions to air

Other emissions to air are direct emissions at the construction project and refer to NOx, CO and particulate matter (PM2.5-PM10). These emissions stem from machine use during exhaust emissions from vehicles, PM generation from the ground but also from tunnelling processes, f.ex. drill and blast. Emissions to air from construction projects affect human health in the surrounding community through inhalation and pollution in local crops and are therefore getting stricter regulations. The main effects of local PM emissions are irritation in eyes, ears, nose and throat but can also aggravate asthma and other upper respiratory deceases. Tunnel and other construction activities have considerable impact on the local air quality and therefore need monitoring in populated areas. Tunnels have in many countries helped in cities and high populated areas to ease traffic congestion. In Norway, tunnels have mainly been used in the challenging topographical environment both inland and on the shore.

Dust is both a risk for the construction workers as well as people living or working close by. The risk is highest for workers working in mines and tunnels. Crushing materials contributes to high risk for dust related risk. The dust from crystalline silica (SiO2) is well known to be a health and safety issue and can cause damage to the lungs when inhaled. The Norwegian government and EU have in place regulations on limits on the amount of silica in the air. Measures to reduce all sorts of dust generation include increased cleaning, using filters, dust binders, and ventilation.

References:

[1] C. Roberts, “Methods of reducing air pollution from tunnel exhaust”, Proc. 14th International Union of Air Pollution Prevention and Environmental Protection Associations (IUAPPA) World Congress 2007, 18th Clean Air Society of Australia and New Zealand (CASANZ) Conf.”, 2007.

[2] https://sintefnorlab.no/tjenester/miljomaling/utslipp-til-luft/

[3] https://luftkvalitet.miljodirektoratet.no/artikkel/artikler/hva-kan-jeg-gjore/#Svevest_v

[4] https://www.airthings.com/no/hva-er-svevest%C3%B8v

3.6.4 Emissions to water

Authors:
Jostein Kjørstad, Acciona Ghella Joint Venture (AGJV)
Tom F. Hansen, NGI

Emissions to water from a tunnel project can broadly be grouped into two operations:

- Runoff water from deposits of tunnel muck
- Water drained out of the tunnel during the excavation process.

In projects where the tunnel muck is deposited in nearby terrain there is a need to handle run-off water for a period of 1-3 years after depositing the masses. The tunnel muck will contain concrete, explosives and particles that will be washed into nature by rainfall. In publication 24 there is described a simple process to handle such run-off water [1] by constructing sedimentary basins and ditches that slow down the process.

Water in the tunnel construction process is used in drilling, grouting, machine-scaling, and water leaks through joints in the rockmass. The water is then polluted by oil from machinery, particles from rock and gravel, explosives, concrete and additives from shotcrete and grouting. To pump the water out into nearby rivers and lakes, there is then need for a

Figure 3.6.5. Sedimentary basins as a simple process to clean draining water from deposits of tunnel muck.

thorough cleaning process, thereby removing chemical pollution, particles, and reducing the pH-level to neutral conditions. Norwegian clients describe such demands in strict contract requirements.

There is standard practice to set up an industrial process that handles the cleaning process to fulfil the requirements. A setup of such a process, constructed for the Follobanen TBM railway project, is described in the following section.

Tunnel water treatment

The project's pollution permit stipulated that all tunnel water was to be treated and discharged to the municipal sewage network (Oslo VAV). The permit required continuous monitoring, flow proportional sampling, online monitoring access and weekly reporting of water quality parameters, such as pH, TSS, oil, nitrogen and heavy metals.

In order to both comply with these requirements, and to recirculate as much water as possible, the project established a large, advanced water treatment plant (WTP). Tunnel water from all 4 tunnels was collected in a detention basin in the caverns and pumped to the WTP outside the adit portals. The WTP consisted of buffer tank, decanter and filter press, pH control tanks, coalescence separator, quartz filters, and activated carbon filters. In addition, there were large industrial water storage tanks for treated water, and an emergency basin.

The WTP had a capacity of 60L/s (216m3/hr), and it treated water at incoming water quality of Total Suspended Solids (TSS) 10-20 000mg/l and pH 12-13, to clean water with TSS <20mg/l and pH 9. The WTP initially used hydrochloric and sulphuric acid for pH reduction, but in order to operate more efficiently, switched to CO_2, which proved highly effective The WTP was operational 24/7 for the duration of the project, with a permanent fulltime operator.

Typically, in tunnel projects, the main water quality issues are related to pH and TSS. None of these parameters have caused problems in this project, because of the water treatment process.

Figure 3.6.6. Water treatment plant under construction.

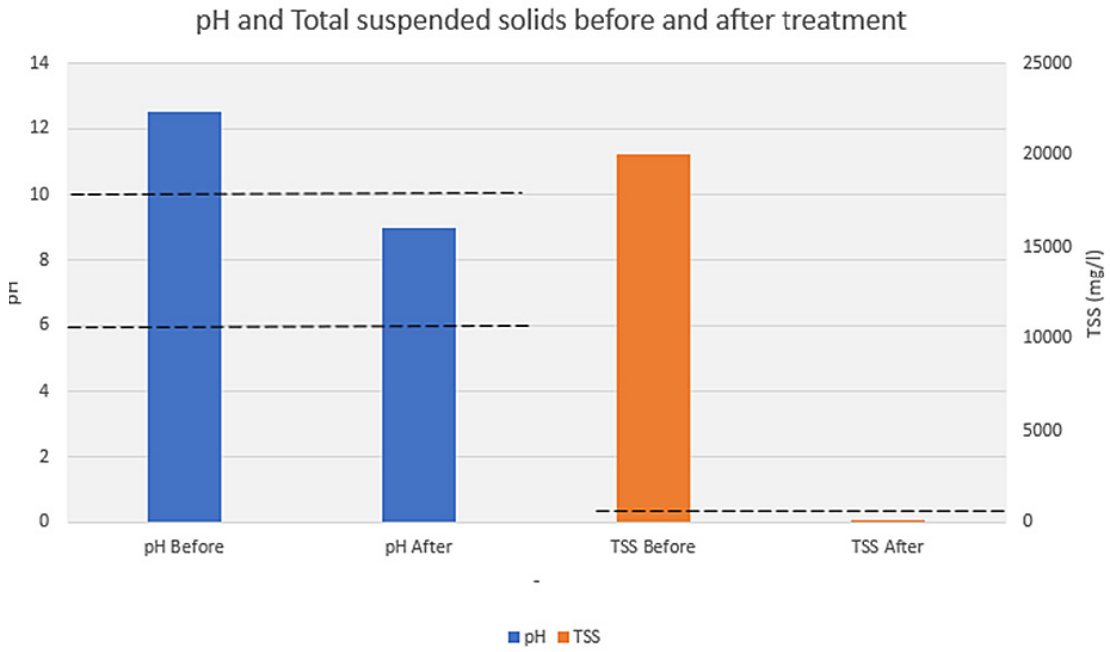


Figure 3.6.7. pH and TSS before and after WTP process.

Furthermore, nitrogen, which is often one of the main contaminants of concern in tunnelling, has not been a problem in this project, mainly due to the use of TBM (compared to drill and blast).

However, the water treatment was not without challenges:

- Unbalanced incoming flow
  - In the early stage of the TBM-drilling, there was limited balancing capacity for the raw water in the tunnel. This resulted in irregular flow into the WTP, which caused operational challenges such as overflows and clogging due to mud build-up in the decanter in the WTP. Overflows were collected in the internal containment system, but the this caused a very high workload for WTP operators.
  - Two parallel detention basins and double pump sumps were built in adit north, which run on 12 hours rotation. Mud build-up in the basins was removed daily by an internal sucker truck and transported to the WTP on the surface.
  - An additional filter press was built to support WTP1, which increased the capacity by 150% from September 2017.
- Treatment capacity
  - To handle the total amount of water more than 60 l/s in the tunnel, the capacity of the water treatment plant had to be increased.
  - A second water treatment plant (WTP2) was built in similar style to WTP1, with 30 l/s capacity. WTP2 was operational from May 2018. Combined capacity of WTP1+WTP2 was then 90 l/s
  - While WTP2 was being built, Contractor installed a temporary WTP in traditional style - using 6 sedimentation containers and acid pH adjustment, which was used to support WTP1 during periods of extra-ordinary high inflow from December 2017 to April 2018.
- Discharge volume restrictions
  - Nearly 50% of the treated water from the WTP was sent to industrial water tanks for reuse in TBMs and on the surface. The remaining water was discharged to the municipal sewer system (VAV) under the environmental permits for the project. The VAV pipeline had a volume restriction of 25 l/s (later increased to 40 l/s) due to pipe size limitations downstream.
  - This meant that the WTP operators had to restrict the discharge rate, and carefully balance the treated water to avoid exceeding the discharge capacity.
- pH adjustment
  - The incoming water was highly basic, with pH in the range of 12-13
  - Initially, pH was controlled with sulphuric acid. This increased sulphate concentrations and caused difficulties in complying with the discharge limit for sulphate.

- Then, the WTP switched to a combination of hydrochloric and sulphuric acid in order to limit sulphate concentrations. High consumption of hydrochloric acid, however, caused corrosion of WTP and uncomfortable working conditions.
- Finally, a CO_2 system was installed for controlling pH. This worked efficiently without any significant drawbacks.

• Hexavalent chromium:

Soon after start-up of the TBMs (TBM1 Queen Eufemia started up 05/09/2016, and by December 2016, all 4 TBMs were running), we observed a clear increase in chromium concentrations in the treated tunnel wastewater, from approximately 20 µg/l to 150 µg/l.

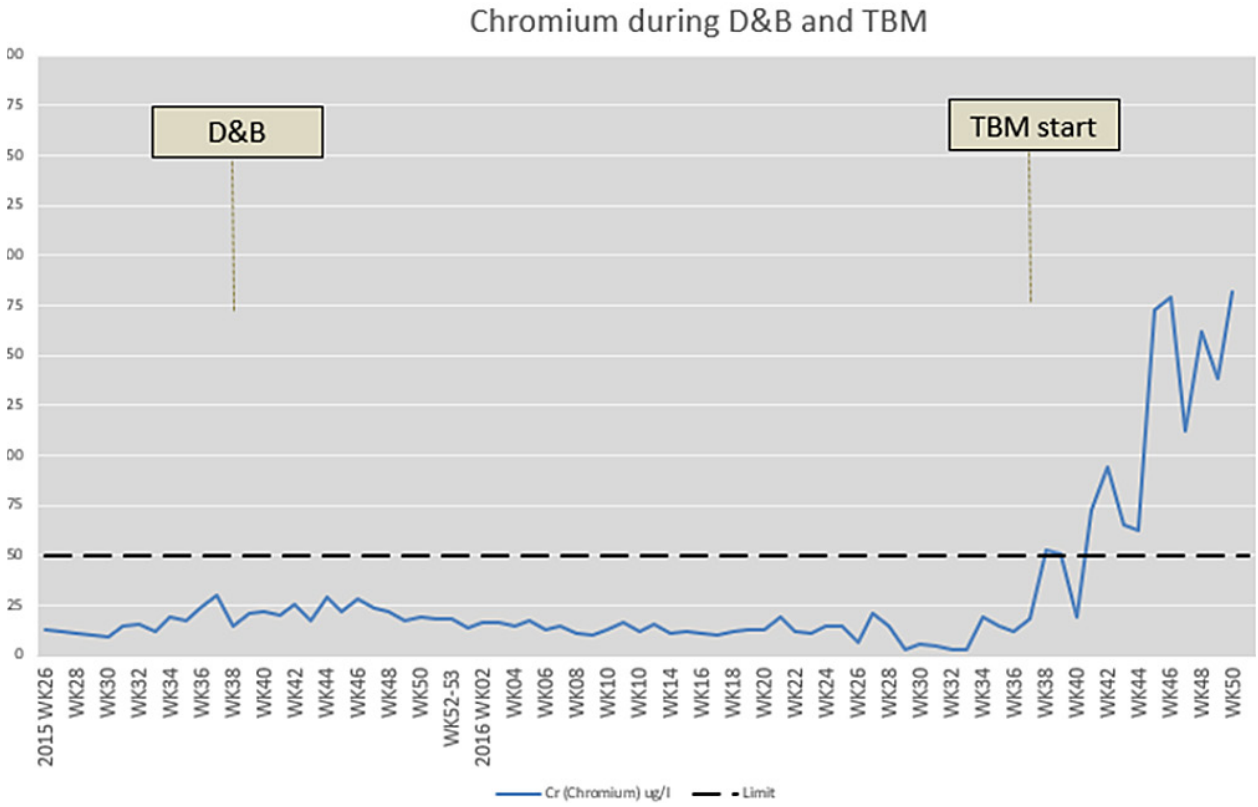


Figure 3.6.8. Chromium levels before and after start-up of the TBMs.

An extensive sampling program was implemented to determine the source of the chromium. It concluded that it originates from the various cement products used in the tunnel (mortar for segments, and pre-grouting), and from the concrete element production. As the water volume from the tunnel was significantly higher than from other sources into the WTP, the cement use in the tunnel was considered as the main source.

Furthermore, it was found that nearly all the available chromium in the water was hexavalent chromium CrVI.

After a series of original research and development work, which included cooperation with consulting, industry and technology experts, AGJV developed several methods for reducing chromium concentrations in the wastewater. With the assistance of Acciona Aqua and Centre for Research and Innovation in Madrid, three alternative methods were tested in laboratory conditions: electrocoagulation, active carbon, and iron sulphate addition. The chosen solution was robust enough to handle large variations in water quality and could be implemented in the current WTP without interfering with the 24/7 operation.

By adding iron sulphate heptahydrate $FeSO_4\ 7H_2O$, water soluble hexavalent chromium was reduced to trivalent chromium, and settled out together with the other particles in the wastewater.

$$CrO_4^{2-} + 3Fe^{2+} + 8H^+ \rightarrow Cr^{3+} + 3Fe^{3+} + 4H_2O$$

$$CrO_4^{2-} + 3\,Fe^{2+} + 4OH^- + 4H_2O \rightarrow Cr(OH)_3 + Fe(OH)_3$$

Figure 8-7: Chemical formula for hexavalent chromium reduction in alkaline and acidic conditions.

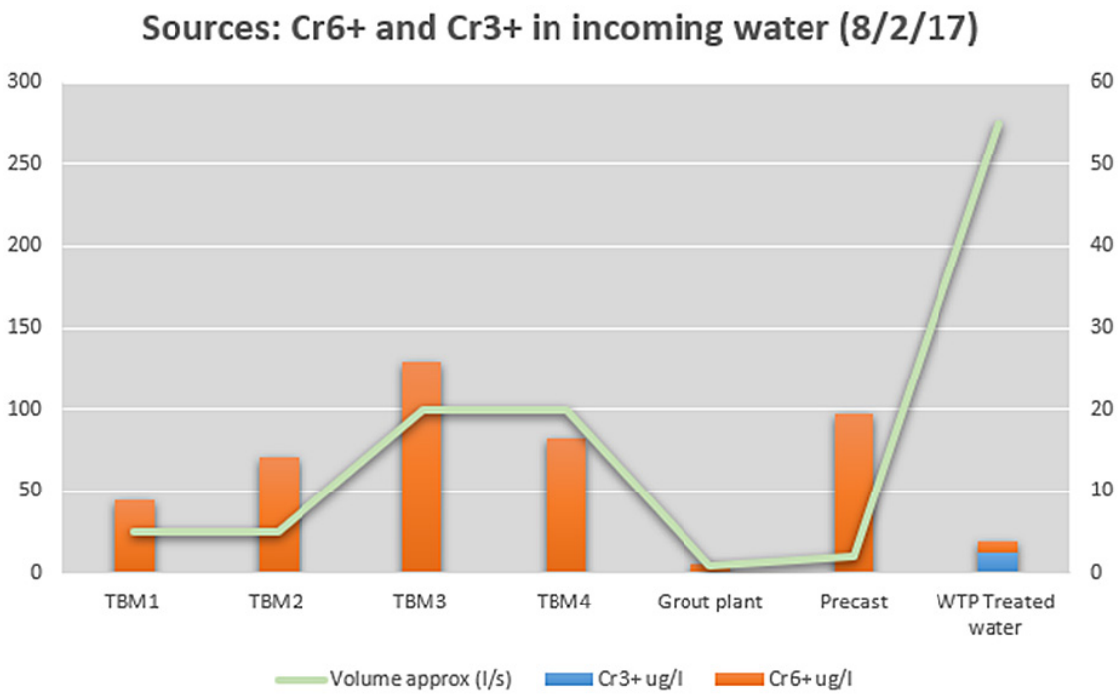


Figure 3.6.9. Source sampling chromium.

The method can be described as follows:

- Dosing tank and pump
- Mixing tank (1500 l), for mixing iron sulphate heptahydrate with clean water
- Addition of iron sulphate mix to wastewater decanter tank (40 m3), together with flocculating polymer, settling out 80-90% of the chromium
- The method is proven to work at pH 10-13, and should theoretically work in acidic conditions as well
- Dosing ratio dependent on water quality, approx. 0,1-0,3 kg/m3 wastewater
- Reaction-time <20 minutes

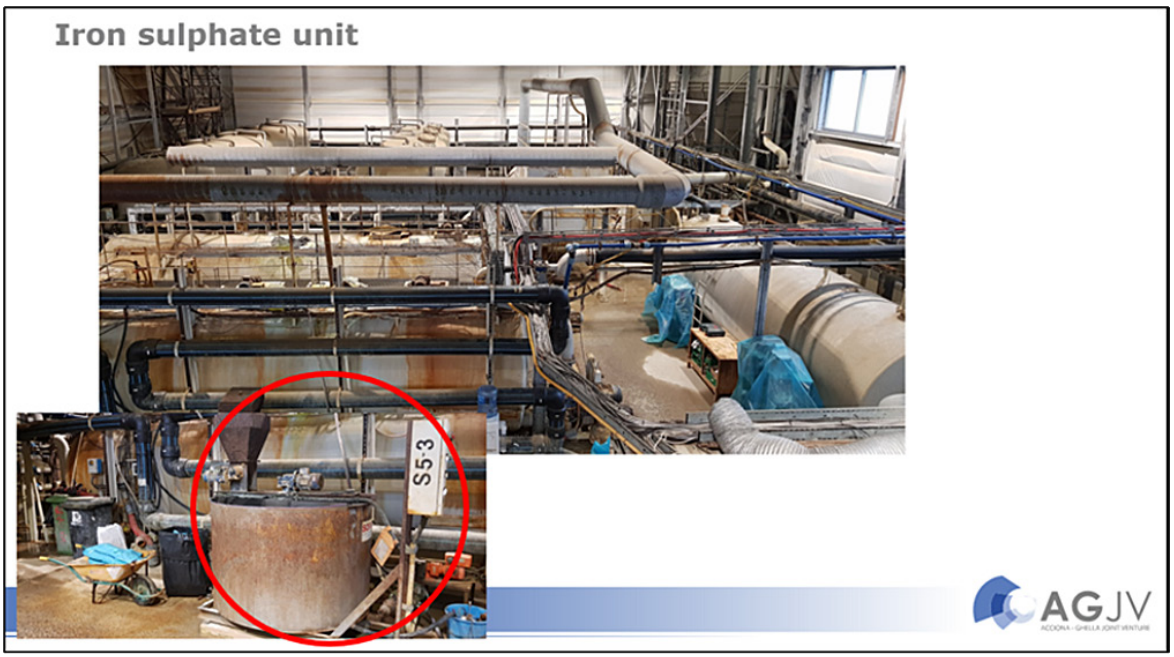


Figure 3.6.10. Iron sulphate dosing unit installed in water treatment plant.

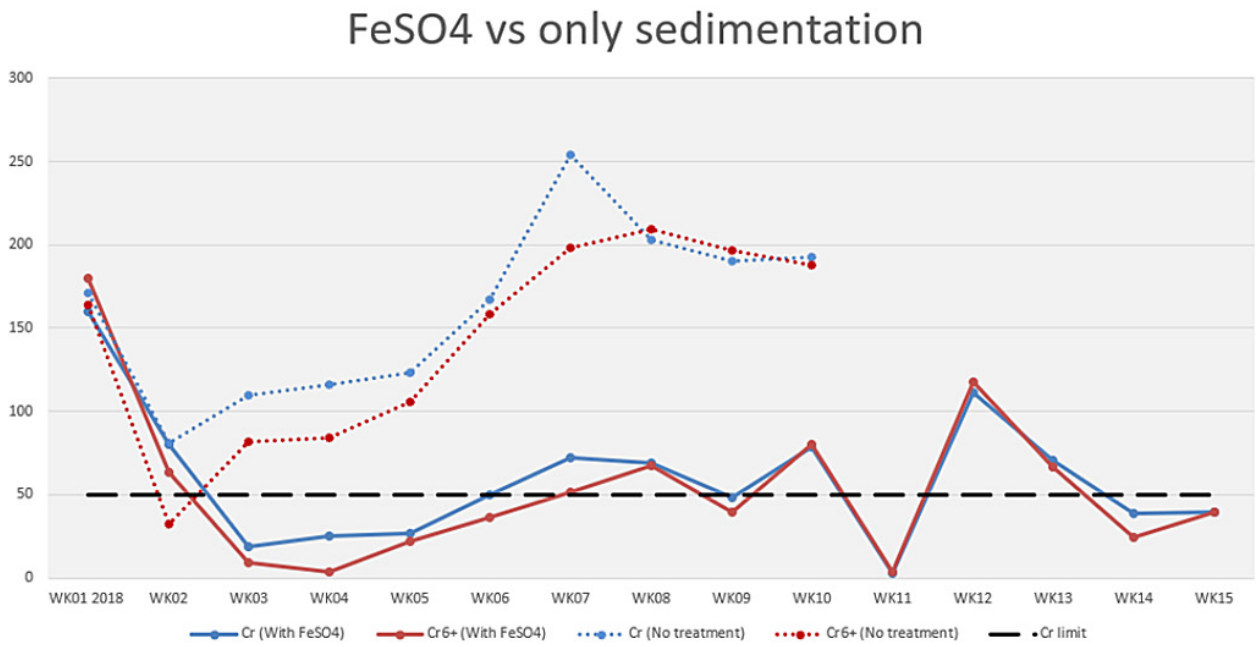


Figure 3.6.11. Comparison treatment with and without FeSO4.

Compared to the total amount of solids, the amount of chromium was so low that it did not affect the contamination level of the dewatered sludge (filter cakes).

As shown in the below graph, which compares wastewater treated with and without FeSO4 treatment, the FeSO4 treatment achieved an 80% reduction.

Chromium level in incoming wastewater varied over time, depending on groundwater intrusion in the tunnels, amounts of pre-grouting, and parallel work activities. There is no direct link to TBM as a driving method. Cement works combined with high water flows lead to elevated chromium levels.

As with all water treatment systems, and any type of recipe, dedicated operators and continued attention is essential for optimal result. While the principles of water management remain the same; project, site, and personnel specific factors will have a significant impact on the success of any water management system. Thanks to the resources assigned to this issue and the dedicated project personnel, AGJV managed to resolve this issue successfully.

References:

[1] Publication 24 - HEALTH, SAFETY AND ENVIRONMENT IN NORWEGIAN TUNNELLING, 2015. https://tunnel.no/wp-content/uploads/sites/3/2020/04/Publication-24.pdf

3.7 Waste management on tunnelling projects

The majority of materials currently used in the construction of facilities and during tunnelling are stored in the facility throughout the lifetime of the structure. With the exception of the materials that are extracted, sludge and water, a relatively small proportion of materials therefore become waste during the construction phase. Nevertheless, some waste is generated during construction that ends up among demolition debris and wastewater or is processed in the facility's waste system.

Rock, sludge and water are the major waste fractions on tunnelling projects. Large amounts of rock are blasted and have to be removed. Concrete, demolition debris and spills from the processes also end up among the waste materials. Spills and fine substances contribute to the contamination of the waste materials and sludge. Waste materials and sludge are defined as industrial waste and must be managed in accordance with the Norwegian Pollution Control Act (Miljødirektoratet, 2018a). Water from tunnelling must be processed in oil separators and sludge basins and, if required, additional cleaning steps must be applied to reach approved pollution levels before the water can be released.

Demolition debris found in waste or wastewater can be a challenge on tunnelling projects (NFF, 2009). Due to the high nitrogen content of explosive substances, the discharge of slurry can be linked to higher algal blooms in the sea as well as to fish deaths in smaller rivers and streams. pH adjustment

and neutralisation of nitrogen are therefore important measures in order to avoid pollution.

Other waste material generated during tunnelling has to be processed through the facility's waste management system. Statistics Norway estimates that 26% of Norwegian waste in 2019 came from the construction industry (SSB, 2021), of which 1.8 million tons from construction and 1.0 million tons from facilities. Please note that natural soil and rock materials are not included in these figures (Lindstad et al., 2021). The construction industry is therefore a very significant contributor to waste generation.

Norway complies with the EEA framework waste management directive which requires that a minimum of 70% by weight of construction and demolition debris (excluding hazardous waste) must be recycled (not including energy recovery) or reused (Norwegian Government 2013). In 2015, Norway recorded its highest reported material recycling rate for construction waste at 62%, but in reporting from Statistics Norway in 2018, the material recycling rate had fallen to 43%, with an energy recovery rate of 28% and a disposal rate of 28%. An important reason for the material recycling rate decreasing during this period was that stricter requirements were introduced for the reuse of concrete due to the content of chromium-6 above the limit values for permitted reuse. In 2020, the requirements and procedures for chromium-6 in concrete waste were changed, and the results of these changes remain to be seen (Lindstad et al., 2021).

National requirements for the degree of sorting of construction waste on site are 60% in accordance with the waste regulations and Chapter 9 External Environment of TEK17 (Statens vegvesen, 2014). It is nevertheless common to contract a higher degree of sorting among developers and contractors. For example, the Norwegian Public Roads Administration and BaneNOR require an 80% sorting rate for production waste (Bane NOR, 2019; Statens vegvesen, 2014). Among committed contractors, it has proved possible to deliver a sorting rate above 90% throughout entire construction projects. The market for recycled material, regulations and technical barriers mean that Norway is still not reaching targets for material recycling.

While there is a desire for a higher degree of material recycling, this must be balanced against ensuring that it does not cause pollution and that technical properties can be documented well enough for use. Regulations have to take multiple factors into account and are therefore perceived by many as a barrier to recycling and reuse.

Waste management regulations

Waste management is an important component in the planning of tunnelling projects. The contractor has to calculate the expected amount of waste on the project and prepare a waste management plan. It is a requirement that waste is taken to an approved waste reception facility, and using waste companies that offer deliver complete waste solutions, including logistics planning, is common.

Reporting

Requirements for reporting waste in building and construction projects are set out in Chapter 9 of TEK17 and SAK10, which is published by the Norwegian National Office of Building Technology and Administration. All building, rehabilitation and demolition projects subject to the Norwegian Planning and Building Act and Section 9-6 of the Norwegian Regulations on Technical Requirements for Building Works are required to prepare waste and environmental management plans and submit a final waste report at the end of the project. This also applies to all other construction and excavation projects over a certain size, including facilities where the project generates more than 10 tons of construction and demolition waste. Examples of facilities and constructions are tunnels, bridges, quay facilities, transformer stations, culverts, guardrails etc. (Statens vegvesen, 2014).

Waste management plan, final report and environmental management

The waste management plan is prepared in the project planning phase and must set out the handling of generated waste, divided into different types and amounts of waste. The final report is submitted at the end of the project and documents actual waste quantities. The amount of each type of waste, disposal location and processing method must be reported. This must be reported for various waste fractions, including paper and cardboard, iron and other metals, plastic, concrete and brick etc.

Fractions of hazardous waste must be documented in detail. The level of source sorting and quantities of each fraction calculated in the waste management plan must also be reported. Waste disposal or reuse/recycling must be documented.

In the spring of 2021, the Norwegian National Office of Building Technology and Administration (DiBK) initiated a process to revise and digitise waste management reports and final reports. The NHP network (National Action Plan for Construction Waste) and the construction industry are invited to provide input for the design of the plans.

There is currently no requirement for a format for the submission of waste management and final reports as long as all points requested in the forms are completed. Final reports are therefore submitted to the municipalities in different formats, and many are submitted manually. Until now, the reports have therefore been demanding in terms of data processing.

Reporting to client
In addition to the waste management plans and final reports, developers have contractual requirements for reporting waste quantities during projects. The different developers apply different systems for this, and the waste categories are reported differently than in the waste management plans and final reports.

In its contracts, the Norwegian Public Roads Administration applies requirements for contractors to submit monthly reporting through the ELRAPP system, which provides digital reporting of waste quantities. Digital reporting simplifies later data processing. Different practices for completing forms and requiring follow-up mean that the data presents some uncertainty and can be challenging to use in the comparison of different projects.

References:

Bane NOR. (2019). *Håndtering av avfall - prosedyre*. https://www.banenor.no/elkraft/veileder/STY-601325.pdf

DiBK. (n.d.). *Avfallsplan - Byggteknisk forskrift (TEK17) med veiledning - Kapittel 9 Ytre miljø*. Direktoratet for Byggkvalitet. Retrieved May 28, 2021, from https://dibk.no/regelverk/byggteknisk-forskrift-tek17/9/9-6/

Laugesen, J., Komulainen, V., Børresen, M., & Elander, P. (2020). *Plastics in the sea from blasted rock - prevention and measures*. Nordic Council of Ministers. https://doi.org/10.6027/temanord2020-520

Lindstad, M., Landet Rannveig Ravnanger, Nilsen Caroline Khoury BNL), Wærner Eirik Rudi, HansenRoar, Kempf Per Fredrik, Reiten Solvår, & Bingh Lars Petter. (2021). *NHP5 - Nasjonal Handlingsplan for bygg- og anleggsavfall 2021-2023* https://www.byggemiljo.no/wp-content/uploads/2021/02/20210215_Nasjonal-handlingsplan-NHP5_2021-2023.pdf

Miljødirektoratet. (2018a). *Faktaark M-1243 - Mellomlagring og sluttdisponering av jordog steinmasser som ikke er forurenset*. https://www.miljodirektoratet.no/globalassets/publikasjoner/M1243/M1243.pdf

NFF (Ed.). (2009). *Behandling og utslipp av driftsvann fra tunnelanlegg*. Norsk Forening for Fjellsprengningsteknikk. Teknisk rapport 09. www.nff.no

Norge Rent, H. (2021). *Rydderapporten 2020*.

SSB. (2021). *Avfallsregnskapet 2019*. https://www.ssb.no/avfregno

Statens vegvesen. (2014). *Håndbok R765 Avfallshåndtering*. www.vegvesen.no/Fag/Publikasjoner/Handboker

3.8 Resources

Decreasing the use of resources could be defined as the most important task in order to become more sustainable in all industries, so also in tunnelling. The general method of tunnelling is an important parameter in this regard and is discussed in earlier chapters. In this chapter we will look into other kind of measures that could improve sustainability within four groups of resources.

3.8.1 Ignition systems and Explosives

When it comes to the use of ignition systems and explosives, the most important issues when it comes to increased sustainability is to reduce the emission to air and to reduce the use of plastic (from the ignition system) which can follow the blasted rock back into the nature. Plastic waste from demolition and shotcrete that ends up in demolition waste is a problem that has received increasing attention in recent years, after plastic demolition cables and reinforcing fibres (PP fibre) from construction have been among the types of plastic found most frequently in Norwegian waters. Plastics from casings and junction boxes have also been found. Sea floor landfill is widely used in Norway, and when the materials containing plastic residue are deposited in the sea, some of the plastic will be deposited among the waste material while some will be spread by wind and currents to the detriment of wildlife and ecosystems and the pollution of beaches and coastline. Beach clearings and studies of plastics in the sea have found reinforcing fibres and demolition cables among the most common marine litter (Drægni & Falk-Andersson, 2019; Norge Rent, 2021).

Studies have been undertaken to understand the challenge, and attempts have been made to clean the waste of plastic, but this has proved demanding and has not been successful (Breyholtz, 2018; Laugesen et al., 2020). The Norwegian Environment

Agency has prepared a fact sheet with recommendations on how to reduce the problem of plastic spreading from demolition debris (Miljødirektoratet, 2018b). The fact sheet recommends the use of steel reinforcement rather than PP reinforcement in shotcrete, which seems to have led to reduced emissions of PP fibres. The Norwegian Environment Agency has also recommended the use of electronic igniters to reduce plastic waste from demolition cables. This results in a reduced volume of plastic, and the plastic that is released sinks and is deposited among the waste material without spreading. The increased use of barriers to prevent spread in the discharge area is recommended as are requirements for cleaning up plastic particles in the area around the ocean floor landfill and keeping records of the plastic (Miljødirektoratet, 2018b). Many clients have followed these recommendations and stipulated requirements for developers in contracts.

NFF knows about two initiatives that can influence the sustainability within this area. One is described in the article for Hypex bio where they are developing a nitrate free explosive from water.

The other initiative is the use of a wire-less ignition system. This will make plastic or metal wires redundant from the borehole to the igniter. So far, this system has been through a successful trial period in the mining industry. However, the cost for this system is far above the level that is feasible within the tunnelling industry, yet.

References:

Breyholtz, B. (2018). Testforsøk - spredning av plast i sjø fra utfylte tunnelmasser skutt med elektroniske tennere. Aldersundet - Rassikringsprosjekt Rv 17 Liafjell.

Drægni, T. T., & Falk-Andersson, J. (2019). Strandsøppel Dypdykk Oslofjorden, SALT. https://www.oslofjorden.org/wp-content/uploads/2019/05/Strandsøppel-dypdykk-Oslofjorden-1.pdf

Miljødirektoratet. (2018b). Problemer med plast ved utfylling av sprengstein i sjø. https://www.miljodirektoratet.no/globalassets/publikasjoner/m1085/m1085.pdf

3.8.2 Handling, Treatment and Disposal of Rock Masses

Jan KG Rohde, Sweco

Introduction

As said in the ITA report no. 21/April 2019 (ref. 1):

Figure 3.8.1. Loading of tunnel muck at the Rosten HEPP, Norway. (Photo Ø. Fæhn.

Handling, treatment and disposal of tunnel muck is today a fundamental issue in an underground project. Considering the potential cost reduction, possible income and environmental effects of tunnel muck, the proper and environmental sensitive disposal is an essential issue of the Life Cycle Assessment (LCA) of a tunnel project. Used directly in the project, there are both environmental and cost benefits.

The statement is valid for any kind of excavated rock, coming, either from tunnels, cuts or any other kind of construction site.

Opportunities

The potential use of excavated rock masses is several, but it depends both on geology and nature of the rock as well as method used for excavation. As examples for use of excavated rock materials, the following might be mentioned:

- Embankments, foundations and landfill
- Land reclamation
- Landscaping
- Earth and rock-fill dams
- Aggregates for concrete and asphalt pavement
- Sub-base, pavement, ballast and superstructure
- Erosion, shore and slope protection
- Masonry walls and gabions
- Rockfall defence
- Construction sites
- Backfill to borrow areas and landscape rehabilitation

In human history, there are long traditions in using rock masses as construction material in projects, already from the early cave man's history.

In roads and railway projects, where mass balance is the goal, the common way of using excavated rock

from tunnels and cuts, has always been in embankment fills along the alignment. In the past, bridges, retaining walls and tunnel lining were built from large rock blocks and rock masonry, structures with artificial, cultural, engineering and historical values. If necessary, separate quarries were opened to produce rock masses for construction purposes in the projects.

By the way, today, rock has its renaissance in construction of retaining walls, as commonly used in the "good old days".

Figure 3.8.2. Raumabanen, the Arche Bridge made from masonary, natural stone.

Figure 3.8.3. The E6 – Dovrebanen Joint Road and Railway project along the lake Mjøsa in Norway, excavated rock used as embankment fill, landscaping, concrete aggregates or temporary stored at Kolomoen for future use (Photo NPRA).

Figure 3.8.4. From the IC Dovrebanen Railway project, good quality rock used for ballast.

Figure 3.8.5. Overview of the Førsvatn rockfill dam, Kjela HEPP, Telemark Norway (J. Rohde 1976).

In hydropower projects, a common use of excavated rock masses, has been for preparation of site foundations, construction of rockfill dams, erosion protection of waterways, internal road embankments and permanent embankment fills for the hydropower plant.

If good quality rock was available, the rock masses were processed and used as aggregates for construction purposes. in superstructure of roads, ballast for railways and as aggregates for asphalt and concrete production. In hydropower plants, processed rock materials have also been used for filter and core materials in embankment dams with asphalt core.

If no, or limited use of the excavated rock is found in the project or locally, rock related opportunities may be turned into problems. In former years, a common practice was to find the cheapest and simplest way to "get rid of" the spoil, either in a nearby dumping site, or leave the problem (or opportunity?) to the contractor for further use of the rock spoil if possible.

Figure 3.8.6. Crushing plant at the Vestfold Railway Project.

Figure 3.8.7. Stationary and mobile rock mass processing plants at the Follo Line Railway Project (B. Gammelsæter).

Today, the national upgrading of the infrastructure in Norway, with highways, railways, water and sewer projects etc. produce large volumes of rock masses both locally and regionally. In addition, there are several planned and ongoing projects above and underground around the country, producing large volumes of rock. The volume of rock produced, far exceeds the local need of rock material during the construction period. Timing of different projects is unfavorable, there is lack of space for temporary storage, and the distance to a potential marked is too far. Potential opportunities and benefits are turned to problems.

Figure 3.8.8. Tunnel muck is a valuable resource, here dumped right outside the access opening to an underground hydropower project (Photo Ø.Fæhn).

During the on-going green shift there has been a change, with great focus on the environmental aspects, sustainability and cost benefits by looking at the excavated rock as a potential source instead of a problem. Studies and research programs have been started, reports produced, and strategies are implemented in project planning, contracts and execution of tunnel projects and other projects with rock excavation and production of rock materials. Plans for handling use and disposal of excavated rock are prepared, and under preparation on local and regional levels to coordinate different “rock producing” projects within regions. Strict national rules and regulations are implemented to reduce the negative environmental effects and CO_2 footprint during excavation, handling, transport and disposal of excavated rock materials, and to improve the sustainability of the projects. Handling, treatment and disposal of large soil and rock volumes has become a big national, economic and environmental issue.

Two examples to mention in this setting are the program “Kortreist stein” and the initiative Bærum Ressursbank both are decribed in chapter 3.8.4.

In most of the projects today, soil and rock management plans are prepared, where focus is on opportunities, cost and environmental benefits.

In some contracts, ideas for potential use of excavated rock materials are implemented as incitement for the contractors during tender competition.

Rock masses from conventional D&B vs. TBM tunnels in Norway

Besides geology and mineralogy, quality of excavated rock for construction purposes highly depends on method of excavation.

In Norway, conventional drill and blast is commonly used for rock excavation, short and simple mobilisation, flexible with respect to various cross sections and low risk related to various geological conditions, water issues in tunnels and technical problems, high skills, professional experience etc.

During the final period of the major hydropower development in Norway, hard rock TBM became an attractive alternative for long tunnels (>2 – 3 km) and had great benefit of the smooth tunnel walls

Figure 3.8.9. Charging a new round at the OREA sewer project in Strømmen near Oslo (photo E. Hannestad, Sweco Norge AS).

Figure 3.8.9. An overview of the Follo Line construction plant at Åsland.

with less friction, and as a consequence, reducing of the tunnel cross section with a considerable reduction of the tunnel spoil volume.

In recent tunnelling in Norway, TBM has been used in the Røssåga hydropower scheme, the Follo Line highspeed rail project between Oslo and Ski, and the Ullriken railway tunnel in Bergen. TBM tunnelling has also been selected as the preferred method for excavating the tunnels in the Oslo Water Supply Project, the raw water tunnel from the Holsfjorden lake tunnel to Huseby underground water treatment plant, and clean water tunnel for further distribution in Oslo.

Important physical differences in excavated rock from conventional D&B and mechanised TBM tunnels are the following:

- Grain size distribution (GSD) curves and shape of the grains
- Content of fines
- Friction angle and cohesion
- Compaction properties as optimal water content and densities

Typical GSD curves and grain shapes from Norwegian tunnels are presented in figure 3.8.10.

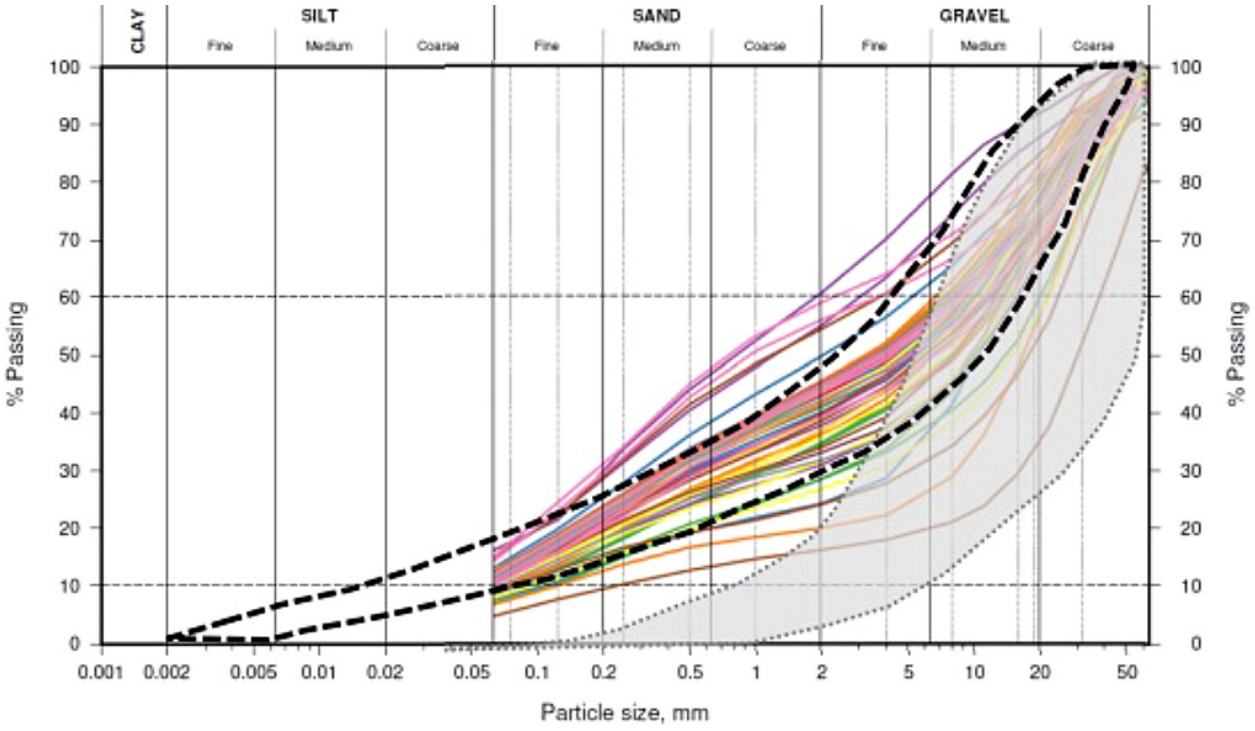


Figure 3.8.10. Grain size distribution curves from the Follo Line Project (in colours), dotted lines give the envelope for GSD curves from TBM in general, and gray envelope for conventional drill and blast GSD curves.

Figure 3.8.11. Overwiew of the TBM tunnel spoil deposit at the Follo Line, foundation of a future township outside Oslo (Photo: BaneNOR).

A majority of the excavated rock from the Follo Line Project, is used as embankment fill for a future township at the abandoned quarry at Åsland (figure 3.8.11). Originally, it was also the intention to use the TBM tunnel spoil for concrete production, mainly segments for the tunnel lining. Unfortunately, it was discovered a too high content of the mineral pyrrhotite in the bedrock.

For evaluating the stability and settlement properties of the TBM masses, triaxial and Standard Proctor tests of the materials have been performed. Results of triaxial tests of rock materials from D&B and TBM projects, are presented in figures 3.8.12. and 3.8.13.

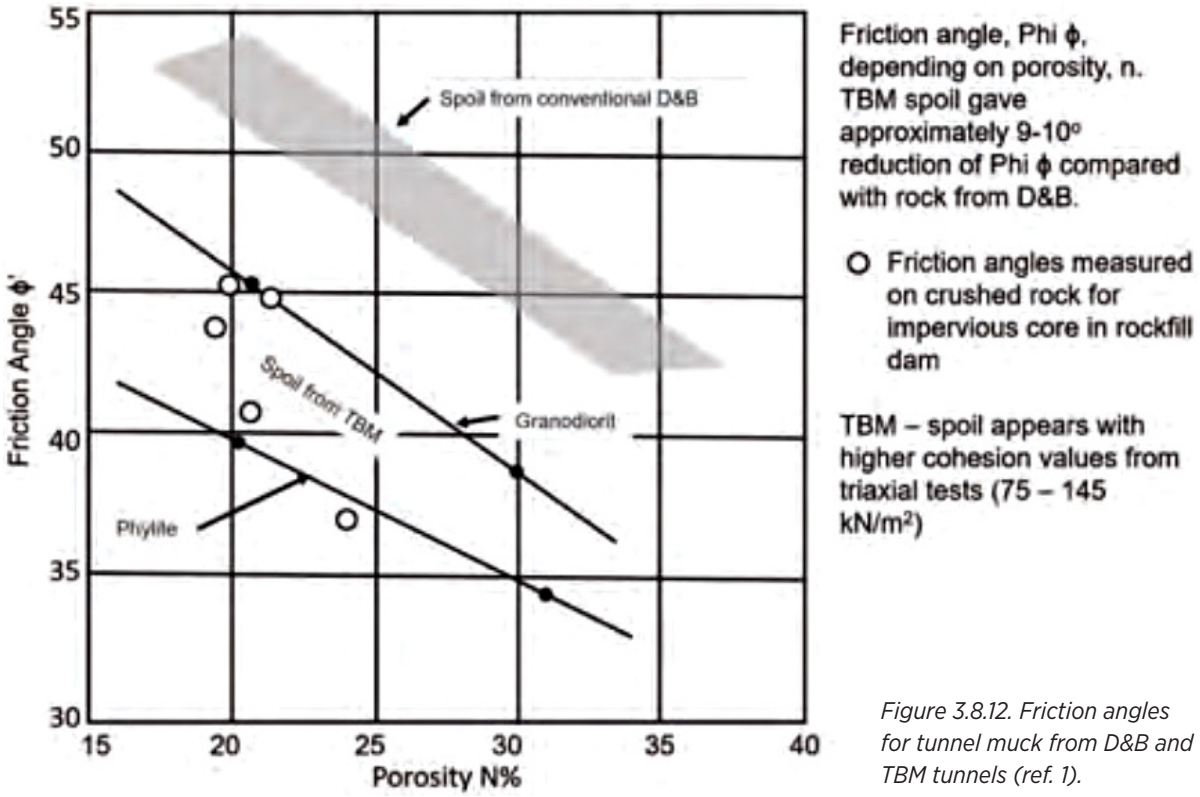


Figure 3.8.12. Friction angles for tunnel muck from D&B and TBM tunnels (ref. 1).

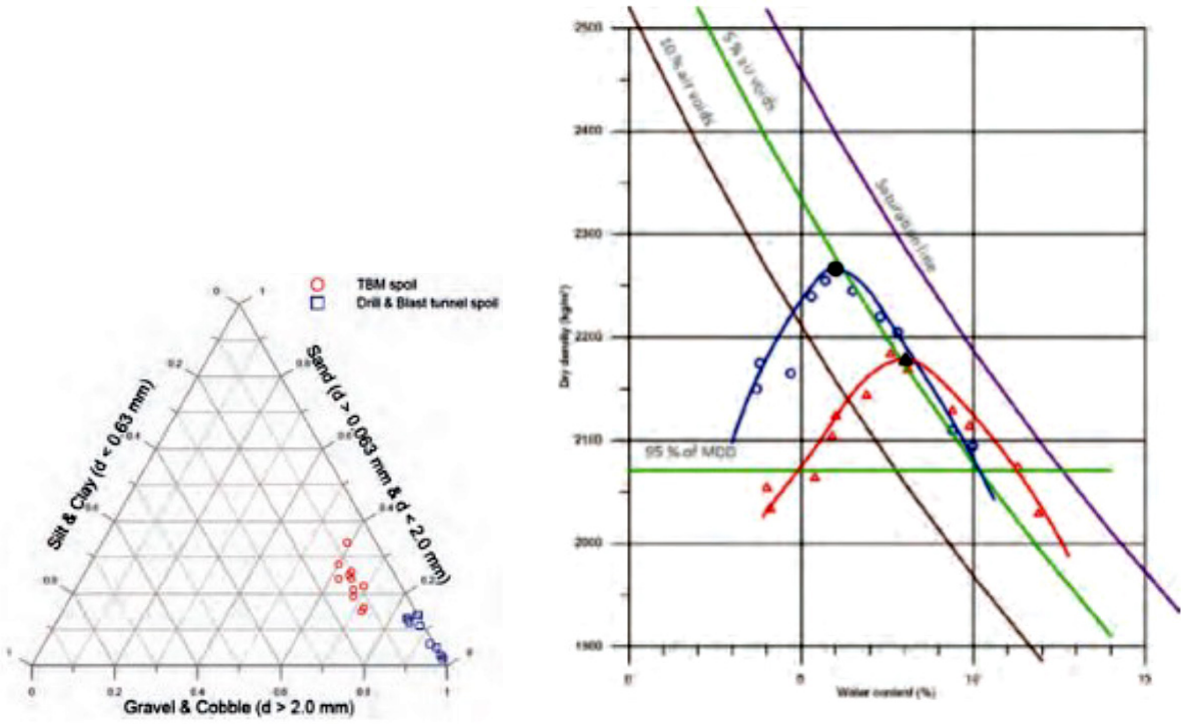


Figure 3.8.13. Diagrams with typical particle size for drill and blast and TBM tunnels (left) and result from SPT test on TBM samples (Statkraft/NGI).

3.8.3 Use of local rock materials in Norway

Author Torun Rise, SINTEF AS

Background

The yearly need for aggregates in Norway (pop 5.5 million) is approximately 13 metric tons pr person. Fifty percent of all production of aggregates in Norway is used in road construction, and twenty percent of all heavy weight transport in Norway is related to transportation of aggregates [1]. Based on this, the project "Use of local materials" ("Kortreist stein") [2] was carried out in 2016-2019. This project was finances by partners from the industry and the Research Council of Norway.

The main goal of the project was to evaluate the possibilities and limitation due to use of local materials from for instance tunnel projects.

Tunnels and infrastructure projects generate several million tons of excess materials every year. Most common is that these materials are deposited in the area where the projects are located, with no plan for further use. A large surplus of rock materials, especially large amounts in a short time, can make it difficult to find alternative areas of use locally. This may result in the fact that valuable resources are lost, e.g., by being dumped into the sea or nearby lakes. There are examples where the materials have been used locally, but then often for low purpose (low value) tasks such as fillings, despite having the quality to be used for other more high-grade purposes.

Kortreist stein

In the program "Kortreist stein" (translated to "Use of Local Materials"), several large road and railway construction projects were evaluated. Several examples of good "intentions" in programs and in municipal area plans were discovered, but they commonly lack a clear connection to the individual project plans, and there were often no areas allocated for sorting and storage of the rock materials. The evaluation also found that the intentions in the zoning plan often are not followed up. There was no clear trend in the projects that were evaluated, except that the surplus rock material often was deposited in the cheapest possible way.

In general, there are several potential savings in the use of local materials. Reduction in transportation involves, among other things, a reduction in transportation costs, road abrasion, dust, and noise. Transportation costs can often be more expensive than the transported material. It also involves reduc-

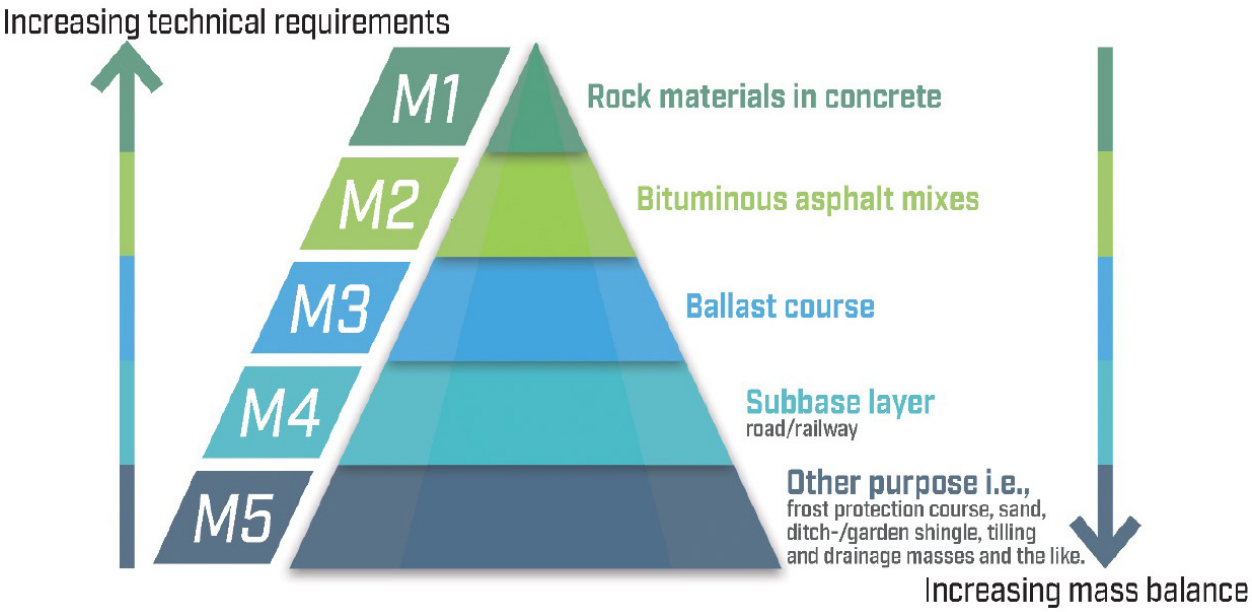


Figure 3.8.14. Optimal use of local materials involves utilizing the technically best materials where good functional properties are particularly important, i.e., use that impose strict material requirements such as concrete and asphalt (M1-M3), while other materials can be used for other purposes (Illustration: SINTEF/Kortreist stein [2]).

tion of environmental impact, and reduction of greenhouse gas (GHG) emissions. In short, the use of local materials improves the project economy, enhances the green profile, all while reducing the depletion of a non-renewable resource.

Based on all the advantages, why is not local materials used in a larger scale?

The Kortreist stein project pointed out 4 main challenges:

- Quality of the rock materials
- Enough area
- Contract form
- National demands and requirements

Quality of the rock materials

The quality of the local rock materials is often considered the main constraint for further use. It is therefore important to have enough information about the rock mass quality as early as possible, preferably already when the zoning plan is prepared. This is important for being enabling good plans for the implementation of the projects and for the utilization of the local materials.

In Kortreist stein a guide was developed [3] with recommendations for investigations and evaluations that should be performed at different planning phases in an infrastructure project, and which information should be gathered for a better utilization of local rock masses. The guide also gives an overview of rock masses in Norway and their suitability as building materials.

The purpose of the guide is to be a supplement to the already existing guidelines from the Norwegian railway and road authorities and may be used at all stages of a project – from early phase to the zoning plan. These guidelines also assist planners of infrastructure projects with preliminary studies of geology and rock quality, to incentivise a higher value utilization of surplus materials from infrastructure projects.

There are different demands for different purposes, for instance the demands for aggregates for use in asphalt and concrete, are stricter then aggregates for use in ditches. This is illustrated in figure 3.8.14. By evaluating the available geological information properly and, if necessary, including additional surveys, the rock masses can have higher value and be used in a more optimal way. These surveys and later analysis help to increase the knowledge about the rocks and their properties and the volume of the different qualities. Based on this, it is also possible to get an overview of what purpose the rock masses can be used for, and the size of the areas that are needed for intermediate storage. When all of this is planned early enough, optimized utilization of surplus materials is possible.

Enough area
It is also important to have enough areal capacity for sorting, processing, and store rock materials at or near the construction site. These areas should be on the agenda as early as possible in the planning process, and preferably marked off and allocated already in the zoning plan. This is also very important due to providing necessary space to be able to keep separate qualities apart.

Contract form
The contract form was identified as one of the success factors for accomplishing more efficient use of local materials. Early involvement is often referred to as one of the major success criterions. If the contractor gets involved late in the planning process, as an example when the project has been planned for several years, it has been found that it is often difficult to make big changes. This limits the projects opportunity for planning and choosing the most rational solutions.

Other important elements related to contracts, is the risk-sharing between the building owner and the contractor, as well as a clear understanding of the responsibilities and involvement in the contract. The parts should have a common agreement of the project goal for aspire to use local materials. Other instruments, such as incentives, can also be used to promote a project's mass balance and use of local materials.

National demands and requirements
The management of naturally occurring materials is regulated by a complex set of legislations. This is based on, but not exclusive to, environmental legislation, waste legislation, soil legislation, land use and building regulations [4]. The Planning and Building Act [5] is fundamental for regional and local areal planning in Norway. There are also a lot of other regulations due to extraction of rock materials, such as the Mineral Act and the Pollution Act. These regulations include all building projects and extraction of rock materials. As concluded in Kortreist stein, there is a need for clarification on these regulations for extraction of local materials in construction projects, versus ordinary aggregate plants.

There are also several technical regulations due to use of rock materials, for instance regulations for masses for use in road construction, railway construction and as aggregate in concrete and asphalt.

Status in Norway today
As described in the introduction; the annual need for aggregates in Norway is approximately 13 metric tons pr person. Approximately 15-20 percent of the produced materials from an aggregate plant is classified as waste because the production results in materials that does not meet the expected quality or properties required by the market standards [6]. It is also known that rock masses, and especially high-quality rock masses, are a non-renewable resource, and that they in some areas, especially around the biggest cities, is becoming a limited resource.

Based on this, extraction of rock materials should be seen in a broader context, with both regulated aggregate plants and temporary plants/construction sites. Therefore, it is important that every project where rock masses are excavated, make evaluations regarding the possibilities for using the materials. These evaluations should be made as early as possible in the planning process, and include elements such as rock quality, mass balance and location of areas for sorting and storage of rock materials.

After the Kortreist stein project, there have been several projects related to the same issue: a better utilization of rock materials in Norway. In the next section, a few projects are described. It is important to mention that there are also several other ongoing projects and initiative in Norway, but not all of them are mentioned here.

Bærum Ressursbank
Bærum municipality has established "Bærum ressursbank (Eng: resource bank)" which is a working to maximise reuse, recycling and find relevant areas of use for surplus masses from building and infrastructure projects. In the next decade, several big infrastructure projects are planned in Bærum, and it's expected that they would generate approximately 25 million tons of masses. This is estimated to generate 943 000 truckloads with a total driving distance of 141 million kilometre. The purpose of Bærum ressursbank is to set focus on these surpluses as a resource that has a value that can be reused or recycled, rather than being treated as waste [7].

Look to chapter 3.8.4.

Circular Management of Rock Materials
In the project "Circular management of rock materials", the project owner Feiring Bruk AS in collaboration with SINTEF, NGU and Fremby, aims to develop a new service to improve the use of rest materials in the construction sector. The new service will establish a business model where Feiring takes a role as a "material coordinator" between different projects in a given region. Today, Feiring mainly sells rock aggregates (virgin materials). However, a new service would enable the company to reduce the

depletion of their own non-renewable recourse, while simultaneously increase their marked shares by offering quality rock materials from external projects, which otherwise would have been sent to deposit for an extra cost to the project owners and construction firms. If successful, the construction firms will be able to sell their excess masses to Feiring, who will test, process (for example crush), and ensure the quality of the material, before reselling it to nearby projects – with the same guarantees, traceability, and documentation as their main product.

Further work

Materials from building and infrastructure projects represent a high resource potential, if used more efficiently. These materials also represent a very important contribution to the need for materials for road construction, buildings, and other purposes. A better way of using the resources is both important and necessary to ensure the need for masses, it is also included in the UNs sustainable development goals, for example in goal 12: Responsible consumption and production.

There is a need for a better resource management in Norway, both locally in the projects, but also on a regional and even national level. As described in this article, there are several challenges along the way, such as quality of the rock materials, enough area, contract form and national demands and requirements. There is also a huge potential with several possible advantages, for example improved resource management, environment, sustainability, and economy. Further focus will be needed to improve the use of local materials, while moving towards a more environmental and sustainable construction industry.

References:

[1] T. Rise, L. Alnæs and I. Rambæk, "Oppnådde resultater i prosjektet Kortreist stein (2016-2019)," SINTEF, ISBN 978-82-536-1643-8, 2019.

[2] "www.kortreiststein.no," [Online].

[3] K. A. Aasly, A. Margreth, E. Erichsen, T. Rise and L. Alnæs, "Forundersøkelser og bruk av kortreist stein, En geologisk veileder," SINTEF Fag 62, ISBN 978-82-536-1645-2.

[4] Nordic Council of Ministers, "Survey of the emergence and use of naturally occurring materials," https://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A1593210&dswid=4764, 2021.

[5] Regjeringen, "https://www.regjeringen.no/en/dokumenter/planning-building-act/id570450/," [Online].

[6] I. Sundvor, S. A. Jensen and G. N. Jordbakke, "Tiltak for utslippsreduksjon fra transport av masser i Oslo. Vurderinger fra næringslivsaktører," TØI rapport 1772/2020, https://www.toi.no/getfile.php?mmfileid=53311, 2020.

[7] Bærum kommune, "https://www.baerum.kommune.no/politikk-og-samfunn/samfunnsutvikling/om-barum-ressursbank/," [Online].

3.8.4 Bærum Ressursbank

Tore Gulli, Ingeborg Briseid Kraft og Kjersti Kvalheim Dunham

Bærum Ressursbank is a pioneering initiative of the Bærum municipality in Norway to enable a collaborative approach between state-owned entities and the private sector in the sustainable management of surplus masses such as rocks, soil and stones excavated during the construction of massive infrastructure projects.

The major thrust of the Bærum Ressursbank is to focus on creating an innovative model for delivering practical solutions to the complex challenges in relation to areas for storage and treatment of surplus masses, risk assessment, costs, zero-emission logistics, environmental compliance, and guidelines.

Set up in the face of an impending challenge of managing over 25 million metric tons of rock, stone and soil that is expected to be excavated from six major infrastructure projects over the next 10 years in Asker, Bærum and Oslo municipalities, the Bærum Ressursbank leverages the following principles:

- **Circular economy:** The excavated masses of stone, soil and rocks must be viewed as reusable resources and not as waste even though Norway is sufficient in rock and stone.
- **Collaborate to innovate:** An effective route to sustainable resource management must be based on a shared responsibility between all stakeholders—and not just the suppliers—to create innovative solutions, manage risks, exchange knowledge as well as best practices.
- **Regional and cross-sectorial perspectives:** A balanced resource management approach must go beyond individual projects and include regional perspectives.

Market system: Bærum Ressursbank proposes a market system for utilizing surplus masses locally as it envisions a circular economy-based value chain. Together with physical storage spaces for surplus mass that the Ressursbank has helped identify, the market system would help optimize logistics, lower pollution, and reduce compliance costs for construction companies.

As a model of collaborative approach, Bærum Ressursbank is seeking solutions for a market-based system from private players in the infrastructure space. A collaborative platform called the **Bærum Ressursbank Forum**, has also been set up for state-owned infrastructure entities, private players, municipalities (Asker, Bærum and Oslo), environmental agencies, politicians, and researchers to come together to explore solutions together. Bærum Ressursbank invites all stakeholders in the environment and infrastructure fields to contribute ideas, knowledge, and best practices to realize the potential in sustainably managing naturally occurring materials from development projects.

Om Bærum Ressursbank | Ombruk | Bærum kommune (baerum.kommune.no)

3.8.5 Steel

Steel is a product that is part of a cycle, and is therefore an important part of the circular economy. An important step in the cycle is that scrap steel can be recycled in electric arc furnaces. After the steel has melted, it can appear in a completely new form and with a new purpose.

All steel used as reinforcement is recycled steel. And one of the main producers of rock bolts also uses recycled steel (and plastic) for their products. Developments show that the steelworks are increasingly using the scrap-based method for producing steel. The need for steel produced from ore can therefore be expected to decrease in the future. How long before scrap-based production dominates, and the cycle is self-sufficient, is uncertain. An important factor for the success of this conversion is the availability of enough scrap steel. Steel is completely recyclable and is the world's most recycled product (BOB and EPA). A crucial reason for this is a well-functioning international market for scrap steel trading. The most important factor is the scrap-based steelworks, which use large quantities. This whole cycle has incentives beyond the economic aspect, and this contributes to the steel industry being sustainable. Steel production produces waste such as slag, chemicals, oils, metals, dust and exhaust fumes. This was previously only dumped. Today, all by-products from steel production are largely 100% utilized. For example, slag is used in road construction, valuable metals are separated from the dust and can be used, for example, in mobile phones. The exhaust gases are currently used in the production of electricity.

As of today, we do not produce any steel in Norway, but we will use this opportunity to talk warmly about our friends in Sweden where they do have several producers of steel (SSAB, LKAB and Vattenfall). Together, they make a unique investment to fundamentally change the Swedish iron and steel industry. Under the name HYBRIT (Hydrogen Breakthrough Ironmaking Technology), they work together to develop the first fossil-free steel. The first delivery was done in August 2021, and they expect full scale implementation by 2026. A game changer when it comes to carbon footprint.

https://www.norskstaal.no/om-oss/miljoe-og-baerekraft/groennere-staalproduksjon-i-dag

https://www.hybritdevelopment.se/en-fossilfri-framtid/

3.8.6 Concrete

Untapped Potential – use of rock masses to prepare geopolymer concrete
Stian Rossi - Saferock

An alternative to Portland-based concrete is geopolymer concrete – a type of inorganic polymers consisting of minerals, typically stemming from waste streams from mining industries and power plants. Furthermore, excavated rocks and other rock masses could potentially also be used to prepare geopolymer cement and concrete. This provides a unique opportunity, as there is less need to dispose of the excavated rock masses.

Geopolymers are a type of alkali-activated materials, where the precursor material, such as rocks rich in silica and alumina, is mixed with a liquid activator to produce a hardened cement binder. Subsequently, the geopolymer concrete is prepared by addition of aggregates, as for conventional concrete.

Consequently, since geopolymer concrete do not contain Portland cement, this type of concrete has a significantly lower CO_2 footprint than conventional concrete. In fact, the production of geopolymer cement has a CO_2 footprint that is at least 70 % lower compared to the production of traditional Portland cement (reference values from the Norwegian Concrete Association). In addition, geopolymer concretes have several properties that are

favorable compared to conventional concrete, such as higher temperature and chemical resistance, as well as significantly lower permeability.

Start-up company Saferock is now working on developing a geopolymer concrete based upon mine tailings from a local ilmenite mine in Rogaland. Current emphasis is on improving strength development, workability, and durability, as well as lowering CO_2 emissions even further. It is hoped that by 2025, it will be possible to manufacture it in a carbon-neutral process so as to sustainably lower the construction industry's carbon footprint.

Reuse of concrete
Elise Mühlbradt BaneNOR

At Follobanen, a campaign has been implemented to reuse the concrete that was used to develop the construction site at Åsland. Concrete floor slabs for the segment factory and other structures were initially going to be demolished and were destined for landfills but will now be used for other purposes. There are mainly three different purposes for which the concrete at Åsland has been/will be used:

1. Backfilling of access tunnels
There are two access tunnels at Åsland. These were initially to be sealed using blast rock from the tunnel in the form of a constructed plug. The purpose of this plug is to carry the load that is to be filled at Åsland, so that an even elevation is achieved for the entire area. In addition, an air pocket was designed between the constructed plug and a watertight concrete plug lower down in the access tunnels. In collaboration with the contractor, a proposal was prepared whereby crushed concrete in the air pocket and a constructed plug made of reused concrete are deposited. In total, approx. 9 000 m3 of crushed concrete will be used in the two access tunnels which, per se, will result in savings of 80 000 kg CO_2.

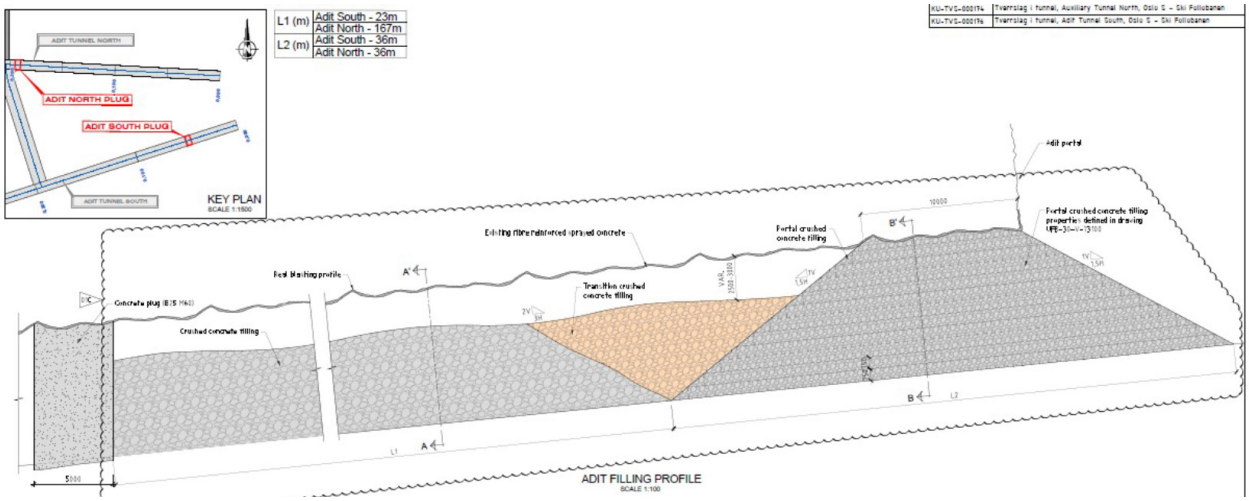


Figure 3.8.15. The filling profil of access tunnels.

2. Substructures for roads at Åsland.
Approx. 2 500 m3 of the concrete has also been crushed according to road standards, so that it can be used for substructures on roads that are to be established at Åsland once the area is returned.

3. Filling material in assembly chamber
Approx. 600 m3 has been used to fill areas where the TBMs were previously installed, so that the escape routes are brought to the correct height in proportion to the railway.

Figure 3.8.16. Chrushed concrete.

Figure 3.8.17. Hammering of concrete slab.

Figure 3.8.18. Reinforcement steel.

Figure 3.8.19. Crushing plant.

SUPERCON and TIGHT – research projects aimed at reducing the environmental footprint of cement-based works in Tunnelling
Eivind Grøv

The requirements from the Greater Society
In 2021 the humankind got more than one 'wakeup call' on the status of climate development. The first one was the report from the UN Climate Panel which by the Secretary General of UN was called 'Code Red' for humankind. Later the same fall the G20 summit took place in Rome in Italy, and this was closely followed by the COP26, United Nations Climate Change Conference, in Glasgow in Scotland. At the same time, the Intergovernmental Panel on Climate Change (IPCC) concluded that climate changes are coming quicker, are more intense, and that the point of no return is approaching if the same trend continues. The COP26 concluded that the goal of our efforts is to pledge further cuts to emissions of greenhouse gasses to keep temperature rises within 1.5°C - which scientists say is required to prevent a climate catastrophe. The international collaboration that translates to national goals for preventing climate change form the base for the entire population on the Blue Planet today on the way forward. The tunnelling and construction industry, which is internationally a huge business needs to be a part of this and take its share to reach these goals.

The tunnelling industry is in many cases providing solutions that contribute to counteracting the climate catastrophe that is being forewarned. However, in the production of these solutions, the tunnelling industry has a long way to go to become a beacon showing the way to reach the goals of the UN Climate Panel and the COP26 Summit.

Looking at GHG emissions for transport infrastructure tunnel today, approximately 50 % of it relates to the construction stage, and the second half relates to operation and maintenance. Looking at the construction stage, the main contribution to GHG emissions is the casting and tunnel lining which alone stands for approximately 50 %. Rock mass grouting contributes around 10 %. A major contribution of GHGs in tunnelling is based on activities where cement is a dominant material. To be able to reach the global goals that have been outlaid by the UN and similar overarching bodies, the tunnelling industry must move forward with solutions and concepts for safe tunnelling, sustainable projects, and environmental consciousness.

Environmental demands
For the tunnelling industry to move towards increased sustainability and significantly reduce emissions, new solutions and methods need to be embraced. One of the most important tunnelling tools to be used would be to encourage the use of more sustainable solutions and materials resulting from environmental demands in contracts. Other possibilities are e.g., early involvement and integrated project delivery. Clients and infrastructure owners can make a difference by instructing direct demands in the tender documents on environmental

requirements for all works to be done and all supplies to be delivered. Implementation of research results and changes in practices occur faster if there is a demand or a type of incentives for the contractors. On the other hand, detailed instructions and demands in various standards can hinder innovation in projects and prevent new technologies from being used.

The tunnelling industry has seen a change in attitude concerning the use of electrical vehicles at tunnelling sites. The industry has moved quickly from diesel driven vehicles to electric driven vehicles for passenger transport, loading and hauling, and other equipment. These are direct responses to clients and owners demands on improved environmental performance and focusing on sustainable projects.

There is no secret that concrete, or cement as a raw material in tunnelling contributes significantly to the carbon dioxide emissions in the tunnelling industry. The tunnelling industry is using cement for rock support (sprayed concrete), for pre-excavation grouting (cement based) and in many cases for the final lining (cast-in-place concrete and concrete segmental lining).

In this context environmental measures need to deal with both the solution itself (a) and (b) the use of materials.

Under point (a) it would be appropriate to question the large amount of materials used when designing tunnels in hard rock conditions and in favourable ground, the requirement to apply cast concrete lining, and the requirement for several decimetre thick sprayed concrete appears unnecessary. Furthermore, doubting the process of pumping cement for pre-excavation grouting for hours and days into the ground, filling up rock joints that are tens of meters away from the tunnel.

Under point (b) it would be appropriate to question whether it is possible to reduce the cement content in the concrete mix design and replace cement with other materials with less carbon intensity, or if it is possible use other materials to obtain the same or better functionality.

The role of research - SUPERCON and TIGHT

The research project TIGHT (True Improvement in Grouting High pressure Technology for tunnelling) included research that produced more cost- and time-effective grouting methods that will benefit the tunnelling society in large. The project also included research that aimed at paving the way forward for rock mass grouting in a way to reduce the carbon dioxide emissions. This was done firstly, by reducing the quantities of cement employed in these works. Secondly, by considering the mix design and its constituents. As a by-product of TIGHT, the idea was born of initiating new research projects that would investigate new materials and substitutes for the large amount of cement that is actually used in cement-based pre-excavation grouting.

Another result of TIGHT is the fact that the tunnelling industry in Norway has cooperated to develop the future procedure on pre-excavation grouting, with the aim of developing procedures that are cutting the material consumption in grouting, thus reducing emissions of carbon dioxide. This procedure involves all aspects of the normal work that are related to grouting, namely; pre-construction testing, determining stop-criterion, selection of grout material and mix design, to mention some.

There is a need to develop competence in more eco-friendly tunnelling, including more eco-friendly concrete mix designs and more durable and functional SCL, contrary to the current trend towards the use of cast in-situ and precast concrete. SINTEF, together with a handful of industrial partners, NGI, and NTNU, established the research project SUPERCON – Sprayed sUstainable Permanent Robotized CONcrete tunnel lining – developing sprayed concrete technology for a green shift in the tunnelling industry.

In the research project, the team will look at how pozzolanic materials could be used in sprayed concrete to replace cement; how to fully automate spraying to make the process more efficient; understanding material properties, design and application in order to increase durability; and new approaches to structural design to allow thinner layers of SCL to be used. Achieving these goals, the project outcome will lead to a leaner construction of tunnels which again will cause less impact on the environment.

The ultimate goal of SUPERCON is to develop watertight and crack-free sprayed concrete. This would make tunnels more economically viable which in turn will have a positive impact on the health and prosperity of communities. In the long run, the project will lead to safer and environmentally better tunnels, which at the same time shortens traveling times within the country. The realization of tunnel projects will also benefit the local communities by transferring traffic underground.

Through these two initiatives, given that our research meets its goals, a substantial contribution to emission reduction in the tunnelling industry will be provided.

3.9 Electrification of machinery

Figure 3.9.1. The new generation electric front loader, developed by AMW in cooperation with Skanska (Photo: Skanska).

3.9.1 Zero emission tunnelling: Electrification is key

The zero-emission pledge is being piloted by the major cities, and already within 3 years – by 2025, Oslo is determined to be zero emission on all of its construction projects. Major projects like Fornebubanen subway system and new water supply involve tunnelling - and will have to comply. City of Bergen is even more ambitious, promising zero emission construction on all its projects in 2023.

The application of electric machinery underground is nothing new – providing advantages such as improved working conditions by eliminating harmful diesel emissions and reducing noise. The reduced cost of ventilation, the longevity and reliability of the machinery as well as reduced energy consumption are more advantages in favor of electrification. By changing from a diesel-based energy supply system to electric, tests have shown reductions in the range of 50% to above 75% in energy consumption.

An important advantage of electrification is that the technology is available. No new major technology must be invented. Even the supply chain is available. Within the past few years, power utilities got the message and are gearing up their ability to supply electric power to projects – where and when needed – even applying bridging technologies such as mobile power-banks in the MWh-class. Major tunneling contractors handle medium high voltage on a regular basis. Once the electric distribution network is planned – no fuel supply is needed.

Nasta AS Special Applications department has been involved in electrification projects for more than 5 years, and the successful projects share some common traits: dedicated planning of energy supply, enthusiastic operators and good working relations with the supplier. Any one of these factors missing and the project is an uphill struggle.

Safety is the major issue when operating underground. Electric machinery shows no tendency to burn more often – in fact a cable electric machine carries limited volume of combustible material to fuel a fire. Li-ion batteries designed for underground mining are considered safe. The risk of anybody being electrocuted can be controlled with safety systems and training of operators and maintenance personnel. With drill and blast tunnelling, the blasting manager apply safe ignitors unaffected by nearby electrical systems.

Underground operations often favor electric machines connected by cable. There are good, solid reasons why, but more mobile machines such as loaders or dump trucks are difficult to imagine connected to a cable at all times. Different catenary systems in combination with batteries are being piloted. More stationary machines with dual energy systems – electric for on-site operations and diesel for transportation is a concept well suited for the loading and descaling operations of tunnelling – and potentially reducing overall emissions by 95% or more.

Examples from state-of-the-art machinery for underground use are given below.

Figure 3.9.2. Zeron ZE350LC fully electric cable zero emission excavator.

Figure 3.9.3. Hitachi ZX290LC custom made for de-scaling and securing of tunnels in combination with drill and blast – also available as electric.

Figure 3.9.4. Hitachi 3500 AC truck soon available as battery and trolley (catenary) – zero emission.

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4 Contribution from our members

4.1 "Many a little makes a mickle"

The Norwegian Tunnelling Society believes that it is important to work with improved sustainability on many different levels at the same time. The proverb "Many a little makes a mickle" covers our thoughts in this regard. In this chapter we have invited our company members to present their achievements and strategies regarding sustainability.

Each company is responsible for their own text and way they have presented the material. We believe that the mix of focus give a representative presentation where industry as a whole stands in the work with improved sustainability.

4.2 Consulting

4.2.1 Grette - Legal advisors for a sustainable future

Jørgen Aardalsbakke, Solfrid Aga and Kaj Marsh Duesund

Introduction

Being a law firm, Grette may not be what you first think of when reading about the efforts done in the Norwegian construction sector to create more sustainable projects and development. As contract and procurement specialists, we know how to execute large road and tunneling projects. We also know the positive effects on placing sustainability on the project agenda – and in contract regulations.

In our work for both public and private parties in the construction sector we always search for effective sustainability measures and how to incorporate them in the legal framework for the project. There is however a lot to be done and we look forward to doing our part in making the Norwegian construction sector truly sustainable in every sense of the word.

Grette's focus on sustainability in our own organization

In our law practice we don't execute any drilling or blasting, but we have in depth knowledge about the logistics and effects of construction works. This knowledge has made us more aware of the impact our own business has on both the climate and social economical sustainability – such as the importance of equality and diversity.

Grette is certified as an Eco-Lighthouse, a certification recognized by the European Commission. This recognition verifies that Eco-Lighthouse business holds the standard and quality on a par with international eco-labelling schemes such as EMAS and ISO 14001.

The ECO-Lighthouse certification does not only apply for our own work, but also in our dialogue with our clients and business partners. We'll always encourage to raise questions regarding their business and its focus on sustainability, social responsibility and human rights.

Grette's contribution to reach sustainability goals in road and tunneling projects

With our focus on sustainability we have, together with our clients, left a clear climate and sustainably mark on several large construction projects, including some of the largest road, tunneling and bridge projects in Norway. This includes new contract regulations, new qualification and award criteria – all with focus on creating safe, sustainable and climate friendly construction projects.

In this aspect we would like to highlight our cooperation with the Norwegian Public Roads Administration (NPRA) in developing a modern format for executing large infrastructure projects in a private public partnership (PPP) model.

The PPP-project Rv. 3/ rv. 25 Løten – Elverum, with design, engineering and building of 27 km of new roads, several bridges and 25 years of operation and maintenance, was finalized with high quality and several months prior to the original schedule in 2020. The project, due to the efforts of both NPRA and the supplier Skanska, reached a Ceequal Excellent whole team award (76,5 %). Among all our tasks, the most challenging and rewarding was the development of the new PPP-contract, with a clear focus on climate and sustainability. The contract paved way for:

- More sustainable and eco-friendly mass management
- Reduction of emissions, both in construction and maintenance phase
- Innovation in design and engineering

This experience has been used and further developed in several infrastructure projects in Norway. A project that stands out here is the largest infra-

Figure 4.2.1. Solfrid Aga, Jørgen Aardalsbakke, and Kaj Marsh Duesund.

structure contract in Norway ever, the PPP-project Rv. 555 Sotrasambandet. This project includes multiple tunnels, open air highways, a four lane - 900m suspension bridge and 25 years of operation and maintenance. For this project we developed new regulations on both corporate social responsibility, ethical requirements and the introduction of a climate budget and a climate account during the execution of the works.

This is a good example of an even more progressive approach to the goals of sustainable development.

Our experience shows that when all parties in a construction project cooperate and work together with common goals, we see concrete results on sustainability.

4.2.2 Multiconsult

Elisabeth Grasbakken, Clas Høsøien, Julie Sandnes Galaaen, Elisabeth Schjølberg og Guri Lindmark.

Introduction

Multiconsult is a leading specialist in engineering design, consultancy and architecture services. The group provides engineering services all over the world in addition to industrial architecture services in the Scandinavian countries. In Multiconsult, we are committed to minimizing the impact of our activities on the climate and environment. We aim to integrate Sustainability as part of our core business. We strive to deliver safer, smarter and greener solutions to customers – and to deliver value to society in the short and long term.

Multiconsult has recently joined the Science-based Target initiative and commits to set climate goals in accordance with the 1,5-degree goal in the Paris-agreement.

The nature is under pressure in all developments, including tunneling. This makes it imperative to set environmental requirements on the agenda in every project. Some focus areas:

- Use new material technology, e.g. low carbon concrete and shotcrete
- Reduce overconsumption of explosives and hence reduce nitrogen in dicharge water
- Minimize plastic pollution from concrete and blasted rock
- Prevent pollution from discharge water to resipient

Examples of how Multiconsult is contributing to sustainable solutions follows.

Stendafjellet

Finalist for Environment Initiative of the year – ITA Tunneling awards 2016

Stendafjellet is a project that has come to life as a result of creative cooperation between Multiconsult and the owner Fana Stein og Gjenvinning AS. The project is situated at the Vest coast of Norway close to the center of Bergen. 18 huge caverns, each 200 m long, 55 m high and 25 m wide are excavated and the rock crushed to supply the city with crushed stone materials. The excavated volumes are used to deposit polluted soil. Area consuming activities are moved from surface and located inside a hill. Crusher plant, storage and distribution areas are contained underground at a location close to main parts of the city. The consequence for third part when it comes to noise, dust, vibrations and groundwater reduction is down to a minimum. Transportation lengths are reduced, the facility is also in proximity to harbor. The facility has been in operation for some time, and the economical results are such that the operation are expanded, with full approval from environmental authorities.

Figure 4.2.2. Production underground at Stendafjellet.

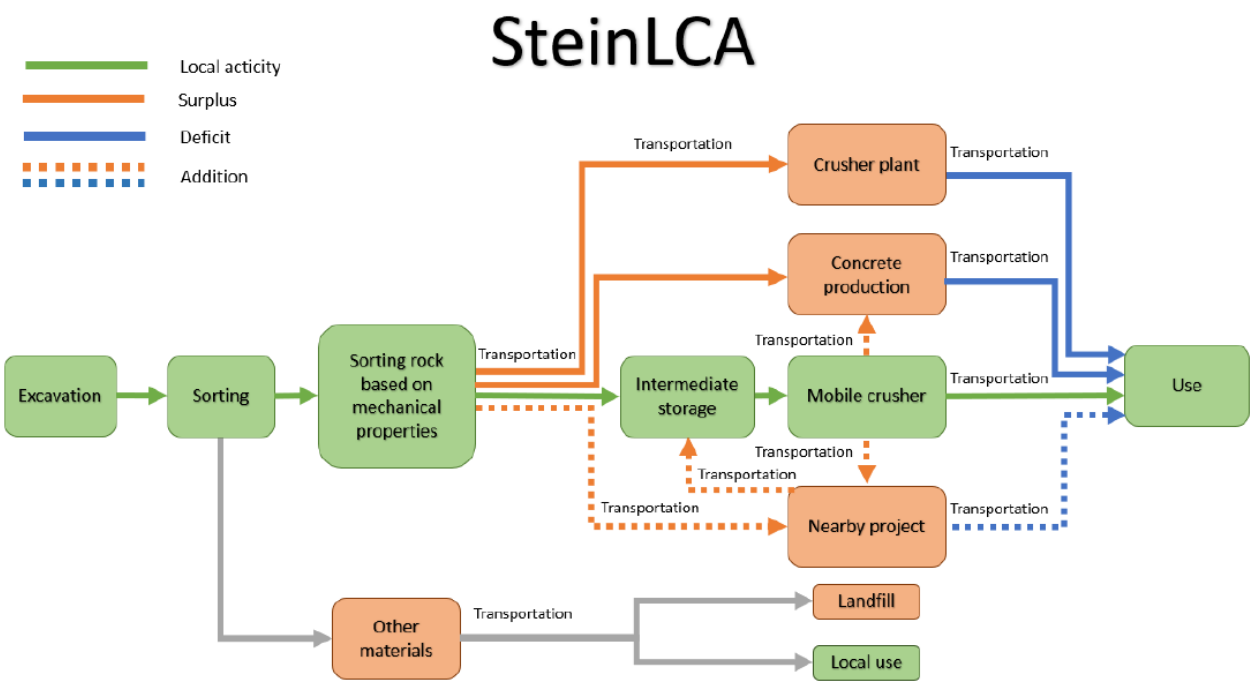


Figure 4.2.3. SteinLCA, the Life Cycle Assessment tool for mass handling illustrated.

SteinLCA- a Life Cycle Assessment tool for mass handling

Kortreist Stein was a research program initiated to develop solutions for high value and sustainable use of masses in infrastructure projects. Veidekke, one of the largest contractors in Norway, was project owner, and the project was run as a consortium with SINTEF as research partner and Multiconsult as the responsible partner for the subproject *Environment and energy consumption*. The goal for this sub-project was to develop a Life Cycle Assessment tool for mass handling in infrastructure projects, *SteinLCA*.

SteinLCA is an excel-based calculation tool for evaluating the climate- and environmental impact from use and handling of rock masses in infrastructure projects. The tool can be used in different project phases and to calculate and compare different solutions regarding transport and handling. Based on calculated values the tool can be used by project owners to support decisions in favor of solutions with reduced greenhouse gas emissions.

The tool is available here www.kortreiststein.no

Prediction model for structure borne sound

Underground works in increasingly densified urban areas, is a necessity as the urbanization process is accompanied with a demand for increased infra-structure capacity. On the individual level the need for, and focus on, quiet homes and sleep quality, means that noise from underground works is a growing issue that should be handled also during planning and preproduction.

During the tunneling works for the Follo Line project in Norway, extensive measurements of structure borne sound tunnel boring machines (TBMs) were carried out. Analysis of the measurement data was used to establish a prediction model for structure borne sound, based on a semi-analytical approach including distance between source and receiver, dissipation in the medium (depending on material parameters) along the wave propagation path, and coupling between the ground and building foundation. There are still uncovered uncertainties related to geological conditions and building foundation/construction, but the model can be used as a survey for projects regarding probable noise levels and potential need for production time reductions or alternative housing during the noisiest periods. This approach is currently in use in the Fornebubanen (subway/metro) and Ny vannforsyning Oslo (water supply) projects applying ArcGIS as a visualization tool.

Figure 4.2.4. Section from ArcGIS view. Red marking high, orange medium and yellow low probability for noise above recommend limit values for tunneling works.

4.2.3 Rambøll

Erik Endre and Susanne Sandanger

Challenging what was previously held to be 'true' can increase sustainability

The approach to the way we build roads has to change in order for us to achieve our common goal of having a more sustainable industry. We believe that a comprehensive awareness of sustainability will be the key to solving the ongoing crises – in terms of climate, energy and the degradation of biodiversity and ecosystems. We have to challenge previous 'truths' and 'best practice' in all phases of a project, increase expertise at all levels and collaborate across disciplines, with authorities and developers and between different industries so that we come up with the best solutions.

Tunnelling is usually assumed to be associated with high greenhouse gas emissions and is therefore often considered an unsustainable solution.

However, traffic in the operational phase also makes a significant contribution to the road's CO_2 emission, but this is often overlooked in a project's total CO_2 emissions from a life cycle perspective.

In several projects our studies (using the Fuel-Save programme) have shown that the optimum road line often indicates that constructing a tunnel is a better alternative to cutting through the landscape, as the CO_2 savings in the operational phase will be significantly higher than the CO_2 emissions that tunnel construction will entail. The physical alterations to the natural landscape, and specifically the impact on biodiversity, agricultural areas, marsh areas, cultural monuments, local environment and outdoor life is in most cases significantly less when building a tunnel than when establishing roads in the open terrain.

By taking sustainability into account in a life cycle perspective in the planning phase, we can show – through a new generation of knowledge and analysis programmes – that greater investments in the construction phase on a road project can provide better overall sustainability than previously assumed.

However, the construction of a tunnel can lead to a significant volume of surplus materials from the construction itself. These surplus materials are not always of such quality that they can easily be reused in the project. It is also challenging to find areas in which surplus materials can be placed, in particular surplus materials with a 'bad reputation'.

Surplus materials which are characterised as non-contaminated materials constitute large volumes in tunnel projects and will occupy equivalently large areas. Areas to be set aside for surplus materials must be included early on in municipal plans, and requirements should be set for re-establishment of the natural biotopes for the areas concerned, so that biodiversity can be re-established.

Black clay shale, for historical reasons and by definition, are considered to be contaminated. This means that such materials were previously transported to dedicated landfills. The societal cost of this solution has been significant, while the income for the landfill has been good.

This means that the landfills are now filled with rocks (which consist of nature's own components and which are part of a natural cycle) instead of being landfills for man-made pollution (= substances that are not degradable, i.e persistant and can be accumulated in food chains).

We need therefore a better and more sustainable solution for material handling, and the solution is under development. The examples from large infrastructure projects in Stange-Løten show the way, where terrain changes are being established rather than driving materials to landfills that must be managed forever, in addition to the fact that the landfills require large areas. In the areas where surplus materials are placed, efforts are made to create conditions so that the natural biotope in the area is re-established. However, there is still a need for further development of the method and approach, so establish certainty that these are robust solutions which will not have unacceptable environmental consequences in the future.

Rambøll finds that sustainability expertise is in demand

Rambøll is an international consultancy firm with Nordic roots. In Rambøll Norway, 1,600 engineers, scientists, architects and management consultants work every day to create sustainable and long-term solutions for our customers and for society as a whole. Sustainability and ethical business practices have been the cornerstones of Rambøll since the company was founded in Denmark in 1945. When Johan Hannemann and Børge Rambøll founded the company after World War II, their aim was to contribute to the building and development of society. They believed that the key to a company's long-term success was decent and responsible conduct towards customers and employees, but also towards society and the natural environment. This is how our mission of 'We create sustainable societies where people and nature flourish' arose.

It is gratifying to see that expertise in sustainable solutions is now increasingly in demand. We are registering more and more requirements related to sustainability, especially for the reduction of greenhouse gases, in tender documents. We are also finding that many of our customers are interested in solutions that facilitate reuse, reduce pollution and preserve biodiversity. We are experiencing increased interest in the way in which our projects can facilitate people's quality of life. We also notice that new EU regulations, in combination with an ever-increasing recognition in the financial world that lack of control over sustainability is a financial risk, increase interest in sustainability among our customers. We have therefore set ourselves the following aspirations for our project portfolio: We will minimise CO_2 emissions in our projects, strive to restore valuable nature, and people's quality of life will be safeguarded. Rambøll Norway has also set goals for its own operations. We will be climate neutral by 2030, based on the methodology of science-based targets as the most recognised method for calculating cuts in carbon emissions. We have also taken measures in our offices, such as reducing energy usage on our premises, reducing food waste, reducing the use of disposable plastic and switching to suppliers who can deliver environmentally certified furniture and office supplies. We have replaced most of our vehicle fleet with electric cars, electric bikes and hybrid cars.

In 2020 we chose to become certified on the basis of the UN's Sustainable Development Goals, in order to obtain an external assessment of the extent to which Rambøll Norway contributes to the fulfilment of our sustainability goals. The certification audit reviewed Rambøll's strategy, action plans, goals and services. Rambøll became the first company in Norway to become sustainability certified. The certification gave us solid insight into what we do well today and the areas in which we have potential for improvement. One of the improvement points highlighted during our certification is that we need to talk more about our sustainable solutions and help disseminate our knowledge. We hope that the examples below can contribute to the development of more sustainable tunnel projects.

4.2.4 Sweco

Merete Saugestad Chief Sustainability Officer

Leading the change

Sustainability is business critical to Sweco. We are highly engaged in finding ways to create, plan and shape the sustainable societies of the future together with our clients.

Sweco takes action

Sweco has decided to reach full climate neutrality by 2040, halving the emissions to 2030 with 2020 as the base year, in line with the Science Based Targets and the Paris agreements. All three Scopes from the GHG Protocol are included, and emissions reductions are already seen with a rapid change of the vehicle fleet, new travel patterns, a demand for sustainable electricity and energy in offices and tougher requirements on procurement. Further measures will be taken in 2022, including having climate as a key parameter when selecting new offices.

Transforming society together with our clients

Our main impact, however, is from our projects, from what we do for our clients. Our greatest opportunity to make a difference lies in our ability to lead and offer expertise in the projects we carry out with our clients.

Going forward we will increasingly focus on setting targets and following up measures with respect to climate emission reductions and climate adaption, concern for nature and biodiversity, mitigating material impacts and increasing circularity, and of course creating societies that are good for people.

As an example, we have developed Sweco's Sustainability Sun to understand and generate a positive impact of our clients' impact on the 17 global goals for sustainable development (SDG).

We are also chairing a group with the World Business Council for Sustainable Development to develop a methodology to be able to calculate and verify the climate impact that we have in projects,

Figure 4.2.5. Opening the Underground Space for Haukeland Station, part of the Bergen Light Rail (Bybane Bergen) (Photo: Pixel & Co).

hopefully to also be used by other consultancy firms in all segments who want to make a difference for the climate.

Together with our clients, we want to transform our societies into a sustainable direction.

Let's take action together!

4.2.5 Norconsult

Kjersti Kvalheim Dunham, Anders Vik and Ketil Søyland

Everyday we improve everyday life!

We can help promote sustainable development by giving the best advice to our clients on how to reduce their project's climate footprint and energy consumption. We regard nine of the UN's sustainable development goals as most relevant to Norconsult.

In a wider context, for us at Norconsult sustainability and sustainable development mean prioritising the environment, social issues and finance. Sustainability arises is the interface between these three areas.

We believe that the advice we give to developers of projects, both large and small, is where we have the best opportunity to contribute to sustainable business.

To contribute to sustainable solutions, during this strategy period Norconsult will focus in particular on ensuring that our clients receive good advice on how they can reduce their project's footprint (greenhouse gas emissions/CO_2-equivalents) and energy consumption (kWh), in engineering design, construction, maintenance, operations, and recycling or demolition.

Sustainability in Norconsults projects

Experience from our projects in the transport sector in recent years indicates that an emissions reduction of 20 per cent is relatively easy to achieve by using specific materials and making other project adaptations. However, we have found that the projects will not be capable of achieving society's goal of a 40 percent emissions reduction unless all measures, both large and small, are considered. In identifying the required measures it is easy to choose "popular" measures, which are not necessarily the best in terms of cost/benefit. To find measures that can be implemented in individual projects, decisions must be based on knowledge-based, interdisciplinary processes.

Concrete, steel, material transport (fossil fuel), explosives and asphalt production are responsible for more than 80 per cent of the greenhouse gas emissions generated by transport projects. Getting involved at an early stage of projects makes it easier for us as consultants to optimise the solutions in terms of greenhouse gas emissions, and avoid using "tried and tested" standard solutions. For example, project emissionscan be reduced by using concrete with lower carbon emissions (low-carbon concrete), but what is often forgotten is that reducing quantities can be just as effective. Making a concrete wall 20 per cent thinner reduces emissions by the same amount. To successfully optimise quantities and material consumption in solutions, we must allocate sufficient time and resources to the projects to execute the optimisation process.

The Norconsult Plus methodology

Norconsult's Plus method is based on our innovation methodology and focuses in particular on identifying opportunities related to greenhouse gas emissions and energy consumption. Through creative workshops with representatives from our client, partners and our own consultants from various disciplines, the project generates ideas that can improve the solutions. These ideas are sorted, ranked and evaluated with regard to viability and cost, as well as other key project goals such as the external environment, safety and mobility.

Norconsult's Pluss method has been used on numerous projects, including the large projects concerning tunnels in the joint Ringerike Line project for the Norwegian Public Roads Administration and BaneNOR, E39 Rogfast for the Norwegian Public Roads Administration. This systematic approach identifies useful and profitable improvement proposals. This demonstrates how the project can implement measures that contribute to society's goal of reducing greenhouse gas emissions by 40 per cent, compared to the 1990 level.

Expertise development increases sustainability of projects

As consulting engineers and architects, it is important that we make our contribution to sustainable development. We have the greatest impact through the advice we give and the solutions we propose to our clients in our projects. It is important that we highlight opportunities that can help to make our clients' projects more sustainable and environmentally friendly.

To identify the best and most effective measures for sustainable and environmentally beneficial advice and solutions, we work to ensure that all projects assess risk and opportunities related to the environmental topics of energy consumption, materials and resources, transport, handling surplus materials and waste, biodiversity, discharges to the ground and water and emissions to the air, interference (light and sound) and vibrations.

4.2.6 NGI

Paul Cappelen, Tom F. Hansen

NGI is an independent research institute providing research, development, consultancy and innovation within the engineering geosciences. Our philosophy is that RD&I (research, development and innovation) goes hand-in-hand with consulting, and we incorporate our research results in our consulting services. NGI is "not for profit" and our financial results are reinvested in expertise, RD&I as well as research infrastructure.

Our strategy

In NGIs former strategy period (2018 – 2021) one of our four focus areas were "On sustainable ground". The UN Sustainability Development Goals (SDGs) identify a number of global challenges. NGI will use its expertise to address these challenges and take on a clear and visible role. We will prioritize business opportunities and research topics within sustainability climate and develop new knowledge and new solutions for challenges faced by society. In this period NGI has merged the market areas for onshore geotechnical engineering with environmental engineering, and also forming a new section for Sustainable Solutions and an interdisciplinary professional group for Circularity and Sustainability.

In our new strategy towards 2025 we emphasize the importance of research and consulting for societal security and the green transition. Society is realigning to a future where growth and development must be in harmony with the planetary boundaries. NGI will contribute with geotechnical and geoscience expertise directed towards climate, energy, environment and societal security. Nature-based solutions, climate adaptation, quick clay and offshore wind are selected priority areas for us in the strategy period. A consequence of this strategy is that NGI shall prioritise research and consultancy work that supports the green transition and increased societal security

Perceptions of sustainability

Sustainability is hard to pinpoint in our projects. Most of our decisions have a sustainability component within us being aware of it. One can definitely state that sustainability is much more than CO_2 emissions and climate change, and that multiple viewpoints is key to sustainable processes.

There are many ways geotechnical engineers can contribute and are contributing to sustainable development through the projects they work on, including the reuse of materials and construction elements, development of alternative materials, improved techniques for geotechnical work, pollution control and remediation of brownfields, mitigation of geohazards, the exploration and exploitation of geological resources, and the development of sustainability assessment tools. NGI made a study of our own colleagues, investigating which clams about sustainability that they found to be of greatest importance. We published these results at the GeoNiagara Conference in 2021.

earthresQue and GEOreCIRC

The earthresQue centre is a Centre for Research-based Innovation (SFI) funded by the Research Council of Norway. The centre will develop technologies and systems for sustainable handling and treatment of waste and surplus masses. earthresQues kick-off was in December 2020 and it may last for 8 years. NGI has a central role, including the Deputy Director.

Parts of earthresQue is build on knowledge from NGI's project GEOreCIRC (Georesources in a circular economy). The main aim of the GEOreCIRC research project was to develop methods that can be used in order to reduce the amount of material that is landfilled and to encourage reuse. The project focused on increasing the reuse of excess and waste materials from building and construction projects that are considered to be clean and that have the potential to be reused. Materials in focus has been: excess ashes from incineration processes, material from tunnel constructions, soil that has been contaminated at a low level, excess materials from the mineral processing industry, chalk stabilized clay and slag. We have investigated methods that can enhance the physical and chemical characteristics of the materials in order that they can be suitable candidates for reuse. All

reports from the project are available at https://www.ngi.no/eng/Projects/GEOreCIRC/#Reports-and-publications

On tunnelling and sustainability
Tunneling cause large CO_2 emissions from all involved processes. The excess mass can cause problems when it comes to emissions or contamination of the surrounding environment. However, all construction of roads and railroads face these challenges. Tunnel projects benefit from minor encroachments on nature compared to other projects that cut though the landscape and may thus be far superior when it comes to biodiversity and social sustainability.

NGI believes that tunneling and the use of the underground are becoming increasingly important. With the phasing in of new low-emission technologies and smart use of surplus masses, underground projects can be made even much more sustainable in the future.

4.2.7 Cowi
Randi Christensen, Ida Nossen, Martin Palm

Together for a liveable and sustainable world
Throughout our 90-year history, we have worked with our customers to deliver solutions with long-term societal, environmental, and human interests in mind because sustainability is part of our identity and incorporated into our business model. With our holistic approach and cross disciplinary collaboration, we can help our clients make input for informed decisions. We believe sustainable solutions should be more than good intentions and talk. We as engineers need to drive the development by evidencing the impact of our projects and show where we make a positive difference.

LCA tools development
We therefore help our clients to develop and drive their LCA tools, to get comparable date on projects. We have supported several clients within Scandinavian and UK by developing efficient LCA tools that helps our client make informed decisions on their projects and evidence the impact of the project. Lates development here have been to create an industry standard for benchmarking CO_2 emissions against functional units. This way it is possibly to assess the effectiveness of the design.

The Fornebu Line
The Fornebu Line is the biggest transport project in the Oslo area in over 20 years. The project includes an 8.2 km long tunnel section and 6 new stations with associated infrastructure from Fornebu in Bærum municipality to Majorstuen in the capital Oslo. In a joint venture with Multiconsult (Design group Fornebubanen), COWI was awarded the contract to design the Fornebu line including earthworks, tunnels, rock chambers, stations, operating base, and superstructure.

During design, a sustainability screening was carried out, to get an overview of risks and opportunities within sustainability. the screening enabled an early conversation on ambition level and specific initiatives on the project. Sustainability embraces a wide range of focus areas, e.g. setting standards for plastic use and recommendations of low carbon concrete.

E39 Fjordkrysning
This project includes studies for new fjord crossings over the Halsafjord and Sulafjord. Adjacent sections of the E39 and other road segments are roughly assessed. The project is a joint venture with Multiconsult and Aas Jacobsen and the joint venture has been assigned five projects for assessment of different bridge crossings.

Sustainability is assessed and implemented based on the CEEQUAL methodology. CEEQUAL is the recognised industry standard when it comes to sustainability assessment for infrastructure and civil engineering projects. The aim is to drive and verify sustainability performance and standards throughout the project.

As part of the sustainability approach, greenhouse gas (GHG) emissions are implemented in the early stages where design, material choice and innovation are assessed. The overall goal is to design solutions that provide the lowest possible CO_2-emissions over the project's life cycle.

4.3 Contractors

4.3.1 Skanska
Randi Lekanger

Background
Skanska Norge is one of Norway's largest and leading contractors and project developers and has had a presence in the Norwegian market since 1906. The company has approx. 3,800 employees and around 200 current projects across Norway at any given time. For more than 100 years, Skanska Norge has built roads, railways, bridges and tunnels in Norway to ensure that people are able to travel safely and comfortably wherever they need to go.

Skanska Norway's aims

Skanska has long made environmentally friendly and sustainable solutions a priority. In 2001, the company was certified to ISO 14001 and has since then built up some of Norway's strongest expertise in the areas of sustainability, climate and environment.

Skanska has undertaken to observe the Paris Agreement and actively applies the UN's Sustainable Development Goals in planning and organising its sustainability work.

Skanska has set itself the long-term goal of being a role model in sustainability and innovation across industries and taking a leading role moving Norwegian business into the low emission society. In order to deliver on this aim, Skanska is thinking both short and long term in the development of its business. This is evident in Skanska's business strategy.

In the short term, Skanska has to become better at utilising the expertise, concepts, technology and delivery performance the company already possesses in the areas of climate and environment, safety, ethics and seriousness in order to increase competitiveness and value creation. Today's expertise, concepts and delivery performance will, however, not solve tomorrow's sustainability challenges or constitute a competitive advantage going forward. Skanska will therefore increase its pace of innovation.

Skanska is currently involved in 14 projects financed by the Research Council of Norway and also has a large portfolio of its own independently financed innovation projects.

In other words, sustainability and innovation are more than just a focus area. Sustainability and innovation are a prerequisite for Skanska's competitiveness and ability to continue to build for a better society.

Skanska's focus areas and facilitators in climate and environment

Skanska Norge has also set itself a clear climate aspiration:

"We need to reduce our climate emissions by 70% by 2030 and become climate neutral by 2045"

Skanska has set 2015 as its baseline year. By 2021, Skanska as a company had already reduced its direct emissions by 47%. (Scopes 1 and 2)

Based on measurements and surveys, Skanska has identified the areas that are believed to have the greatest impact on reducing environmental and climate footprints.

The company has focused on energy efficiency, circular economy, material resources, machinery and land use changes. In order to achieve the greatest possible effect from the measures implemented within these areas, know-how, willingness to cooperate and effective tools are also required. Skanska has therefore also identified facilitators that help to get the most out of the measures that are implemented within the focus areas. The facilitators selected are R&D and expertise, strategic partnerships, measurement, management and documentation and communication.

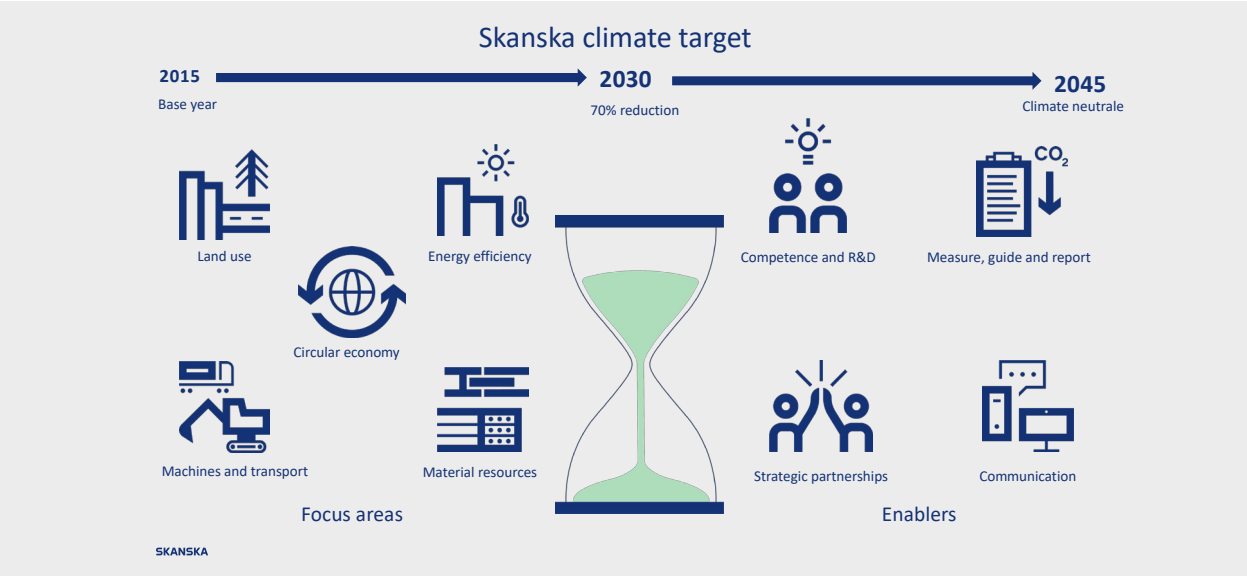


Figure 4.3.1. An illustration of Skanska's climate road map.

Figure 4.3.2. Bagn - Bjørgo, the bridge leading directly into the tunnel (Photo: Skanska).

Figure 4.3.3. Using low-carbon shotcrete as the first project in Norway on a major scale (Photo: Skanska).

E16 Bagn – Bjørgo

The project was a section of the extension of the new E16 through Valdres and opened in October 2019.

The project included a total of 11.3 km of road where 4.3 km was tunnel. The new section of road and tunnel means that locals, holiday cottage owners and professional drivers have been given a safer and faster route through Valdres.

This was Norway's first CEEQUAL-certified road project. The project focused on environmental measures as well as measures to benefit the local community. Rock from the tunnelling was used as filling material under the new local road. Surplus material was also used to raise and flood-proof the local sports field for the benefit of the local population, while short-term use of the materials led to a reduction in greenhouse gas emissions.

Surplus material from formwork was acquired by the ski association for use in the construction of local ski bridges.

D12 Light Rail

Contract D12 is one of several contracts on the Light Rail in Bergen. Skanska chose to offer Ceequal certification of the entire project, and in the work with the climate budget for the project, it became clear that low-carbon shotcrete would be a very effective solution. This is the first project in Norway that has used low-carbon shotcrete on a major scale. Its use will provide a climate benefit of approx. 850 tons of CO_2 equivalents. The development of this product has taken place in collaboration with contractors from the entire value chain. Entreprenørservice, Unicon, BASF, the Norwegian Public Roads Administration and Skanska first performed testing on two projects before the shotcrete was used on a large scale on this project.

Figure 4.3.4. Traffic training for school children (Photo: Skanska).

Skanska's social sustainability work

Skanska's work with social sustainability is about integrating social sustainability into its core business in order to build for a better society and consolidate its reputation and attractiveness. It is about always identifying, understanding and interacting with the various stakeholders on Skanska projects.

On many of Skanska's major construction projects, where a great deal of large machinery is in operation and a great deal of transport takes place, the company often arranges safe traffic training in collaboration with local schools. The aim is to provide children with information and training in traffic safety, with particular emphasis on how they should conduct themselves in areas with construction traffic.

4.3.2 Sustainability in the tunnelling division of Hæhre Entreprenør

Irene Sveva

About Hæhre's activities

Hæhre Entreprenør AS (Hæhre) is one of Norway's largest construction contractors and a privately owned Norwegian company. Strong traditions, professional expertise with a focus on production and

robust machinery are some of our strengths. Hæhre undertakes infrastructure projects related to roads and railways, bridges and structures, tunnels, airports and land development, as well as hydropower and energy projects. This article describes sustainability measures for tunnel projects in Norway in general, and Hæhre's activities in particular.

Hæhre adheres to business ethics principles that describe our basic obligation to act in a responsible manner and in accordance with Norwegian laws and regulations. We also require that our subcontractors, contractors and other partners follow these principles. Our contracts set requirements at supplier level for the environment, social conditions and ethical business activities. Hæhre relies on globally recognised initiatives and conventions, including the OECD's guidelines for multinational companies and the ILO's eight fundamental conventions for decent working life. Hæhre has been a participant in the UN Global Compact since 2016, and we are certified to ISO 14001 Environmental Management.

Hæhre is a significant player in the local communities surrounding our projects. It is important to us that the projects become an integral part of the local community and that we contribute to increased value creation and economic development through local employment, local procurement, infrastructure and sponsorship of local associations and sports events.

Our projects involve major interventions in the landscape. Hæhre focuses on limiting the interventions of our activities as much as possible and does not use larger areas than necessary to perform the job. Temporarily sequestered land is reinstated to its original condition or has its purpose changed in accordance with specific agreements with landowners, e.g. by arranging for new cultivation.

Road and tunnel construction leads to large emissions of greenhouse gases. The largest emissions are from construction machinery, material transport and area changes when the road is built and indirect greenhouse gas emissions from the production of materials. Hæhre contributes to achieving the national reduction targets set for the building and construction sector in the National Transport Plan (NTP). To gain control of our own emissions, we calculate greenhouse gas emissions both for our own business and for the largest projects in our portfolio. Hæhre also sets requirements for suppliers and partners to reduce indirect emissions related to material production.

Rental Group, Hæhre's sister company, owns more than 2,000 units of machinery. This machinery has a low average service life and continuous efforts are made to reduce greenhouse gas emissions from use of machinery. Our skilful managers and engineers are in continuous dialogue with our machinery and equipment suppliers to develop and adapt these and ensure that they work well in our operations and contribute to improving machinery for the industry as a whole. In recent years, some of the machinery and equipment used in tunnelling has been electric. In 2020, more than 86% of the machinery in Hæhre met strict emission requirements in accordance with STEP 4 as well as EURO 6. A high environmental category provides increased efficiency, less noise and lower emissions.

Tunnelling operations in Norway and Hæhre

In recent years, Hæhre has taken a number of measures to promote sustainable tunnelling operations. This article summarises some of the key measures Hæhre is proud to have implemented.

A tunnel project involves large amounts of material that needs to be disposed of. In Norway, we have a long tradition of tunnelling, and Hæhre, like our competitors, has gained solid experience in the utilisation of materials. Often a great deal of quality stones can be reused for building roads or other infrastructure. Local use and reduced material transport are significant factors in minimising congestion on the road network and reducing greenhouse gas emissions. They also have positive economic consequences. In many cases, however, we encounter barriers to optimum utilisation of materials. These barriers are related to planning, lack of space or conflict with requirements contained in regulations and manuals.

Restricting blasting is also a sustainable move. Careful blasting of the contours can mean that no more blasting than necessary is done and the amount of blasting stone material is kept to a minimum. Although careful blasting may require a few more working hours and slow down progress in the short term, with good planning it is financially and environmentally beneficial in the long term.

In Norway, we have been skilled at grouting and sealing the rock to a sufficient degree. Permanent securing of the rock increases the service life and reduces the need for rehabilitation and maintenance. Working sustainably requires that we think in life cycle. Increased service life will in many contexts result in lower total greenhouse gas emissions.

Most tunnel projects require cleaning down to the solid rock. Materials resulting from this are often

extensive and consist of a large variety of fractions. These materials are defined as waste as long as it cannot be documented that the materials are clean and have a purpose within the project. With Hæhre's extensive use of new machinery, electrical equipment, a focus on daily maintenance and machinery inspection as well as excellent routines for monitoring and immediate handling of deviations, the degree of pollution has decreased considerably. This combination, as well as solid routines for systematic sampling and sorting, has reduced the quantities of contaminated materials taken to landfill. We also ensure proper handling of materials without the risk of pollution.

Sustainable use of materials means using the lowest possible volume of materials with the longest service life and quality. Many materials are used in tunnelling, but the most important are concrete (elements), steel, asphalt, pipes, insulation materials and electrical installations. Although requirements for quality and dimensions are largely governed by requirements contained in manuals, it is still possible to optimise them further. Small reductions on each individual XPS board can result in large reductions overall in a tunnel. We have examples of this at Hæhre.

A specific example of the development of greenhouse gas-reducing solutions for the tunnel industry is a collaborative project between Ølen Betong, Hæhre and the consultancy firm Aas-Jacobsen with the aim of reducing the CO_2 footprint from concrete elements. By developing new concrete recipe, reducing the thickness of the elements and optimising production and logistics until delivery on a tunnel project, the CO_2 footprint has been reduced by approximately 25%. This development has also resulted in a reduction in costs of up to 15% per square metre and doubled service life – from 50 to 100 years. With commercial use of carbon capture and storage from concrete production, we are further able to reduce CO_2 emissions by up to 50%. The first elements of the new type were mounted by Hæhre in a tunnel on the E39 Mandal East – Mandal City road project in the first half of 2021.

There are many challenges involved in implementing sustainable tunnel projects. In addition to those mentioned above, these include rigid requirements in environmental regulations and manuals, tight progress plans that reduce optimum planning and applications for deviations and demanding financial conditions. Recent years have seen major improvements in terms of the environment and sustainability,

Figure 4.3.5. Tunnelling on the E16 Kvamskleiva project (Photo: Tommy Hagen, Hæhre).

but a large untapped potential still exists. In order for us to be able to take the big and necessary steps towards a more sustainable future, we depend on the developers and the authorities also moving in the right direction so that we can overcome our common challenges together.

4.3.3 Sustainability in LNS

Eirik Fredheim

Background

Leonhard Nilsen & Sønner AS is a Norwegian entrepreneur company located in the far north of Norway in Andøy municipality. The company was founded in 1961 by Leonhard Nilsen and Malvin Nilsen. LNS is a company that specializes in tunneling and mining ranging from Svalbard in the North to Antarctica in the south. LNS is a corporation divided into several different companies with LNS Mining and LNS AS as the parent companies operating with mining and tunneling, respectively.

The importance of local involvement

LNS is a company that always strives to have as many local employees, suppliers and subcontractors as possible. By employing from the local community, suppliers and subcontractors we reduce the amount of CO_2 that is emitted by transportation and get to use local knowledge about the environment and nature around our projects. LNS Greenland, one of the companies in the LNS corporation, extracts rubies in Greenland. Here the goal was to have at least 75 % local workers. Today there is exclusively local workers recruited from nearby areas. The share of female employees is about 40 % which is rarely found in a mining company. LNS Spitsbergen operates from Svalbard to Antarctica and operate in a vulnerable arctic climate. In Svalbard there is maybe some of the world's strictest laws and regulations regarding environment and sustainability. Thus, focus on environment, emergency preparedness and sustainability are among the primary goals for LNSS.

Our headquarter is located in the Andøy municipality. The local community is therefore an important aspect around the headquarter. LNS have arranged a football school for local youths in collaboration with Bodø/Glimt, the number one ranked team in the country, several times to encourage local talents and to ensure the prosperity of local youths. LNS is one of the main sponsors for the football club Bodø/Glimt. By sponsoring Bodø/Glimt we have committed to the Action Now program for sustainability. Here we have chosen particularly to focus on sustainability goal 9 and 11. Sponsorship of local sports clubs and organizations have always been important for LNS. We now sponsor both local sports clubs and a theater where local youths get to explore and develop their talents both on and off the stage.

Tunnelling in LNS

LNS have a policy to continuously try to reduce the amount of climate gases we emit. We always try to use the newest technology in machines to reduce the amount of CO_2 and NOx gases emitted. All of our drilling rigs are powered by electricity and our shift buses at our project Nykirke-Barkåker runs on electricity. All the machines at our project Nykirke-Barkåker runs on HVO100 that reduces the amount of CO_2 emitted significantly. Additionally, the machines use biologically degradable hydraulic oil that reduces the impact on the environment. LNS was the first contractor in Norway using an all-electric shotcrete robot and one of the first in the world using and all-electric shotcrete robot from Normet. The shotcrete robot is a one hundred percent BEV driven machine, the machine runs by battery package and plug in high voltage electrical system while spraying. The shotcrete robot was first located at our project in Nykirke-Barkåker and is now located at a tunneling project in the Faroe Islands. LNS continuously monitors the amount of diesel used in our projects and the amount of idling. We continuously try to reduce the amount of idling and usage of diesel in our machines. In every project there is a risk of contamination of soil and water. We therefore have absorbents to collect oil in every machine in every project we have as a first emergency response. In our tunneling projects there is also a container with absorbents and lenses close by where potential accidents may happen. Making tunnels requires a lot of energy in all the processes. LNS have therefore tried to reduce the amount of energy by using a frequency converter on the fans used for air supply, thermoregulation, led lights and turning of heat when the gate to the workshop is open.

Figure 4.3.6. Breakthrough at Nykirke-Barkåker.

Being an entrepreneur that extracts minerals, builds tunnels and have a series of machines means that we produce a lot of waste and have a lot of different chemicals and products. LNS continually try to reduce the amount of waste being produced, recycle and reuse materials. Last year we recycled 85,2 % of our waste meaning that less than 15 % of the waste was either used for energy recovery or went to a landfill. This year we are improving this number and our goal is to improve recycling every year. We optimize every facility to increase the amount of waste being recycled and buy as much of the materials we can in bulk to reduce packaging. We also contact local farmers and others that may be interested in materials we no longer can use but may be used in other ways and then reduce the amount of waste. Handling of chemicals in LNS is important for both health, safety and the environment. We have a policy not to use any products on the Norwegian candidate list or REACH (SVHC) list. Chemicals with high risk for either safety, health or the environment is being considered for substitution or substituted as often as possible. A lot of work has been done to reduce the number of chemicals being used in LNS and the number of chemicals used today is now significantly lower than it was a few years ago.

E6 Kvænangsfjellet

One of our newest projects is E6 Kvænangsfjellet, which is a project for Nye Veier. LNS is the main contractor and the project is located in Nordreisa and Kvænangen municipality. The project consists of two tunnels (5,9 km), construction of a new road (ca 8,1 km) and a bridge. The surrounding area consists of small towns with up to 1800 inhabitants. This is the first project for LNS that is going to be CEEQUAL certified. There are several important environmental aspects in the projects including as examples: A protected waterway, reindeer, energy usage, climate gases and more. Building tunnels provides a lot of extra masses to handle. In this project there was estimated that 250 000 m3 of masses had to be put in internal landfills. By optimizing the project this number is approaching zero m3 making the need for transportation far less and thus reducing the amount of climate gases significantly. The surrounding area is vulnerable with a protected waterway in the catchment area meaning that measurements for protecting the environment is crucial. The project has been optimized regarding several aspects to reduce the amount of climate gases along with reducing the effect on the environment. All of the waterways in the area are being monitored and measures have been made to reduce the impact on waterways. The area is an important area for reindeer and one of the main goals of the projects is to reduce the impact on reindeer. We therefore have close contact alongside our client with the reindeer owners. The project has also been optimized to reduce the impact on the reindeers. One example is using tunnel masses to reduce the incline towards the road making the need for roadside barriers unnecessary. Reindeer crosses E6 multiple times a year and with no roadside barriers and lesser incline makes this a lot easier.

Figure 4.3.7. Start of the project at E6 Kvænangsfjellet (Photo: Claus Jerstad, Nordfra.no).

In the surrounding municipalities of E6 Kvænangsfjellet we are in an open dialogue with the local employment office trying to employ some people that can't find a job for different reasons. The project has a high focus on ethical labor practices and environmental standards and all our subcontractors are reviewed before they are signed. Our subcontractors at the projects are exclusively local subcontractors. By using local subcontractors and some local suppliers we provide a significant economic impact on small towns in the area. We are also exploring opportunities to connect LNS to local organizations for sponsorship in both the nearby municipalities. We are then looking for organizations that involves youth, culture or sport to help local organizations prosper and make an impact to the local area.

LNS advantages

LNS is one of the few companies that combine mining and tunneling. By using the knowledge gained from both these types of projects we have a lot of experience. LNS can be looked at as a medium sized entrepreneur in Norway. LNS have experienced that the demands from clients have been stricter regarding sustainability, climate and the environment over the years. This is of course a positive thing which helps LNS improve even further with regards to sustainability. Within the company there is trend towards more mining projects around Norway. Norway is a country with a substantial amount of minerals that can be used for electrification and

more. Extraction of these minerals in Norway would be more sustainable than in developing countries. LNS follows all Norwegian laws and regulations and additionally internal requirements and demands from clients. This provides safe working conditions, ethical labour practices, strict environmental demands, use of renewable energy and less CO_2 emitted compared to developing countries. LNS as previously mentioned use many local suppliers and employees making rural societies thrive.

LNS have been ISO 14001 and ISO 9001 certified for several years. Being certified in these standards means we get audited every year and that we seek improvement in every aspect of the business. Every year a new topic that regards environment and sustainability is reviewed. The management team in LNS is involved every year in this process and make suggestions for both topics and improvements. The environmental manager and CEO have monthly meetings to discuss improvements for the environment, reducing climate gases or improve sustainability.

4.3.4 Gjermundshaug

Kristoffer Grøv

Since the publication of the 'Our Common Future' report by the World Commission and led by Gro Harlem Brundtland in 1987, sustainability has grown in popularity and reputation. Sustainability has not only become a recognised term in politics and on social media, but has been used as a competitive advantage/requirement and an opportunity to create solid business models in various industries. Sustainability and green transition are concepts that are used interchangeably, but which strictly denote the same thing, namely reducing humanity's footprint on earth and facilitating good social/societal as well as economic conditions.

The construction industry still has some way to go, not only in terms of CO_2 emissions, but also in facilitating social and economic sustainability. The construction industry is known for being a climate aggravator and is often called the 40% industry. Globally, the construction industry accounts for approx. 40% of greenhouse gas emissions (SINTEF, 2020), and in Norway the construction industry accounts for 2 million tonnes of CO_2 in direct emissions, of which building materials, transport and land use are not included (Report Stortinget 13 (2020-2021)). This can and must be reduced through a more holistic focus on sustainability. This article will show simple and practical examples of sustainability measures that not only highlight CO_2, but show a holistic approach to the concept of sustainability. The examples are taken from the Gjermundshaug Group where I work as sustainability manager, and all the examples have been completed in the last six months. Gjermundshaug Gruppen (GG) is a developer group that owns five companies, three of which are developers and two are technology companies with a total of approx. 300 employees.

The UN (2021) defines sustainability as development that meets current needs without destroying the ability of future generations to meet their needs. The term contains three key aspects: environment, economy and society. All three aspects are interdependent and should interact over an extended period of time. Sustainability has recently been incorporated as a key part of the Gjermundshaug Group's strategic plan for 2020-2025 in which specific goals have been set and Sustainable Development Goals have been selected. The Gjermundshaug Group has selected the following Sustainable Development Goals to focus on: no. 5. *Gender equality, no. 8 Decent work and economic growth, no. 9 Industry, innovation and infrastructure, no. 12 Responsible consumption and production, no. 13 Climate action and no. 17 Partnerships for the goals* In this way, the company has tried to look broadly at the concept of sustainability and work towards all aspects of the concept. Sustainability is already a priority for the Gjermundshaug Group in decisions taken by management and the work performed by three employees in this area. As a developer, the company wishes to create lasting value for society by using the fewest possible resources and making a positive contribution to the local communities in which it is present. The company also has a desire for sustainability to be become an integral concept in all parts of the company – from the CEO to machinery operators and ground workers. The company recognises that sustainability is important to the construction industry for several reasons: 1)

because the use of resources in the world is too high and 2) because sustainability can mean a competitive advantage in tender competitions. In this way, sustainability becomes carrot and stick for the construction industry.

According to Grøv (2019), the restructuring of the construction industry is in its infancy. In Norway, some operators are investing heavily in fossil-free and zero-emission technology while others are sitting on the fence and waiting. Sustainability and green transition, on the other hand, are about much more than fossil-free and zero-emission technology. Good sustainability and green transition is about seeing the opportunities to make a positive difference for the good of today's society as well as societies of the future. It is also about circular economy, recycling, eradication of hunger and poverty, good health and education, equality and equal opportunities for all regardless of gender and education, innovation, responsible consumption, preventing economic crime such as money laundering and undeclared work, justice and cooperation between operators. All of these topics can be addressed through small and simple measures that improve sustainability in the construction industry.

The examples of sustainability measures below are not meant to laud the Gjermundshaug Group's sustainability work, but are intended as inspiration for other operators to allow them also to contribute to a sustainable construction industry even if they do not use emission-free construction machinery. Here are some examples of sustainability measures in GG:

- Collecting deposits from offices/site offices in bags from Infinitum. The money is transferred to selected local teams/clubs in the areas in which we operate. Reducing waste, focusing on circular economy and supporting the local community in which we operate. Sustainable Development Goal nos. 12, 13 and 17.
- Setting a sorting rate target of more than 80% of waste. Sustainable Development Goal nos. 12 and 13.
- Focusing on waste fractions that go to material recycling to increase the proportion that goes to material recycling and reuse. Sustainable Development Goal nos. 9, 12 and 13.
- Setting up an agreement to return old workwear to our workwear supplier. Sustainable Development Goal nos. 9, 12 and 13.
- Continuous and direct digital monitoring of machines idling using various systems that reduce fuel consumption, reduce CO_2 emissions and utilise machinery more efficiently. Sustainable Development Goal nos. 9 and 13.
- Focusing on using local actors on projects. Reducing transport distances and supporting local businesses. Attempting to reuse asphalt, materials etc. On rv3. 18-30% of all asphalt is recycled on some plots. Sustainable Development Goal nos. 9 and 13.
- Donating clean materials to farmers or sports teams on projects with surplus materials so that they can use the materials for local purposes. Sustainable Development Goal no. 17.
- Supporting various teams/clubs in the local area, e.g. Lillehammer Football Club, Elverum Handball and Alvdal IL. Helping young people to take up sports and supporting good health. Sustainable Development Goal no. 5.
- Focusing on increased recruitment through summer jobs, student assignments and membership in trainee schemes to ensure good recruitment and encourage more women to join the construction industry. Sustainable Development Goal nos. 5 and 8.
- Working on preparing greenhouse gas accounts and sustainability/social responsibility report. Sustainable Development Goal nos. 9 and 13.
- Creating cultivation areas of old landfills on road projects and making it easier for farmers to get more arable land and better crops. Sustainable Development Goal nos. 8 and 9.
- Using apprentices on projects to ensure recruitment. This comes under Sustainable Development Goals nos. 5 and 8.
- Request EPD in purchasing. Sustainable Development Goal nos. 9, 12 and 13.
- CEEQUAL-certify employees who work on HSE and sustainability. Sustainable Development Goal no. 13.

Norway is a rich country with a well-functioning democracy, a high degree of technological development, a strong education system and generally flat decision-making structures in businesses. In order to create a green transition and a sustainable construction industry, the industry has to 'turn many small streams into a large river'. We have to implement many small measures and make the construction industry sustainable over time by 2030 and 2050. This is because Norway is a country with diverse geography and topography, high plains, sharp peaks, deep and long fjords, a fertile climate in the south and an Arctic climate in the north. The construction industry consists mainly of small and medium-sized contractors rather than large ones. The major radical changes are therefore expected to be difficult to implement for the majority of businesses in the industry. It therefore seems unrealistic for the industry to tackle difficult problems now, as these will lead to radical changes and create uncertainty which, in

turn, will affect the operation of facilities. On the other hand, many small incremental changes over time is a more realistic and preferred strategy to avoid sustainability work affecting the companies' operations. Examples of such small measures can be found in the section above.

Many roads lead to Rome, and if the construction industry stands together and cooperates, the road will be significantly shorter. To get there, the industry has to start implementing small measures before big changes can be seen. Willingness to change and the willingness to see new paths and opportunities are key to achieving this. Remember, it is better to implement many small measures than one major measure or no measures at all.

References:

UN. (2021). *Sustainable development*. Obtained from https://www.fn.no/tema/fattigdom/baerekraftig-utvikling

Grøv, K. (2019). *Grønn omstilling- Anleggsbransjens byggeplan på veien mot lavutslippssamfunnet*. [Master's thesis]. Norwegian University of Science and Technology

Report Stortinget 13 (2020-2021). *Climate Plan for 2021-2030*. Norwegian Ministry of Climate and Environment. Obtained from https://www.regjeringen.no/contentassets/a78ecf5ad2344fa5ae-4a394412ef8975/nn-no/pdfs/stm-202020210013000dddpdfs.pdf

SINTEF. (2020). *Framsikt 2050. Hvordan ser framtidens bygg- og anleggsnæring ut?* Obtained from https://www.sintef.no/contentassets/ccf2b-fe7339a4a75af3a5a8bfafdccff/framsikt-2050-rapport.pdf

4.3.5 Implenia

Silje Holen

Background

Implenia Norge AS is a part of Implenia Group, the leading provider of building and construction services in Switzerland. The group also operates in Germany, Austria, France, Sweden, Poland and Romania. The group had sales of NOK 36.2 billion in 2020 and has approx. 8,700 employees. The company Implenia AG is listed on the stock exchange (IMPN.SW).

Implenia Norway is headquartered in Lysaker in Oslo and comprises the subsidiaries Norbridge AS and Midtnorsk Betongsprøyting AS. Implenia Norway has around 540 employees and a turnover in 2020 of approximately NOK 2 billion.

Founded in 2006 in the merger between Zschokke and Batigroup, Implenia can look back on around 150 years of history in the construction industry. The company strives for a sustainable balance between financial success and social responsibility, and sustainability is one of Implenia's 5 core values.

Implenia's tunnelling experience in Norway dates back to the acquisition of Betonmast Anlegg (2011) – including tunnelling company Mika AS – and Mesta tunnel (2014). Implenia Norway's area of expertise is complex infrastructure projects combining tunnels and bridges, where the company has many years of experience. Implenia Norway offers services in concrete structures, bridges, tunnels and rock chambers, water and frost protection, as well as tunnel rehabilitation. Implenia is currently building large infrastructure projects such as Moss-Sandbukta-Saastad for Bane NOR and E39 Svegatjørn-Rådal for the Norwegian Public Roads Administration. In 2021, Implenia began tunnel work on Fornebubanen K2A and will begin tunnel and concrete works on E39 Lyngdal øst - Lyngdal vest.

Implenia Norway's 2025 sustainability goals

Sustainability is an integral part of everything that Implenia does. It is essential for Implenia's future as a company that they are environmentally, socially and commercially sustainable.

Figure 4.3.8. Implenia's main sustainability goals.

Implenia develops and builds according to the highest sustainability standards and contribute to the further development of these standards. They work with sustainable partners and continuously collaborate to improve. Implenia convinces and supports their clients by offering project-specific sustainability concepts and implementing outstanding sustainable solutions during construction. Both E39 and Fornebubanen K2A are assessed according to the CEEQUAL standard.

Implenia aims for net zero emissions by 2050 and a reduction in group-wide CO_2 emissions by 15% by 2025. The company employs professional sustainability management on all projects to prevent environmental incidents. Environmental incident reports are measured in KPIs. Implenia develops new circular business models and promotes closed material cycles. Implenia has set itself ambitious sustainability goals and strives to reduce the environmental impact of its construction sites.

A binding environmental standard is applied to all projects, including requirements and measures relating to waste disposal, soil protection, water treatment, noise reduction, air pollution control and energy requirements.

Sustainability initiatives

There are several ongoing sustainability initiatives at Implenia. Several of these are developed in collaboration with the Implenia Innovation Hub. This is a framework to encourage and help employees transform their ideas into innovation. The aim is to generate added value and to provide employees with tools, skills, time and resources to achieve their goals, thereby facilitating the innovation process.

In the following, three of Implenia's sustainability initiatives are described in more detail.

Hydropilot

The construction of roads, tunnels, bridges and other transport infrastructure has until now largely relied on diesel as an energy source. Implenia has ambitious sustainability goals for their operations, and they fully support the Norwegian government's goal to ensure that all transport sector construction sites will be fossil-free by 2025. That is why Implenia Norway has signed a collaboration agreement with TECO 2030 ASA to jointly develop and pilot hydrogen powered construction site solutions. The companies will collaborate to develop and pilot the fuel cells needed to reach ambitious climate goals. The project has received support from Enova.

TECO 2030 is an innovative engineering and equipment development company aiming to significantly increase the use of renewable energy, specifically in the form of hydrogen fuel cells, and reduce the environmental footprint of the shipping industry. Hydrogen fuel cells can be used for large ships and other heavy-duty applications, such as powering equipment used at construction sites.

Figure 4.3.9. TECO 2030.

Repurposing a bridge

Recycling is increasingly popular, but repurposing a bridge is perhaps not an obvious choice. Brødrene Rodegård, Joint venture Implenia-Isachsen (IMIS) and the Norwegian Public Roads Administration were prepared to think out of the box, and that is why an old bridge from Sandvika is soon to be rebuilt in Nesbyen.

The construction of E16 between Sandvika and Wøyen include local roads in Sandvika and their connection to the new highway. The project also includes the removal of five bridges. IMIS, a consortium formed by Implenia and Isachsen, had torn down four of these when project manager Ronny Abelsen received a phone call.

Figure 4.3.10. Dismantling: The Birkheim bridge is carefully taken apart so it can be lifted out in one piece.

Figure 4.3.11. Heavy duty: The bridge is carefully transported to Nesbyen. Photo: IMIS (https://nyheter.byggfakta.no/ta-en-bru-og-la-den-vandre-196490/nyhet.html).

"I knew that quite a few bridges had to be demolished in Sandvika as part of the E16 project. So, I contacted them to see if one of these bridges might be suitable for repurposing," says Kent-Johnny Rodegård of family firm Brødrene Rodegård AS. The construction company was founded in the mid-1960s by Kent-Johnny's parents. Now run by the four Rodegård brothers, it specialises in excavation, blasting and construction.

The plan is to rebuild the bridge that used to stand in the middle of Sandvika over the Rukkedøla river in Nesbyen. This environmentally responsible contractor believes there is considerable potential for repurposing in the construction industry – certainly a lot more than is happening now. "The bridge elements I received from Sandvika were as good as new and reusing them was the obvious choice; it's a win-win situation," says Kent Johnny Rodegård. "I've always been interested in recycling, because it's more eco-friendly and cost-effective. I believe there is a lot of waste in the Norwegian construction industry, and that a lot more building materials and equipment could be repurposed."

"This is an excellent example of the circular economy in practice. It shows very clearly that repurposing is possible and, in many instances, profitable," says Ronny Abelsen. "Increased recycling of materials and development of new, sustainable business models are two of the main objectives of Implenia and Isachsen Anlegg going forward. So, I hope we will see many similar examples in the years to come."

Sustainability at Fornebubanen project K2A

Implenia is the main contractor at Fornebubanen K2A. Fornebubanen is a fossil fuel free construction site with sustainability at the very core. All construction machinery and transportation trucks run on either electricity or biodiesel. For transportation between sites and barracks, the traditional pickups are supplemented with electric shift buses and electric bicycles. This reduces both CO_2 emissions, noise, and parking issues at the sites.

In order to further develop their sustainability credentials, Implenia is working to certify the project with a CEEQUAL Construction Only award. In relation to this, Implenia is developing its own climate reporting for the project. Measures implemented on the project include using low carbon concrete, short transportation distances for rock and masses, and reuse of waste and materials whenever possible. For example, EPS insulation from one part of a demolition at the Fornebuporten site was reused as temporary noise reduction for another part of the site.

Figure 4.3.12. Making a difference: Environmental engineer at Fornebubanen K2A, Karin Haave Oskasin, wants to steer the construction industry towards a more sustainable path.

Collaboration with subcontractors using digital planning program VisiLean further promotes cooperation and effective planning, thus reducing waste and inefficiencies in the process.

With regards to more traditional environmental measures such as water reuse and waste sorting and reduction, the project has two tunnel water treatment plants, each of which recycle more than 75% of the water used, and a waste sorting rate above 95%.

Sustainability report
More information about Implenia's sustainability work can be found in their online sustainability report:

https://implenia.com/en/sustainability/sustainability-report/

4.3.6 AF Gruppen

Erik Frogner

AF Gruppen is Norway's second largest contractor whose vision is *Clearing up the past, building for the future*. Sustainability is key to everything we do. The following figure illustrates our goals for climate tracking and circular economy:

AF Gruppen is Europe's largest demolition and environmental management contractor and offers a high degree of recycling. At three environmental parks, contaminated waste material is transformed into new resources using innovative environmental technology developed by AF. These include recycled sand and concrete aggregates produced from recycled contaminated excavated waste materials.

Industrial construction, including sustainable tunnelling, is performed by the largest business unit in AF Gruppen, i.e. AF Anlegg (AF). AF is certified in accordance to ISO 14001 and is also starting to gain experience with CEEQUAL project certification. Projects are located mainly in Norway, but in 2020 we were also awarded E4 Bypass Stockholm, a large tunnelling project for the Swedish Transport Administration. AF works on tunnelling, including interior works, primarily with our own skilled Norwegian employees (> 90% unionised) and our own machinery, often proprietary. Over time, this has given us the ability to develop expertise, methods and solutions that continuously contribute to reducing the carbon footprint associated with our tunnelling.

Some examples/areas that contribute to a reduced carbon footprint in completed and ongoing tunnelling projects can be found below:

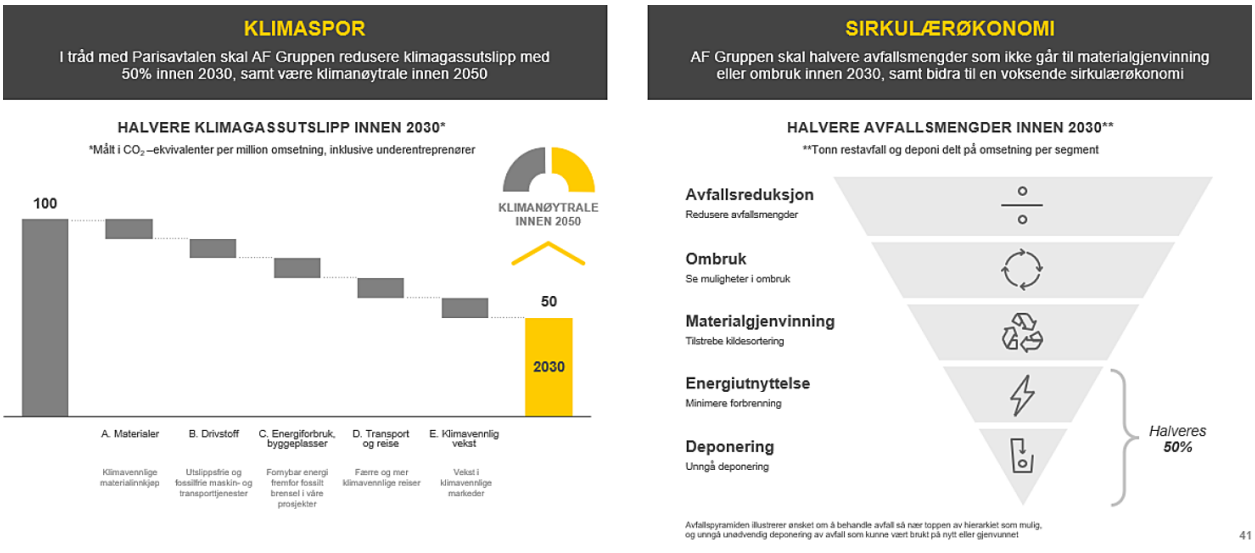


Figure 4.3.13. AF Gruppen's goals for climate tracking and circular economy (in Norwegian).

Electrification of machinery

AF uses modern machinery in adapted sizes, which generally uses state-of-the-art low-emission technology. There is usually grid power available for tunnelling projects. This facilitates a high degree of electrification of machinery and equipment. This is positive both in reducing the project's greenhouse gas emissions and in reducing the impact on the health of tunnel workers.

About 75% of AF machines and equipment used for the installation of water and frost protection have already been electrified.

AF has recently completed an innovation process for developing an electrified main loader for tunnelling operations which will fit most transport tunnel cross-sections. The prototype of this will be put into operation in 2022, and a preliminary sketch of the loader is shown below.

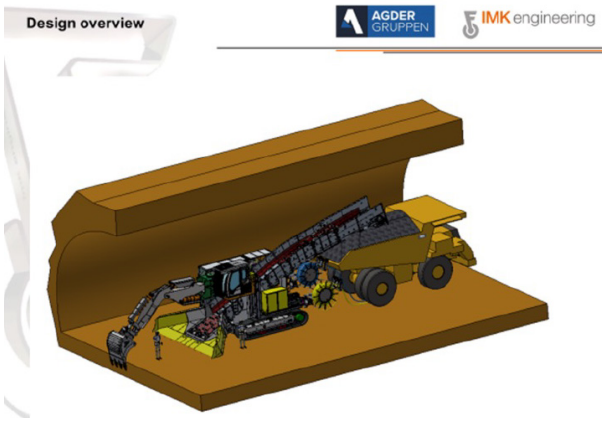


Figure 4.3.14. Electrified main loader.

Reuse of rock

An important factor in reducing the carbon footprint from tunnelling is planning for the best possible use of the rock from tunnel operations. Using the rock for various purposes within the project and avoiding transporting rock material out of the project for surplus disposal will always be a priority. In recent major road projects, AF has established effective routines for frequent mapping and testing of the mechanical properties of the rock, so that rock from our tunnelling can, for example, be crushed and used as a reinforcement layer or as an aggregate for local production of asphalt or concrete. AF knows that regulatory requirements for mechanical properties often can be unnecessarily strict and that an dispensation process to relax some of these requirements may increase the use of 'local rock' significantly.

AF has further experienced that the potential for acidic rock may affect the extent to which the rock from tunnelling can be reused. For the E6 Roterud-Storhove project in Lillehammer, AF has an early involvement contract for Nye Veier. The contractor is responsible for the development and management of the project in a collaboration phase approximately two years before the start of construction. On this project, there was a danger that large volumes of rock from the 4.2 km long Vingnes tunnel located in the Brøttum formation could be considered to be acidic and thereby as contaminated waste material that required external disposal. After significant mapping and extensive geochemical and environmental analyses, it is now believed that all the rock from the tunnelling can be declared safe and reused for road construction on the same project.

Concept development and optimisation

The greatest potential for reducing the carbon footprint from sustainable tunnelling is also to reduce indirect emissions through reduction of quantities/scope. On several major turnkey contracts, AF has in recent years developed and optimised solutions in collaborationwith advisors and customers. Structured innovation processes are often used in this context.

AF often starts by optimising routing/line selection and focusing on establishing a balance of waste materials and optimal waste logistics. On a transport project, bridge structures and tunnels produce a significantly higher carbon footprint than external road/rail. This means that the greatest focus is on reducing the length of bridges and tunnels.

Portal constructions at the end of tunnels is also often unnecessarily bulky and long and have challenging geometry/cross-sections. Here the functional requirement for protection against falling rock

Figure 4.3.15. Grouting equipment.

should primarily be dimensioning. AF also has solid experience of focusing on accurate contours to reduce the amount of overhanging rock. Important tools include accurate drilling and use of electronic igniters.

Over time, AF has developed equipment, expertise and methods for tunnel grouting. By optimising the injection procedure and using controlled hardening, AF has been able to reduce the volume of cement used for grouting by up to 60% on several tunnel projects. AF's newest, proprietary state-of-the-art grouting equipment can be seen in figure 4.3.15.

4.4 Suppliers and specialists

4.4.1 Foamrox

Kari Askeland

A unique and lightweight product that lowers emission by half

Foamrox has created a unique product for a more sustainable tunnel construction. The prefabricated elements are made from 100% recycled glass (cellular glass) with a thin outer coating (polyurea). It's currently being used in over 50 Norwegian tunnels, replacing concrete in technical buildings, emergency exits and kiosks, fire barriers, frames for emergency cabinets, draw pit and lid, with a goal of eventually delivering the tunnel vault itself.

The Foamrox material weighs 90% less than concrete, which makes it easy to install manually, without the need for heavy machinery. The installation time is exceptionally short in comparison to the same build made from concrete. A Foamrox technical build takes only a few days to be completed and as soon as it is up it is ready for the next stage, such as electrical installations and so on. The quick installation time makes a big difference to project costs and duration, but more importantly, the material used lowers greenhouse gas emissions by over 50%.

To better illustrate how the use of Foamrox can lower CO_2 emissions, Norconsult have done a calculation on a specific project, Rogfast, a 27-kilometer-long subsea road tunnel currently under construction in Rogaland in Norway. It's being developed by the Norwegian Public Roads Administration and will include several technical buildings.

By using Foamrox technical installations as described above instead of concrete, it will reduce the greenhouse gases by more than 50% (from approx. 3 500 tCO2e to approx. 1 700 tCO2e.) This number is from a manufacturing point of view and does not take into consideration the savings that could be achieved on transportation and installation.

When it comes to transportation, the low weight of the Foamrox material means that lorries can transport more compared to concrete. Based on an 18-ton truck, calculations show that it would be able to carry over four times more Foamrox material and yet weigh nearly three times less than if it was carrying concrete.

Based on transportation of 100.000m3 a year, the number of trucks used would be reduced by 8,400, which in turn would lower CO_2 emissions by 20,000 ton (Foamrox uses 6000 ton, whereas concrete uses 26,000 ton).

Figure 4.4.1. A technical room in a tunnel in Norway mounted without the use of heavy machinery.

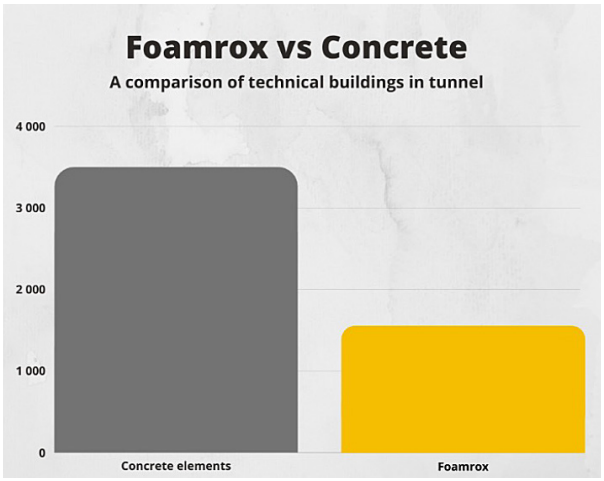


Figure 4.4.2. The graph illustrates the savings that can be made on CO_2 emissions in a tunnel by using Foamrox elements in technical buildings instead of concrete elements.

Figure 4.4.3. Foamrox used as fire barrier between tunnel sections.

Figure 4.4.4. An emergency station made from Foamrox elements mounted behind the tunnel vault.

As already mentioned, the Foamrox material weighs 90% less than concrete, and can be installed manually or with electric tools/machines, a major plus for health and safety. Installation is quick and easy, and without the need for heavy machinery, the risk of accidents and injuries are greatly reduced.

4.4.2 Ølen
Lovise Amanda Lærdal

Ølen Betong's focus on the climate and sustainability work

Our sustainability strategy
The global climate challenges are a responsibility facing us all and something Ølen Betong places high on its agenda. Our aim is to do business without harming the environment. We work continuously to ensure that our products and our use of raw materials have as environmentally friendly and sustainable a life cycle as possible throughout the production process.

We are environmentally certified to NS-EN ISO 14001. To ensure that this work is integrated into our corporate governance, we have chosen to base our aims on some of the UN's Sustainable Development Goals.

Nine of 17 Sustainable Development Goals selected by Ølen Betong with a description of how they are built into our business can be found below.

"No one can do everything, but we can all do something."

Environmentally friendly and sustainable concrete elements for transport tunnels

Reducing emissions from construction and logistics is a high priority in our company. We work continuously on the optimisation of EPD for tunnel elements, which makes it possible to achieve the lowest possible CO_2 emissions during the product's life cycle. The carbon footprint of the concrete elements for the entire life cycle from raw material to finished product for tunnels is documented using EPD (Environmental Product Declaration).

Low carbon concrete is Ølen Betong's solution for a green and sustainable choice of concrete. The composition of the concrete ensures low greenhouse gas emissions per m3 of concrete produced which also allows for the concrete's durability requirements. Environmentally friendly additives, research and development on aggregate material as well as cement, which makes up a smaller part of the concrete volume, give us the right quality of concrete with a significant reduction in emissions.

The result of research and development in recent years means that we now supply concrete elements for transport tunnels using low-carbon concrete, which has much lower overall emissions than was previously the case. Developments have resulted in a reduction in CO_2 of 21%, which amounts to 9.833 kg/m2 of CO_2 equivalents.

Cement is a raw material in the concrete that makes up approximately 10-15% of the total carbon footprint. In the production of our environmentally friendly concrete elements, we have achieved a reduced cement usage of 22%. In addition, we have reduced the use of reinforcement by 33%. The total cost per m2 produced and delivered element in the tunnel has been reduced by 12-15%. This is proof that effective sustainability work ensures results on the bottom line.

Figure 4.4.5. Concrete elements from Ølen.

In addition to significant reductions in emissions, these improvements have also had several positive ripple effects, where the dimensioned service life of the concrete elements has been increased by 100%, from 50 to 100 years.

The cleaning of concrete elements can be performed with environmentally friendly chemicals throughout their life cycle.

Ølen Betong has completed dimensioning and certification of all the concrete elements for transport tunnels in the concept for the T9.5 and T10.5 profile road network, based on the Norwegian Public Roads Administration's Handbook N500. The profile can be expanded with the use of flat elements in the centre of the roof so that larger and wider tunnels can be constructed using the same concept. This method provides large savings at all stages, not least in terms of moulding equipment.

We have supplied this type of tunnel element for the E39 Mandal – town of Mandal project and are now supplying the E16 Bjørum – Skaret project.

Ølen Betong is also an important supplier of prefabricated concrete elements for technical buildings and SoS posts. The complete foundation for the structure is also prefabricated. The completed structure is installed in the tunnel in approximately six working days and is then ready for further electrical installation.

Premanufacture of elements in the factory provides sound economy, excellent quality control and reduced emissions to the environment.

Important factors that are not visible in our EPD

Our EPD presents the emission factor per m2 of concrete element produced and supplied for a tunnel. It is important to point out that several significant factors play a role in the overall environmental accounts for a construction project. These factors must be taken into account by the client when the choice of building materials for construction projects is made and overall environmental accounts are prepared.

Local raw materials

A significant proportion of the aggregate for the production of the elements is sourced locally at our own factory. This reduces energy consumption and emissions into the environment in the form of reduced import of raw materials.

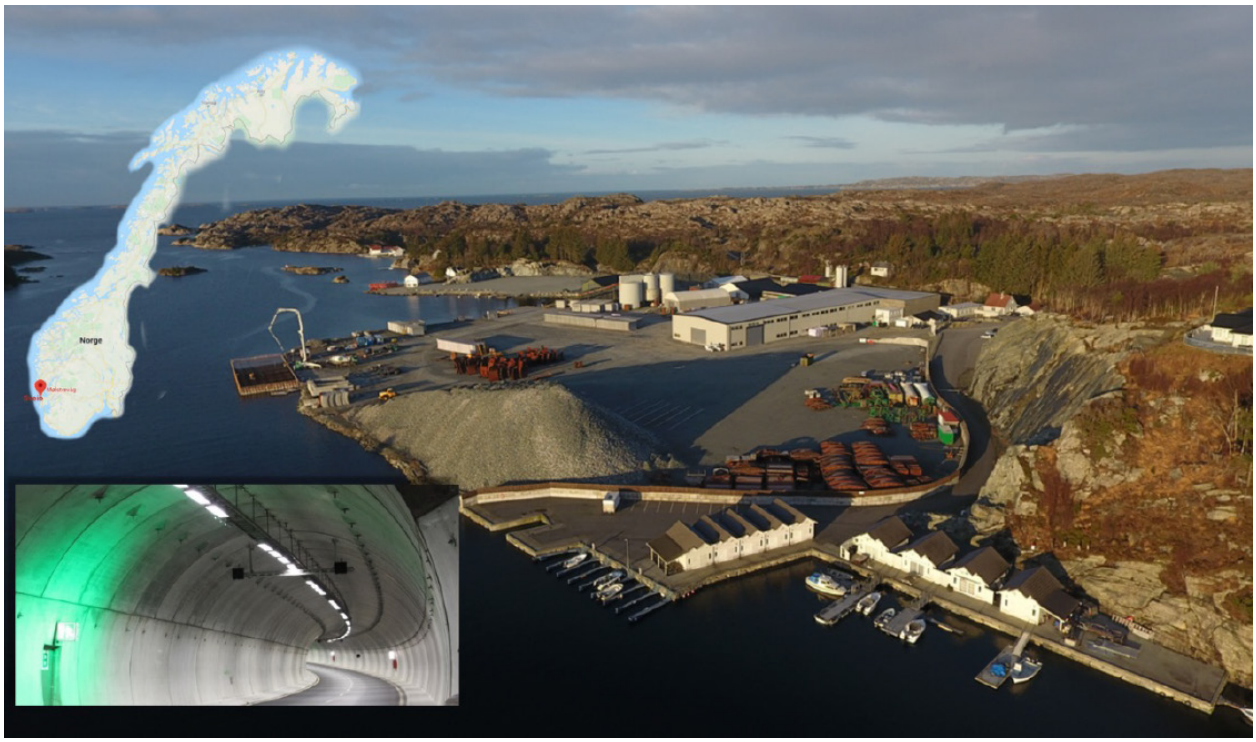


Figure 4.4.6. 1 Factory in Mølstrevåg, Sveio.

On-shore power for ships

The elements are transported by ship from their own quay to temporary storage points in ports all over Norway. From there, we arrange our own transport of the elements to the tunnel installation site. On the quay at our factory, the ships use on-shore power when loading. This reduces significant greenhouse gas emissions, improves the working environment and reduces noise in the period during which the ship is docked.

Optimised transport fleet

For our transport fleet, we have a strong focus on effective transport planning based on the best possible utilisation. We have regular meetings with our hauliers to highlight environmentally friendly driving using action plans and associated training. The vehicles are equipped with GPS fleet control that generates 'driving behaviour reports' which are distributed and closely followed up on with our transporters and drivers. In recent years, this has produced with results that document significantly higher levels of environmentally friendly driving with a reduction in fuel consumption. This is not only good for the environment, but also for safety and fuel economy.

Figure 4.4.7. 2 Loading tunnel element quayside in Mølstrevåg.

Electrification in operations and transport and investment in solutions that provide higher load weights are measures that are being worked on so that we can further reduce our environmental impact. Vehicles are replaced with new ones when they are 5-7 years old. New vehicles with Euro-6 engines as well as updated technology and reduced environmental emissions are now being used.

Low maintenance costs

Concrete is a strong, durable, flexible and malleable building material that is able to withstand chemical and mechanical effects well. The tunnel elements that are designed for a service life of 100 years can easily be maintained using environmentally friendly materials. This results in low and predictable maintenance costs with reduced energy consumption and carbon emissions. It is important that maintenance needs and service life are included in the

calculation when considering choice of materials and the environmental impact of downtime/closed tunnels during maintenance periods.

Fire in tunnels
Concrete is a fireproof material. In a tunnel fire, the extent of damage to the concrete elements is normally small. The concrete can withstand considerable temperatures without being deformed or weakened.

Reuse/Material recovery
The current generation has to take responsibility for renewing, maintaining and improving the world's resources for future generations. Concrete products can be reused for the same purpose or other purposes such as new structures or, for example, for terrain rehabilitation. Provided that the documentation of quality/durability satisfies the new design.

Carbon capture in the cement industry
In 2021, the Norwegian government decided to make major investments in the cement supplier Norcem's CO_2 capture project. The project in Breivik mainly involves capturing CO_2 emissions produced by cement production, transporting and storing it safely under the seabed. The project aims to capture 400,000 tons of

CO_2 annually. Which will mean a further CO_2 reduction of approx. 50% for our tunnel elements.

Climate award for Haugalandet 2020
Consideration for the environment is important to us and our descendants and we want to be a role model for our industry. Therefore, we are proud to announce that Ølen Betong was awarded the Climate Prize by the Business Association at Haugalandet in 2020.

Concrete as a material is environmentally friendly, has a long service life and can be reused. With the right planning and design, the use of concrete as a material will be able to reduce overall environmental impact, also with a view to changing use in the future. Building with concrete means showing consideration about the environment. It is also why Ølen Betong's slogan is a **'solid future'**.

4.4.3 NORCEM – ZERO vision
Kjell Skjeggerud, HeidelbergCement

NORCEM has set ambitious goals for CO_2 reduction from their production of cement. We have a zero vision before 2030 which requires several ambitious measures for energy efficiency, alternative fuel, new cement products but most importantly, carbon capture & storage. In order to realize CO_2 capture in Brevik, Norcem will invest many NOK 100 millions as our own share of the Longship project previously presented (section 3.6.2).

The cement industry in Europe is subject to the EU CO_2 emissions trading system: EU ETS. As a measure to achieve its climate objectives, the EU has tightened the allocation of free emission allowances to industry and this trend will continue to become stronger in the years to come. We must accept that all free emission allowances will disappear in the period leading up to 2030. As a result, there is a strong movement in the allowance price, which is expected to continue in the period ahead. At Norcem, the consequences are already visible through a significant increase in costs for releasing CO_2 and thus also for producing cement.

Our goal with CO_2 capture in Brevik is to be early to take measures to reduce our emissions and thus also the movement of costs involved in emitting CO_2. Our project, which is the first in the cement industry, will contribute to the development of knowledge, which will, in turn, help to reduce the costs of CO_2 capture. At some point, the cost curve for releasing CO_2 and the cost curve for capturing CO_2 will intersect, and then the vast majority of cement producers in Europe will have some form of CO_2 capture. We believe that being ahead of the game will be profitable from a long-term perspective.

The reduced availability of traditional substitute materials such as Fly Ash and Slag has also contributed to a sharp price increase for these ingredients in our products.

Together with the general movement of prices with regard to our input factors, this means that everyone must be prepared for a sharper increase in the price of cement in the coming years than we have been accustomed to. Norcem will adapt to the trends in the market independently of the CO_2 capture project in Brevik.

In the first instance, we will be implementing the project in Brevik. In Kjøpsvik, it will be natural to wait until developments are such that more cost-effective capture solutions are available. This means that, for a period of time, we will have cement with CO_2 capture available from just one of our plants (in the first few years this will be the situation for all plants other than Brevik). The production capacity in Brevik is not big enough to meet our needs throughout Norway, and sectors in the market will also have to use cement from Kjøpsvik in the future. Effective logistics are currently the basis for the supply

pattern. We do not have a logistics apparatus that is in a position to make cement from both Brevik and Kjøpsvik available throughout the market. In the future, it will therefore also be the optimisation of logistics that will be the guiding factor in the supply pattern. For projects in Southern and Central Norway, it would therefore be a natural thing to assume that there will be access to cement with CO_2 capture from 2024, while, in Northern Norway, it will be necessary to prepare for not having cement with CO_2 capture for a few more years to come. In the event of individual projects where cement with CO_2 capture is absolutely essential also in the north, Norcem will go a long way to achieve this, even though this will mean long transports by tanker truck, with associated increased costs and increased CO_2 emissions.

Saferock

As the most widely used building material in the world, concrete plays a significant role in the carbon footprint of the building and construction industry. Its key component, cement, is the source of about 8 % of the world's CO_2 emissions, according to think tank Chatham House.

As a response to this, the Norwegian green tech startup company Saferock has now joined forces with an interdisciplinary team and is taking the vast step from research to broad practice and full-scale production. Their joint venture partners include not only the University of Stavanger but also the renowned architectural studio Snøhetta.

Globally industrial processes generate vast amounts of various residues with untapped potential. Saferock's patented technology gives new value to these unutilized by-products. The ambition is to develop low CO_2 emission concrete as an alternative to the established Portland-based concrete.

Saferock is receiving NOK 11.5 million from Enova, a state-owned enterprise that works to transform into a low-emission society. The money will be used for a pilot plant for the commercialization of proprietary technology to produce climate-friendly geopolymer concrete that will be up and running within this year.

- Enova supports those who lead the way and pave the way for more sustainable products in the construction industry. This pilot project can demonstrate that the solution can be scaled from the laboratory stage to industrial size while maintaining product quality. This is new technology that we need to achieve the climate goals of reduced emissions, says CEO of Enova Nils Kristian Nakstad.

4.4.4 Protan

Pål Fossum

In a world where mobility is essential, tunnels and underground constructions are at the core of a well-functioning society. A society that is however evolving and constantly facing new challenges.

In Protan, we want to be part of this change and we want to contribute in a more sustainable world by prioritizing global sustainable development goals in all our segments.

Protan is present in tunnels and underground constructions from the excavation phase, through their flexible ventilation systems, to the construction and lifetime of the tunnel, with their full waterproofing system.

It is thus essential for us to estimate concrete effect and results of our actions towards this goal. Here are some examples of taken measures:

Goal 13: CLIMATE ACTION

CO_2 Footprint:

A lot of focus is directed towards the CO_2 footprint of products in the construction industry. However, it is often forgotten that when talking about sustainability and environment, the story does not stop at the factory gate, and that products have an impact during their complete lifetime.

Protan unquestionably assesses the complete life cycle of their products by including all stages from production of raw materials to end of life treatment, including transport and of course installation.

Waterproofing membranes/systems can be found in the vault of the tunnel or in the portal area. Several material options are available for each application and choosing the right components can have a noticeable effect.

Within worldwide used waterproofing membranes, two main materials are selected: TPO and PVC. By choosing PVC, as produced by Protan, we can reduce the equivalent weight of CO2 per m2 by approximately 18%.

Regarding the portal areas, in addition to TPO and PVC, a substantial number of partners are still using bitumen (single or double layer), that has a substantial higher footprint compared to both PVC and TPO. Indeed, a single layer bitumen solution increases the equivalent CO_2 weight per m2 by approximately 72% compared to similar system in PVC.

By providing EPD, we tell the complete story about a product's environmental performance throughout all stages in its lifecycle – from cradle-to-grave. This allows for standardised comparisons between carbon footprints and other environmental impacts for products belonging to the same product category. This provides more transparency and a better foundation for making more informed and conscious product and system choices in our industry. EPD are also registered in various European platforms (EcoPlatform, ECOProduct) that give a global and more sustainable aspect to our products.

Goal 12: RESPONSIBLE CONSUMPTION AND PRODUCTION

Material sustainability:
The construction industry is the second biggest consumer of polymers in the world. It is thus important to focus on preservation of resources and make sustainable choices.

Protan's homogeneous tunnel membranes are produced including up to 50% of recycled material.

The recycled materials are either coming from own production waste or from other industries that have the required quality and traceability.

The Norwegian market accepts already an unlimited amount of recycled material in their waterproofing systems (following Norwegian Handbooks N500 or R510) as long as the quality of the finished product is ensured. There is however a still non negligeable amount of countries limiting the use of recycled material in these applications, thus restraining possibilities for manufacturers.

In Norway, the Norwegian Tunnelling Society reports an average of 70km of new tunnel each year, representing approximately 1,26 million m2 of waterproofing membrane each year. For a standard Type III membrane, 1,5mm thick, there is thus a potential of using 1134 tons recycled polymer per year, only in Norway.

In addition, as part of its journey towards sustainability, Protan is also exploring different paths to provide better products in numerous sectors.

For reinforced tunnel membrane or ventilation ducting in tunnels and mines, PET textiles are used to increase robustness and minimize impact of any damage or tears. Protan is currently evaluating recycled PET textile as a sustainable alternative. Just by taking into consideration ventilation duction, Protan would contribute in using over 3 million m2 of recycled textile each year. Combined with other sectors using PET-textiles (roofing, technical textiles, ...) there is an extremely high potential worldwide.

In addition to delivering products free from REACH candidate list substances, Protan is also working closely with suppliers to introduce environmentally friendly plasticizer as used in PVC membranes, that would have a substantial positive environmental impact, as they represent over 7,5 million tons globally, and over 1,35 million tons in Europe (Source: *2018 IHS and European Plasticisers estimate*).

Circular economy:
Protan has worked out an arrangement to collect old ventilation ducting after use in mines or tunnels. This to ensure correct handling of the materials and preserving resources. Indeed, by believing in quality materials above economical solutions, we contribute also in reducing our mark on the environment: by using a smart and innovative washing system and thanks to high quality materials, our ventilation ducting can be reused numerous times.

Production:
Our production processes have been optimised to ensure energy saving and sustainability are prioritized. Some of the improvements that were implemented are for example using InfraRed heating source instead of hot air or residual heat from cooling process is recovered and used as heating in factory and office building.

Goal 9: INDUSTRY, INNOVATION, AND INFRASTRUCTURE

Durability:
With a life expectancy over 100 years for our tunnel membrane, we ensure a durable and reliable system that contributes to a more sustainable world.

Energy effective ventilation system
Protan Ventiflex ducting are specially developed to deliver fresh air with a low friction factor to ensure better air quality at face.

4.4.5 Normet

Daniel Risbeck

Sustainable Tunnelling with Low Carbon Approaches leads to Lower Project Costs
"We have the technology for constructing low carbon sprayed tunnels, both with material technologies and Battery Electric Vehicle (BEV) based equipment", says Ross Dimmock, Vice President Tunnelling of the Normet Group, "but I am not sure if everybody knows that these low carbon solutions

Figure 4.4.8. BEV Sprayed Concrete Robots.

also mean that you may have lower cost projects." The main drivers influencing the carbon reduction in sprayed concrete tunnels are in the field of equipment, materials and education/training.

The different technologies reducing the carbon footprint in sprayed concrete tunnels already exist and can significantly contribute towards meeting the Paris Accord, not only due to the use of electricity from renewable resources. To reach an acceptance generally, a mechanism of incentivisation is strongly recommended both for the whole industry, as well as for contractors and the supply chain. In the meantime, saving tonnes of carbon must become the highest value and priority. Besides new technologies in tunnelling like battery electric vehicles, a designer needs to set best practices and adapt the design to align with low carbon concrete materials and application approaches. Sprayed concrete must be accepted as concrete and flexible low carbon materials must be used for thinner, more efficient and safe linings. Although higher upfront costs of for example for BEV equipment are generally expected, the short payback through fuel savings, lower lifetime costs and a reduction of ventilation are only some advantages with the low carbon footprint and should be the main reasons to adopt this new technology.

Equipment

New electric drive and modern EU Stage V diesel drive shows up much lower emissions and CO_2 in tunnelling than ever. Using Battery Electric Vehicles, no CO_2 will be produced in the tunnel and the carbon footprint is further reduced if renewable resource-based electricity is used. BEV´s provide a better working environment, no fumes, more powerful equipment, faster tramming, much fewer ventilation demands, less noise and finally less overall lifetime costs. Especially for long distances, the effects are amazing not only for tramming but also for spraying with electric-powered rigs by an in-tunnel power supply.

The accuracy of spraying is still improving by using tools like scanners or automated boom control to improve and support the nozzleman´s job operating large robotic spraying rigs. Integrated control dosing systems means less waste, fewer problems, less re-work and less rebound due to high mixing efficiency at the nozzle. This means reduced amounts of concrete, less cement and as a result lower costs and faster construction. Special concrete pumps with low pulsation and a continuous flow of the three components of concrete, air and accelerator maximise the quality and safety of producing high dense homogeneous sprayed concrete.

Increasing efficiency of battery and recharging technologies, upgrading or retrofitting of existing thermal engines to electric drive, scanners and semi to fully automated spraying increasingly is leading to a lower carbon approach.

Materials

Especially by developing the sprayed concrete itself, the best results of lowering the CO_2 emissions are feasible. By replacing for example 40 % of Portland Cement with ground granulated blast-furnace slag (GGBS) and substituting steel fibres with low carbon option such as polymer structural fibres, a carbon saving of 43 % is possible. And the research on lowering this number by even further replacement of cement, and with cement-free geopolymer solutions is in the pipeline.

The main issue in the current process is the cement with up to 75 % embedded carbon in the mix and here especially the Portland cement as the main active ingredient with the current range of accelerators for the spraying concrete. The setting and early age performance is driven by the chemical reactions and its this reaction that is the main focus of changes.

Higher performance sprayed concrete mix design, fibres, alkali-free accelerators (AFAs), pozzolans, new design approaches and standards, sprayed waterproofing membrane technologies that form composite, permanent sprayed concrete linings, makes it possible to reach a thinner tunnel lining and therefore, more sustainable tunnel construction overall.

High-performance concrete allows up to 25 % thinner lining than conventional approaches what means savings in steel reinforcement and cement and as a result not only carbon reductions, but project time and cost savings.

Another big point in reducing CO_2 is in striving for a greener, circular economy by maximising recycling and reuse, to reduce waste, plastics, and the dependency on new resources. Recycling of tunnel equipment, rental options to maximise the useful life of equipment, re-use of components, re-build of machines, recycling of aggregates and the use of ash, as well as other waste products in concrete, shows plenty of potential. Not to forget recycling of packages for construction materials, chemicals, adopting bulk tanks, re-using steel liquid drums and more. This may lower the general amount of carbon and natural resources.

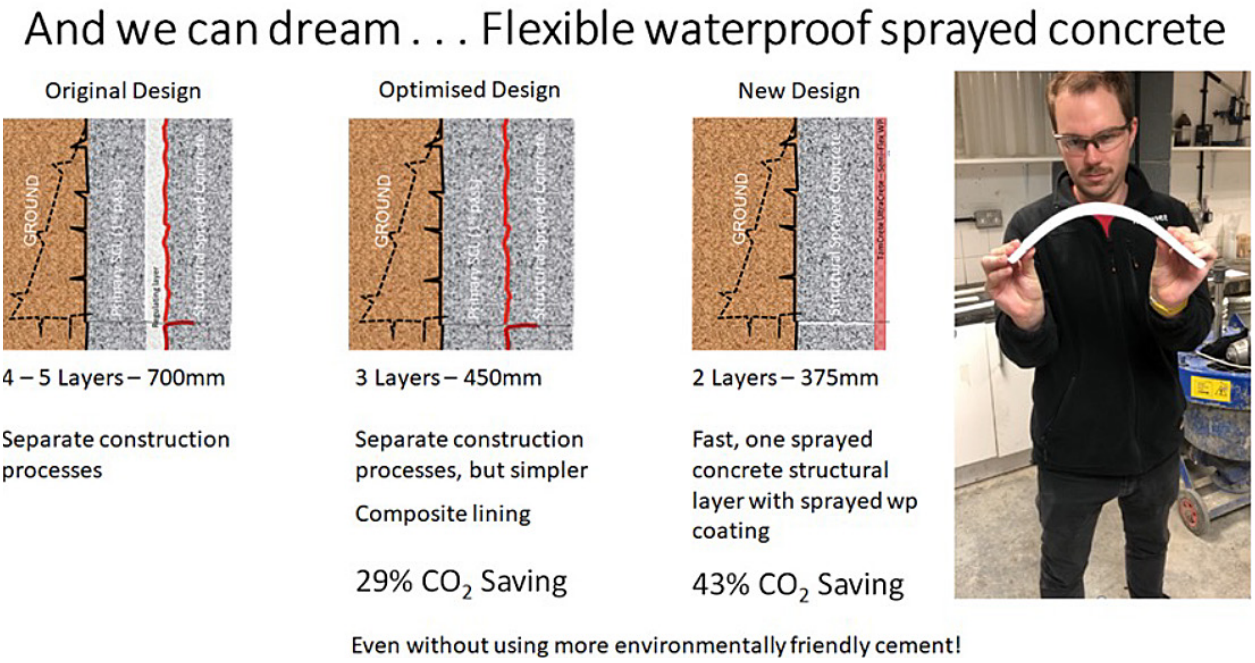


Figure 4.4.9. New design for shotcrete layers.

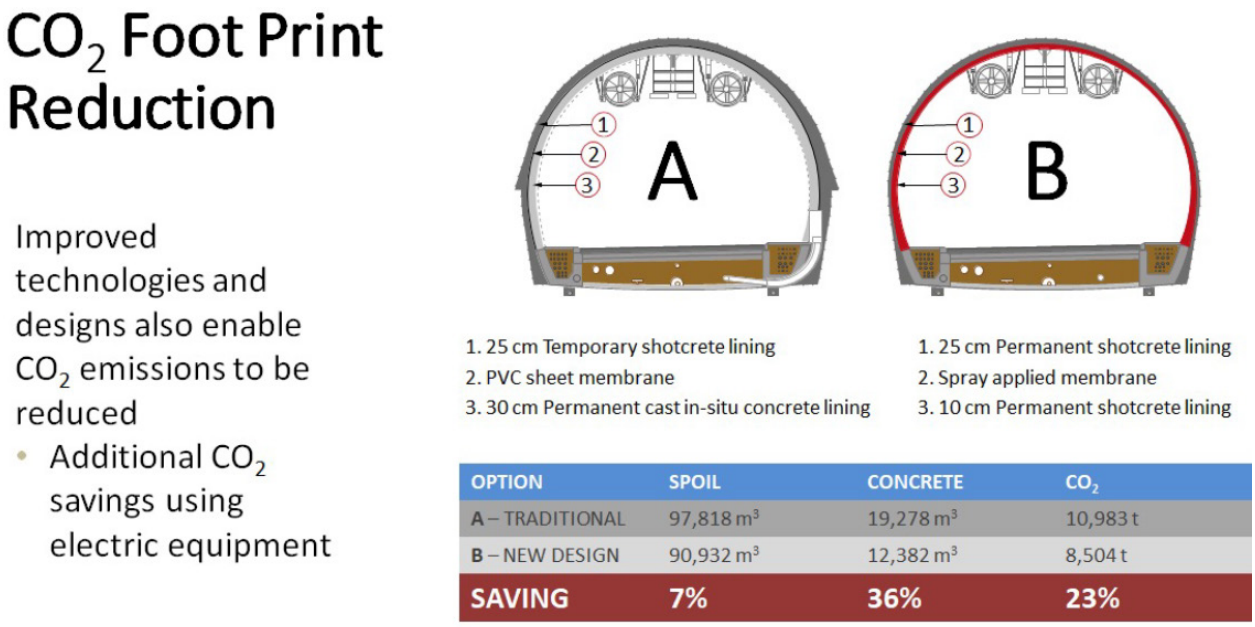


Figure 4.4.10. The use of shotcrete as permanent lining can reduce CO_2-emmission.

Figure 4.4.11. Examples of shotcrete surfaces.

Education and Training

Last but not least the training and education of the staff is a big part of the puzzle. To raise the skills of the nozzlemen using the equipment, handling the materials, and working in the tunnel is very important. Only highly educated and trained, experienced nozzlemen can reduce waste, minimise rebound and lower the use of sprayed concrete together with the best available equipment and technology. To use this technology and to offer highly qualified training is as important as the technology itself to reach the lowest carbon mix.

4.4.6 Devico

Rune Lindhjem

Devico strives to achieve a sustainable operation throughout its organization, for instance by sourcing materials and services locally, and to ensure workers' conditions are acceptable. We also utilize renewable materials when possible and recycle as much as possible of material waste. For the tunnelling industry it is, however, the technology and services offered that can contribute to more sustainable construction, by providing an improved basis to optimize design, position the tunnel alignment and plan the construction stage.

Directional core drilling (DCD) technology is used in the pre-investigation phase of tunnel construction to drill and retrieve core samples along the planned tunnel alignment. While all pre-investigation techniques collect important data, the core sample from a DCD operation provides an added benefit in that it presents a continuous sample of the tunnel alignment. This gives the opportunity to map and under-

Figure 4.4.12. Retrieved core samples (Photo: Devico).

stand geological features with high accuracy and reliability.

While an improved understanding of the ground conditions provides an enhanced basis for optimization of the tunnel design and alignment, it also affects the planning of the construction phase. Stabilization needs, groundwater control, construction progress etc. can be estimated with higher accuracy and be better prepared in advanced.

Projects using DCD

In Norway, DCD has become a common method for pre-investigation of tunnels, and particularly so for sub-sea tunnels. Several high-profile projects have used the method, including Rogfast, Ryfast, Moreaksen and the "ship tunnel", to name a few. The data, typically in combination with data from other pre-investigation techniques, have led to shallowing and shortening of tunnel alignments, optimization of stabilization and improved preparedness for changes in geology and presence of challenging zones.

See devico.no for more information about the products and services offered by Devico for directional core drilling, alignment of drill rigs and surveying of boreholes.

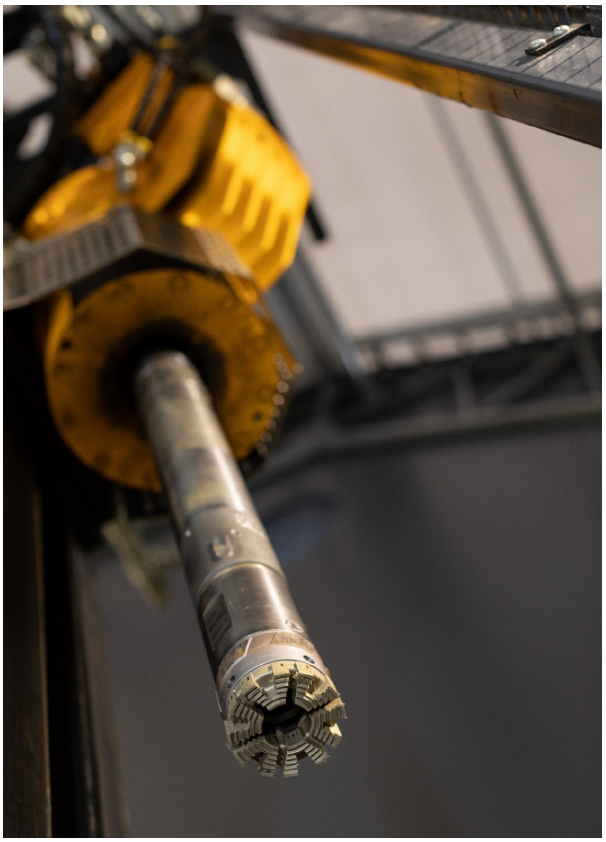


Figure 4.4.13. Detail picture of boring equipment (Photo: Devico).

4.4.7 BeverControl

Thorvald B. Wetlesen

We have identified 11 of the 17 Sustainable Development Goals where we are committed to make a specific contribution through our daily work. We strive to make the workdays for both our employees and for our end customers safer, more efficient and more enjoyable. This way we also work for a more sustainable industry. Below we list some examples on how our activities are aligned with 11 of the goals.

- **Goal 4** - Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

The last five years we have had automation apprentices from the local vocational school. It is a win-win situation giving young professionals the chance to learn from hands on experience, and we get to know talents for future recruitment as well as getting valuable help in our production and service teams. We think it is part of our social responsibility to help young professionals to get job training. Furthermore, we encourage motivated students to continue more advanced studies, in fact several of our former apprentices now study at colleges and universities.

- **Goal 5** - Achieve gender equality and empower all women and girls

It could be a great loss to only recruit from a part of the total talent pool – we employ based on qualifications regardless of gender, religion and ethnicity. This is also reflected by our owners when members of the board are to be elected. We applaud the increase of women working in a previously male

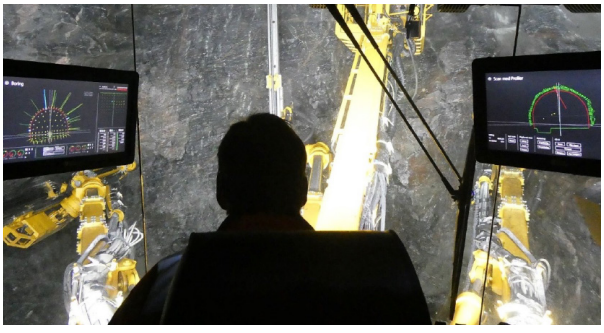


Figure 4.4.14. Machine control of drilling rigs has been pioneered by Bever Control. The computer-controlled system increases the drilling accuracy which is a main contributor to optimised drill and blast tunnelling. A protected and healthy working place for the operator contributes to a safe operation. Photo: Norwegian Road Authority.

Figure 4.4.15. Drilling for a run-of-river hydropower plant in Sumatera, Indonesia. Photo: FMM.

dominated industry. When working abroad we do like to mention that in Norwegian tunnelling industry there are many female role models. Surprisingly, in some countries, women in the tunnel are said to bring bad luck – we believe that a mixed workforce will improve the quality the work being done.

- **Goal 6** - Ensure availability and sustainable management of water and sanitation for all

Our customers are makers of underground water and sewage infrastructure. Currently we are closely involved in the project to create a channel for a second water source for Oslo municipality, water supply security should have a high focus everywhere in the world.

- **Goal 7** - Ensure access to affordable, reliable, sustainable and modern energy for all

Our customers are also heavily involved in the construction of hydropower plants. Most of the electricity in Norway is generated with hydropower and water tunnels have been constructed here continuously the last 100 years, there are more than 1600 hydropower plants in Norway today. Our products are also used internationally for hydropower projects. Right now, we have a customer working on a major expansion of a power plant in Sumatera, Indonesia. There are many developing countries that has a huge potential in harvesting more energy from water.

By helping our customers to be efficient, accurate and safe in their work, we contribute constructively to the construction of the future green energy sources and water and sewage infrastructure.

- **Goal 8** - Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Automation in the underground industry has high focus also because it can play an important role in increasing the safety for the staff. More automatic and remotely controlled operations can reduce the need to expose workers to a dangerous environment. From the very beginning we have had the aim to develop products that can reduce risk for accidents during construction and for creating a robust and safe underground structure for its full lifetime.

- **Goal 9** - Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Constructing underground space may have an important negative impact on the environment if it is not done carefully.

Underground construction may lower the ground water level and tap lakes for water unless properly managed. Our solutions for grouting management assist the contractor in optimising the process to ensure watertight constructions. The cost of grouting can be up to 30% of the total tunnel construction cost, so precise and real-time monitoring during the grouting is important also for cost control in the project.

Excavated masses must be treated properly, the rock masses may contaminate the environment due to content that can be radioactive, contain heavy metals or acid substances. One such example is black shale that can be found many places in Oslo area where we continuously take into use new underground space. By analysing drilling data, we can identify possible black shale early in the operation and plan the transport and dumping of the polluted masses to safe deposits efficiently.

- **Goal 10** - Reduce inequality within and mong countries

As an independent company we sell and support our products worldwide both in developed and in developing countries. It has been a privilege to be able to assist economically important construction work in countries such as Chile, Bhutan, Brazil, Colombia, South Africa, China, Indonesia, Philippines – contributing to safe and efficient underground work in all corners of the world.

- **Goal 12** - Ensure sustainable consumption and production patterns

In our production we follow the EU RoHS Directive by avoiding hazardous substances in our electronic components, and we also monitor our supplier's

compliance to the Responsible Minerals Initiative (RMI) in order to avoid the usage of tungsten, tin, tantalum, gold from conflict areas in our products.

- **Goal 13** - Take urgent action to combat climate change and its impacts

We have identified two processes in the construction of tunnels where we believe it is possible to do significant reductions in the use of cement whose production is requiring much energy and also is an important contributor to CO_2 emissions.

The first process is the application of shotcrete for rock support. By our experience, it is quite normal that the actual volume of shotcrete applied is 20% or more above what is specified. By giving the shotcrete operator a tool to efficiently check applied thickness, the shotcrete layer will be closer to the required thickness. Europe's most automated ore mines, and also one of the biggest consumers of shotcrete, LKAB in Kiruna in Sweden, has successfully implemented such a strategy to reduce the shotcrete consumption.

The second process is the grout injection process used to eliminate inflow of water. By actively using information from the drilling process and closely follow the flow and pressure during the injection, it is possible to reduce the total amount of grout spent significantly.

- **Goal 16** - Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

We believe in fair and transparent competition; cartel agreements and corruption hinder efficient use of the society's resources. This is reflected in the way we insist to conduct our business relations.

Figure 4.4.16. LKAB, Kiruna, Sweden. The shotcrete operator discusses spraying performance with the production planner. Scans are used to calculate the applied shotcrete thickness directly after spraying. Photo: Bever Control.

- **Goal 17** - Strengthen the means of implementation and revitalize the global partnership for sustainable development

As a company with a high focus on export to tunnel and mining industries around the world, we believe innovation can be increased through international cooperation. Our end users come from both industrialised and developing countries and we believe our technology contribute to safer and more efficient underground operations wherever it is used.

You can find more information at www.bevercontrol.com, feel free to contact us at mail@bevercontrol.com.

4.4.8 Celsa

Susanne M. Nævermo-Sand

The carbon neutral future of steel

Celsa Nordic already has a circular business model, and its steel has less than half of the CO_2 footprint of its competitors. Climate initiatives have gone from being a cosmetic measure that was nice to have to constituting core business. At the steel manufacturer Celsa Nordic, this is the way things have been for a long time.

"Our steel has less than half of the carbon footprint of our competitors, but we cannot charge more than they do," explains Carles Rovira, CEO of steel manufacturer Celsa.

Every week, Celsa recycles a volume of scrap metal equivalent to two Eiffel towers, which gives them a key position in the Nordic reinforced steel market. The tunnelling industry is also feeling the demand to become more climate friendly. Celsa's rock bolts are now gaining ground as they have a much lower CO_2 footprint than those produced by Celsa's competitors in the Norwegian market.

There are two main explanations for the fact that Celsa's steel has lower carbon emissions than its competitors. Firstly, all Celsa's steel is produced from scrap metal, i.e. it is recycled. Secondly, the energy used by Celsa is renewable hydropower. "This means that we already have a circular business model in place," explains Carles Rovira.

The Spaniard has been the CEO of Celsa Nordic for 12 years. He loves the culture and working methods of the Nordics. Every week he commutes between his family in Stockholm and the company headquarters in Mo i Rana just north of the Arctic Circle.

"At Celsa, we are interested in giving back as much

as possible to the local communities we operate in. That means working sustainably and paying back as much as possible to the local community," he explains.

In partnership with Susanne Nævermo Sand, Celsa Nordic's sustainability manager, Rovira leads the work on ensuring that Celsa's steel will be entirely carbon neutral by 2030.

As is well known, both the EU and Norway propose that greenhouse gas emissions should be cut by 55% by 2030. If the goals set out in the Paris Agreement are to be met, the whole world has to become carbon neutral by 2050.

"A drastic change is needed," says Nævermo Sand. She is concerned about how complex this change will be. "Sustainability must be increased on several different levels at the same time if the change is to be achieved. Firstly, it is important to ensure that all employees understand and the company culture reflects the importance of this. Secondly, you have to develop the right technology and at a cost that makes it worthwhile. You then also have to add the branding, create a desire among customers to buy sustainably and contribute to a more circular business model."

The Spaniard Carles Rovira believes that one of the most exciting things about operating in the Nordic region is how far the region has come in thinking about sustainability. "The Nordics are very well advanced. Technologically advanced and with a will to invest in the circular economy and sustainability. Leading a company that is at the forefront of technology in an area that is so important is very exciting," he says.

Greenwashing on its way out

Nævermo Sand is pleased that greenwashing is finally on its way out. "For far too long, sustainability was a word you could use without taking it very seriously. It was only cosmetic or, rather, greenwashing. That period is definitely and thankfully over. Sustainability and circularity now have to be implemented throughout the value chain. The pressure is both financial and commercial, and those who do not succeed in getting their employees and companies involved in this change will struggle. Steel can be produced based on two input factors. Based on iron ore or scrap metal, with 2 or 0.4 tons with greenhouse gas emissions per ton respectively."

She emphasises that circular steel is about more than recycling. "If you want to be able to call yourself circular, you have to focus on the use of the by-products you produce. We currently manage to reuse as much as 95% of our by-products further down the value chain, and one of our sustainability goals is to increase this to 100% by 2030 – to complete the circle." The by-products are used, for example, as an energy source in the rolling furnace, and rubber granules are used instead of anthracite in the steel furnace.

Stringent requirements in public procurement in the Nordics have contributed to the region taking the lead in Europe in this field. One of the most exciting projects Celsa is currently working on is a green hydrogen project in partnership with Statkraft. Hydrogen can be used as fuel on several of the company's ships. "But much of it is imported, and in many of the countries it is exported from, the prerequisites for operating in an environmentally friendly way are just not there. Unfortunately, we can still feel that price is prioritised over climate, but we believe that in the long run this will change, and those who don't pay attention to the climate will pay dearly for this mistake in the long run," concludes Nævermo Sand.

4.4.9 Vik Ørsta

Anita Stokke Blomvik

As a manufacturer in a high-cost country, Vik Ørsta is dependent on investing greener, smarter and more innovatively to ensure future competitiveness. With a high degree of automation and technology development, the company holds its own among international competitors, including when environmental impact is taken into account.

Figure 4.4.17. Newly painted rock bolts components.

Figure 4.4.18. Grouting tubes in recycled plastic.

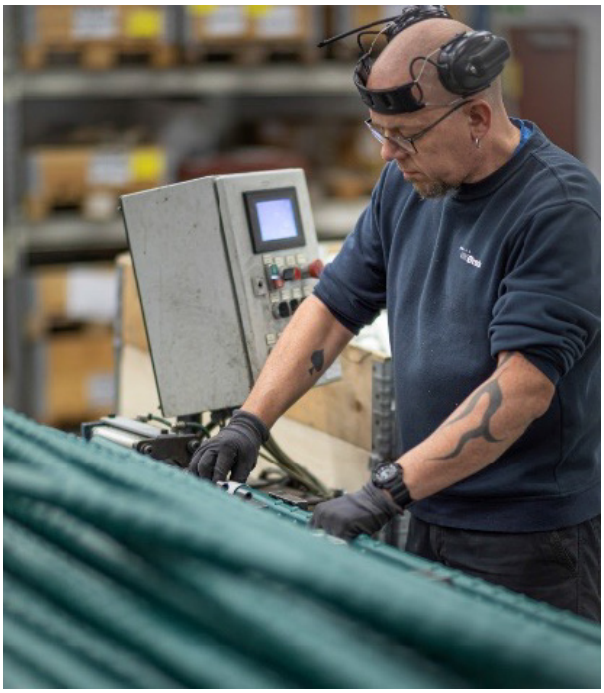


Figure 4.4.19. Assembly of CT-bolt.

"To us, it is important to be able to deliver a product that impacts the environment as little as possible when it is manufactured," explains Department Manager Rune Holstad from Vik Ørsta. "We have used recycled steel as standard for a long time, and two years ago we took the leap and switched to recycled plastic as well. Now all our injection pipes for rock safety bolts are made from recycled ropes from the fishing and aquaculture industry."

In addition to recycled materials, Vik Ørsta benefits from access to Norwegian hydropower for its production. Renewable energy accounts for 98% of the Norwegian power supply, and Norway has the lowest emissions in Europe. This gives Norwegian industry an advantage, but certainly does not mean we can rest on our laurels in our work on becoming a low-emission society.

"With such good access to clean power, it is only natural that manufacturing should take place here. Then it is up to us to ensure that emissions are as low as possible," says Rune Holstad. "We spend a great deal of time and resources to ensure this, and we have been certified to ISO 14001, the world's most recognised environmental management standard, for more than twenty years."

In order for Vik Ørsta to be involved in the future, they are keen to stay ahead and further develop their product portfolio. The expertise that has been built up throughout the company's 75-year history is one of the things they are most proud of and which provides a solid basis for further development.

"We still think that tunnelling is the most exciting thing there is, and we are happy to make adjustments and further develop our products to ensure that they are as environmentally friendly as possible," concludes Rune Holstad.

Figure 4.4.20. Rune Holstad with a rock bolt.

Figure 4.4.21. Rock bolts from Pretec.

4.4.10 Pretec
Erik Andre Karlsen

Rock bolts made to last – and why we should care
At Pretec we think one can't talk sustainability without talking service life! Most important action after a decision about building is made, and optimizing design is done, is to make sure what we build is made to last. Lifetime has to get increased focus if we are going to talk about sustainability.

The common misconception when we enter the world of lifetime considerations it to presume it will be at too high cost, but that's not necessarily the case. But the devil is in the details, and they need some attention. So, to ensure that a structure (ex tunnels) is built to last, we need to look at the materials that are used to construct it. Any weak links will naturally reduce the whole structures service life and waste time, money and resources that can be put to better use.

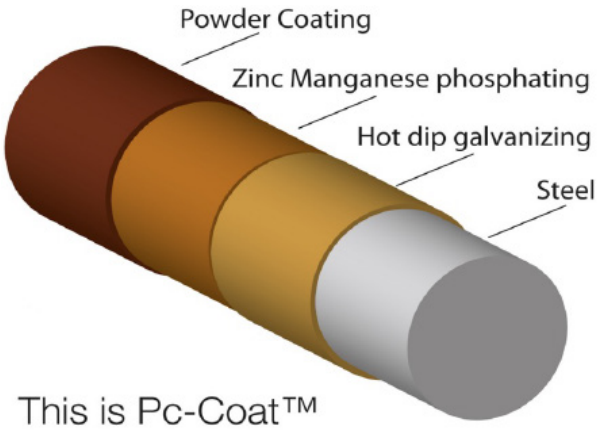
As a producer of rock support products, we aim to make the most durable and well documented products to make sure it doesn't become the weak link in any tunnel project. Rock bolts = safety, and what isn't sustainability if not taking care of safety and lifetime together all at once?

Figure 4.4.22. Control of coating thickness.

Rock bolts, as this article is focusing on, is a key material in most tunneling projects world over. Depending on tunnel design the rock bolts lifetime is often critical for the whole structure's lifetime, so no compromise should be done. Problem is steel corrodes. And most rock bolts are made of steel bars or tubes of some kind. It needs to be protected.

The good news is that there are well tested and documented solutions for achieving over 100 years' service life on your rock support products. And the best part is that it's cost efficient when done the right way, and the technology is available most places in the world.

With Norwegian road authorities in the forefront Scandinavia has been handling this successfully for many decades with a solid specification on corrosion protection on rock bolts, known as duplex coating, that allow them to design tunnels with 100-year lifetime without a fully casted inner lining. This has become one of the most tested and documented methods of corrosion protection on rock support products, ensuring that our tunnels last in the most demanding conditions of the artic.



Duplex coating - The optimal corrosion protection for rock bolts

Duplex coating is the best proven system for rock support. The name Duplex coating refers to the two main components which is hot dip galvanizing (HDG) and powder coating (usually epoxy). Two well-known corrosion protection combined gives a synergy bigger then the two separately can achieve.

As with anything though, to achieve a quality result that provides the intended service life the devil is in the details, so designers have to understand the importance of these details. The coating has to be according to harmonized standards and producers have to be able to document that they deliver according to the standards and specifications. Preferably producers should be certified with a quality management system as ISO 9001 to ensure that they are professional.

Process standards for the duplex coating should be HDG according to EN ISO 1461 and epoxy powder coating EN 13438 with the defined thickness on each layer and documentation ensuring quality is according to standards and designers and regulators get what they pay for. More detailed specification on this can be found in Norwegian road authorities handbook for tunnelling N500.

The powder paint protects the zinc layer if applied properly and the zinc layer is a stable surface with the right pretreatment (Zinc-manganese phosphating). This ensures that the hot-dip galvanizing and powder coating together provides a long lifetime in corrosive environments.

Drilling with HDG and Epoxy coated (PC-Coat) SDA show the durability and rest function of the corrosion protection even though partly damaged under the most extreme installation. Powder coating is also an environmentally friendly and economical process with little waste and no volatile solvents. This provides a good working environment and significant cost savings.

Reference

- Pc-coat brochure
- NTN “temporary and permanent rock bolts”
- SVV handbook for tunnelling

4.4.11 RG-Group

Kato Stien

With a high level of machine utilisation, the Rental Group business model is the biggest and most important contribution to sustainable operations in RG Tunnel. Many contractors are moving towards reducing the capital they have tied up in their machinery. This contributes to added turnover in the rental market. For RG Tunnel, this has given us the opportunity to invest in new equipment that offers the best environmental and safety solutions.

Digitalisation is also an important investment for RG Tunnel. We work on solutions that make accessible all applicable data capture that provides customers and users with information and further contributes to more automated processes, new routines and positive changes in behaviour. In a wider context, digitalisation is about exploiting the potential of increased profitability and sustainability – both for our customers and for RG Tunnel as a company in a developing industry.

Knowledge and skill sharing internally in the group consolidates the solutions and implementation ability offered by the service organisation. The same applies to engineering, logistics and the search for optimum machine utilisation.

Figure 4.4.23. Examples of drilling equipment.

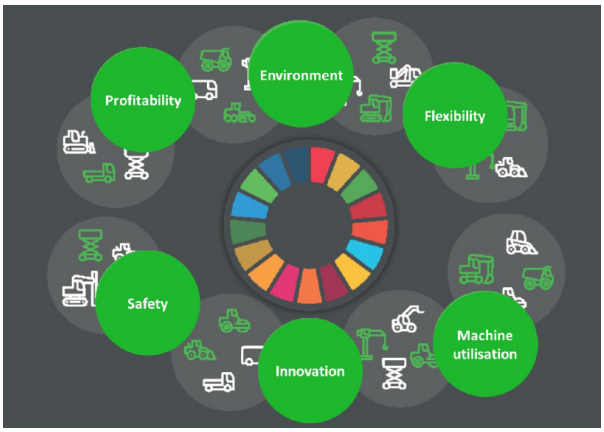


Figure 4.4.24. Focus on sustainability in RG Tunnel.

Figure 4.4.25. An example of modern machinery, Cat 988XE.

Cat 988XE boosts productivity and reduces fuel consumption considerably. Compared to the 988K, its predecessor, the 988K XE provides a 25% increase in productivity and a 20% reduction in fuel consumption. Cat 988K XE has the same horsepower, but still delivers more efficient loading and transport because of its stepless electric driveline.

4.4.12 Forcit

Vegard Olsen

SUSTAINABILITY IN FORCIT – A NORDIC EXPLOSIVES MANUFACTURER AND CONSULTING COMPANY

It's not possible to separate the Norwegian businesses completely from the Forcit Group, when speaking of sustainability related issues. Both Forcit Norway and Forcit Consulting in Norway follow and benefit from the Group level vision, strategies, actions, and efforts. In this article we will present shortly our concern goals and road map, as well as local initiatives and efforts made and implemented in the two Norwegian Forcit companies.

The year 2020 form the basis for the first Forcit Sustainability report "Forcit Group – 2020 Sustainability in short", available on >> forcitgroup.com. This report describes the LCA (Life Cycle Analysis) and EPD (Environmental Product Declaration) work made the recent years, and the actual levels of various parameters decided to measure and follow closely the coming years. Please read the sustainability report for more thorough and detailed information.

No goals and plans are "written in stone", however they give direction of what focus areas the owners of the company want for the coming years. The two figures below summarize the picture of the Forcit sustainable thinking and focus sectors to achieve the company's overall ambition - "To reach carbon neutrality in our own production in 2035".

Figure 4.4.26. Forcit sees sustainability as a multidisciplinary entity with non-fixed interfaces. Safety affects both environmental emissions and profitability, and profitable company can continue investing in technologies that reduce environmental impact and in enhancing life.

Figure 4.4.27. Forcit's focus sectors.

POWER SUPPLY AND CONSUMPTION

Compared to many other countries, the energy mix in Norway has a natural positive influence on Forcit's two Norwegian companies, as the average Norwegian energy mix is 98%. Even so, reduction in energy consumption is important, as for instance surplus energy may be sold to foreign markets and replace fossil energy sources.

Forcit Norway bulk stations, workshops and industry storage tents require warm indoor environment, all year through. In wintertime the energy loss can be substantial. Air-to-air heat pumps are installed in all new storage facilities, including some older buildings, to reduce energy consumption. All new warm tents are built with extra insulated walls. Continuously the cost and benefit of these actions is evaluated for all existing locations.

TRANSPORT AND LOGISTICS

Norway in general has well-developed infrastructure for charging electrical cars. Also, the Norwegian Government subsidize the purchase and use of electrical cars. Forcit Consulting has found it beneficial and environmentally to purchase electrical service vehicles. At the moment 50 % of the cars are electrical, and the rest will be replaced gradually.

Transportation of explosives goods resembles a large amount of the CO_2-emissions in the Forcit business, travelling from factories in Sweden and Finland or from external manufacturers in Europe, and from local storages to the customers. ADR-regulations restricts use of electrical power in explosives transport. All Forcit bulk trucks have EURO 5 or 6 motors, and renewable fuels are in our focus and under research. This will give a good contribution in reducing greenhouse gasses.

Forcit is also dependent on transport of semi-finished raw materials. The bulk emulsion explosive contains gassing agents, and the gassing agent contains water. Until recent year the gassing agent has been produced in Kemi in Northern-Finland, generating thousands of fossil driven transport kilometers down to Western and Southern Norway. In 2021 Forcit Norway invested in a gassing agent mixer at the bulk station located at Norsk Stein Quarry on Jelsa. The mixer also produces gassing agents for other similar Forcit bulk stations in the Southern part of Norway, giving a considerable reduction of diesel consumption.

Another important Forcit strategi is to optimize logistics by building larger explosives storages close to market areas and the biggest customers, and even deliver full trailers directly from factory to the customer storages. By this, less kilometers are needed to get the explosives at site.

WASTE HANDLING

Good practices and routines in waste handling is one of the focus areas within FORCIT Group. The major carbon footprint reduction potential lies in the explosives production plants. Long term efforts have been made to reduce spill in the production processes. Reusing materials and resources, formerly looked upon as waste, minimizes the utilization of virgin material and reduces Forcit's environmental footprint. Simultaneously this improves profitability in cases where the residual streams have economical value. In Vihtavuori plant in Finland, reduction of explosive waste in 2020 compared to 2019 was 20 %.

INNOVATION

The recent decade Forcit has been active in looking into developing nitrogen free mining explosives, to avoid nitrogen oxide fumes (NOx) in blasting gases. Hydrogen peroxide (HP) has been the main nitrogen free environmentally friendly alternative to ammonium nitrate (AN) which is the most used oxidizer in mining explosives. Environmentally the HP-explosives improves the exhaust gasses and better the water-soluble conditions compared to AN-based explosives, amongst other things. Basic performance parameters like energy, gas volume, VOD and sensitivity to initiation are more or less the same. Challenges will arise from very reactive nature of HP. Handling safety requires very rigorous routines, product sleep time and resistance to water are quite limited. Recent tests are successful, and work with certification and formalities are ongoing.

Forcit realize that digitalization as an important part of the future, also in the blasting industry. Digitalization helps the customers in collecting data for analyzing construction capacities and work for optimization and more effective processes.

The Fordex (Forcit Digital Excavation) platform includes the digitalization of the new tunnel emulsion charging units EMC3, as well as surface bulk trucks and using the O-Pitblast® blast planning software. Cooperation with other mining and construction companies, is necessary to combine data the drill rigs, loading and hauling equipment, shotcrete units and surveying data.

By collecting, processing, and analyzing available data from these different platforms, high end optimization of blasting and increased efficiency of work processes can be made. The potential lies in better blasting results, giving less overbreak in tunnels and

Figure 4.4.28. The new tunnel emulsion bulk charging unit EMC3.

reduced shotcreeting, less loading and hauling of muck pile and potential reduced bolting. In surface operations typical benefits are reduced explosives consumption and drilling, higher loading capacities and better capacities in the downstream crushing processes.

CONSULTING AND TECHNICAL ASSISTANCE

Forcit Consulting is strongly involved in minimizing the impact of blasting on the environment, property, and people. Measuring and expert services provided by Forcit Consulting affect all three aspects of our sustainability triangle: they increase safety, minimize, and help to control environmental impacts, and increase the cost-effectiveness of mining. However, we also focus on minimizing CO_2 emissions, both from our own point of view and from the point of view of mining in general.

Use of the digital platforms – analyze, conclude, and adapt results into processes are services Forcit offer in both companies. The Nordic mining and construction blasting industry has a common history and contains many similarities, for instance geologically, by weather and socially. Knowledge and experiences are spread across the Nordic countries, and both the Norwegian Forcit companies take advantage of these resources.

FUTURE POSSIBILLITIES

During production the emulsion matrix reaches over 100°C, and heat loss is a potential energy source. At the moment no specific actions are made to utilize this excess heat potential, however technology and solutions are available.

Even though electric ADR transport is not allowed, Forcit investigates the possibility of electrification of the surface charging process. Today the bulk emulsion pumping power source is the truck's diesel engine. The potential is large as the time for emptying a full truck takes three to five hours. In future this annual potential carbon footprint reduction is substantial.

About Forcit Group

Forcit Group is a Finnish company that provides explosives products, services and knowledge related to blasting, charging and environmental impact assessment, as well as a desired Insensitive Munitions technology partner globally. Forcit have built its expertise since 1893 and the head office is still in Hanko, Finland. Forcit is a privately owned and independent player with a strong Nordic value base.

Forcit consists of three business areas: Forcit Explosives – the leading partner for civil explosives and related services. Forcit Consulting – the consulting services partner offering a wide range of expertise, services and training for construction and excavation. Forcit Defence – a trusted partner for high class insensitive munitions-based defence systems for global markets.

Forcit Norway AS is sorting under the Explosives business unit and Forcit Consulting AS naturally under the Forcit Consulting business unit. Forcit Group has set an ambitious strategic target to be a leader in sustainability in our business area.

4.4.13 Hypex Bio

Tron Nytrøen, Thomas Gustavsson, Tim Hunt

Concentrated hydrogen peroxide is now through a newly developed mechanical process the major ingredient in a new hydrogen peroxide emulsion for mining and tunnelling, making one of the world's dirtiest industries far greener. The CO_2 emission reduces with some 90% and NOX-gasses and potential for ammonia residuals is totally removed.

There is no more efficient way to break rock than by utilising chemical potential energy, save perhaps, waiting for erosion! Today's modern bulk explosives are safe and efficient, a badge earnt through many decades of development, usually through trial and error. In Europe, one of the most common forms of bulk explosives is an ammonium nitrate emulsion. ANE is a fantastic technology that among other things, can be chemically sensitised upon placement

Figure 4.4.29. Hypex B01 Emulsion.

Figure 4.4.30. Thomas Gustavsson – founder of Hypex Bio Explosives Technology AB.

in the blast hole, is extremely stable in a wide variety of rock conditions, is highly waterproof and able to sleep fully sensitised for extended periods if required.

The major drawback of AN emulsions, indeed any of today's nitrate-based explosives, is the significant environmental footprint generated during the production process and blasting operations. Very broadly, a typical AN emulsion is derived through three main energy intensive steps. The first is by sourcing hydrogen from methane, where high pressures are used in the presence of a catalyst to generate hydrogen gas and carbon monoxide. The second is by combining this hydrogen with nitrogen from the atmosphere in the Haber Bosch process, producing ammonia, and the third is by utilizing the nitrophosphate process, resulting in ammonium nitrate and calcium carbonate. All three steps require significant energy inputs that, in almost all cases, are derived via fossil fuels. In a best-case scenario, with respect to the Norwegian market, this results in 3kgs of CO_2 for every kg of AN produced. Furthermore, the detonation of nitrate-based explosives results in carcinogenic nitric oxide gases (NOx) and water-soluble ammonium residues.

These are all issues well known to the industry.

In 2018, AB Etken Teknologi began research and trials into a novel bulk explosive in the form of a water gel with a hydrogen peroxide oxidiser. The results were very encouraging. Trials with a prominent Swedish mining company resulted in number of full-face tunnel rounds successfully charged and fired, providing excellent blast results. Independent measurements of exhaust gas profiles and blast residues proved that this explosive was indeed nitrogen free. There were drawbacks though, specifically due to the gel itself. A water gel, by definition, is an explosive where all components are water soluble, hence, this essentially meant that, from a practical point of view, it was economically infeasible to fully arrest all oxidation, resulting in a very short effective placement timeframe and the potential for reactivity with minerals in the rock mass.

However, both the environmental and blast performance of the water gel was so encouraging that Etken resolved to solve this HP stability problem through development of a stable HP emulsion, something that, to the best of their knowledge, had never been achieved before. In early 2020, a method was developed allowing for long term stability of hydrogen peroxide with a fuel source in a stable, unsensitised matrix. Soon after followed a chemical gassing solution, resulting in a hydrogen peroxide emulsion explosive that can be sensitised on site under bulk loading conditions.

The company, Hypex Bio Explosives Technology AB was incorporated with the task of commercialising this technology, essentially providing the platform

Figure 4.4.31. Pilot with Hypex Bio in a tunnel.

for complete focus to bring this and only this product to fruition.

In addition to the aforementioned environmental advantages, there are a number of other positive operational and environmental aspects with respect to HP explosives, specifically:

- A cold production process (no need to keep matrix warm unlike AN emulsions)
- No HP matrix crystallisation potential (as with nitrate salts)
- No reaction with shotcrete to produce ammonia gas
- Detonation gas profile is only water steam, CO_2 and small amounts of CO
- HP explosives produces more gas volume per unit than AN explosives upon detonation
- Unused and/or spilt matrix breaks down to water and hydrogen (plus some fuel components)
- When hydrogen is sourced via electrolysis of water using hydroelectricity (as it is done in Norway), then the CO_2 footprint of HP is negligible.
- Velocity of Detonation testing shows on par results to AN explosives
- Significant potential to utilise renewable fuel phase sources, such as plant-based oils.

While the future is bright for HP explosives, this is clearly a product in the development phase, a number of technical hurdles still need to be cleared, not least, transitioning from the laboratory to an active production environment, providing the requisite production volumes at the required quality levels. However, if Hypex Bio's hydrogen peroxide emulsion explosives perform as they are expected to, then this is a significant step towards decarbonising the civil explosives industry by essentially producing a renewable, nitrate free explosives from water.

4.4.14 Franzefoss

Linda Skryseth and Hedda Garshol Jensen

Status of sustainability at Franzefoss AS and Franzefoss Pukk AS

Every day, Franzefoss strives to live up to its vision: *The best choice for society*, and is now developing its first sustainability strategy for the group (Franzefoss AS, Franzefoss Pukk AS and Franzefoss Gjenvinning AS). Franzefoss recognises the UN Sustainable Development Goals, with main focus on five of them. By working on one sustainability goal, we may also work indirectly with other goals. Therefore, we have selected goals that we can contribute to in our daily operations. The main goals we have selected are, Goal 8 (Decent Work and Economic Growth), Goal 11 (Sustainable Cities and Communities), and Goal 12 (Responsible Consumption and Production), and Goal 13 (Climate Action). The re-use of rock and masses will support all four of these goals.

In the Oslo area, the demand for raw construction materials may exceed the resources that are available. Re-use may help meet this demand while simultaneously providing locally produced stone. For several years, Franzefoss has received stone from construction projects, which has then been processed and sold again. We also take part in larger projects that look at how to better utilise reclaimed masses better. For Franzefoss, it is important to focus on using the right stone quality in the right place, in order to contribute to a more sustainable use of resources. Therefore, our geologist assesses all masses that are to be received in order to find the appropriate area of use for the stone masses. We therefore also place requirements on the customers who are delivering the masses, so that we can achieve the best possible conditions for utilising the

Figure 4.4.32. Franzefoss has main focus on four of the UN Sustainability goals.

masses properly. For instance, the masses must be free of pollutants such as oil spills and dirt. We have also calculated how much stone we can bring to our facility, so that we can help resolve the municipality of Bærum's need for mass management.

The re-use of masses will allow us to save our own resources. Most of our quarries break very high-quality stone, which should be saved for industrial aggregates and projects that demand the highest quality. Being able to receive lower-quality stone for projects with less stringent requirements, a big advantage and a more sustainable use of the resources. This will also reduce the total amount of stone in circulation in the industry, so that the industry can reduce the amount of stone being deposited.

Example – Lyngås and the Fornebu Line

The new metro line from Fornebu to Majorstua in Oslo is one of the biggest ongoing infrastructure projects at the moment. The stone masses from here are primarily slate and limestone, which have relatively poor mechanical properties. This means that these masses have a limited area of use. Franzefoss's geologist has had a good dialogue with the geologist on the project, gathering as much information on the deposits as possible before we began receiving it. As the quality of the stone from this place is non-optimal, and we know from experience that customers often want the best possible quality, there was some uncertainty about how the circulation of these rock deposits would be. Before the summer of 2021, we nonetheless began receiving stone at our facility in Lyngås. Here, the Fornebu rock has been broken down into different contractor goods, which have sold out in a flash. These goods proved to be super-popular, and Lyngås could proudly post record sales, thanks to these masses that initially were of little interest as raw construction materials! Since then, the masses have been taken in at several of our facilities, and we're hoping for similarly good turnover here.

Example – Snø and Bondkall

In 2018-2019, our facility at Bondkall received a lot of stone from the construction project Snø at Lørenskog. Having tested the stone for mechanical and chemical properties, we noticed that the quality was good enough for it to serve as industrial aggregate. We therefore managed to establish an agreement to use the stone from Snø as concrete aggregate, which enabled the facility to provide industrial aggregate while at the same time saving its own resources. At the same time, we faced a number of challenges related to the stone received from this project, as we received a lot of contamination along with the stone.

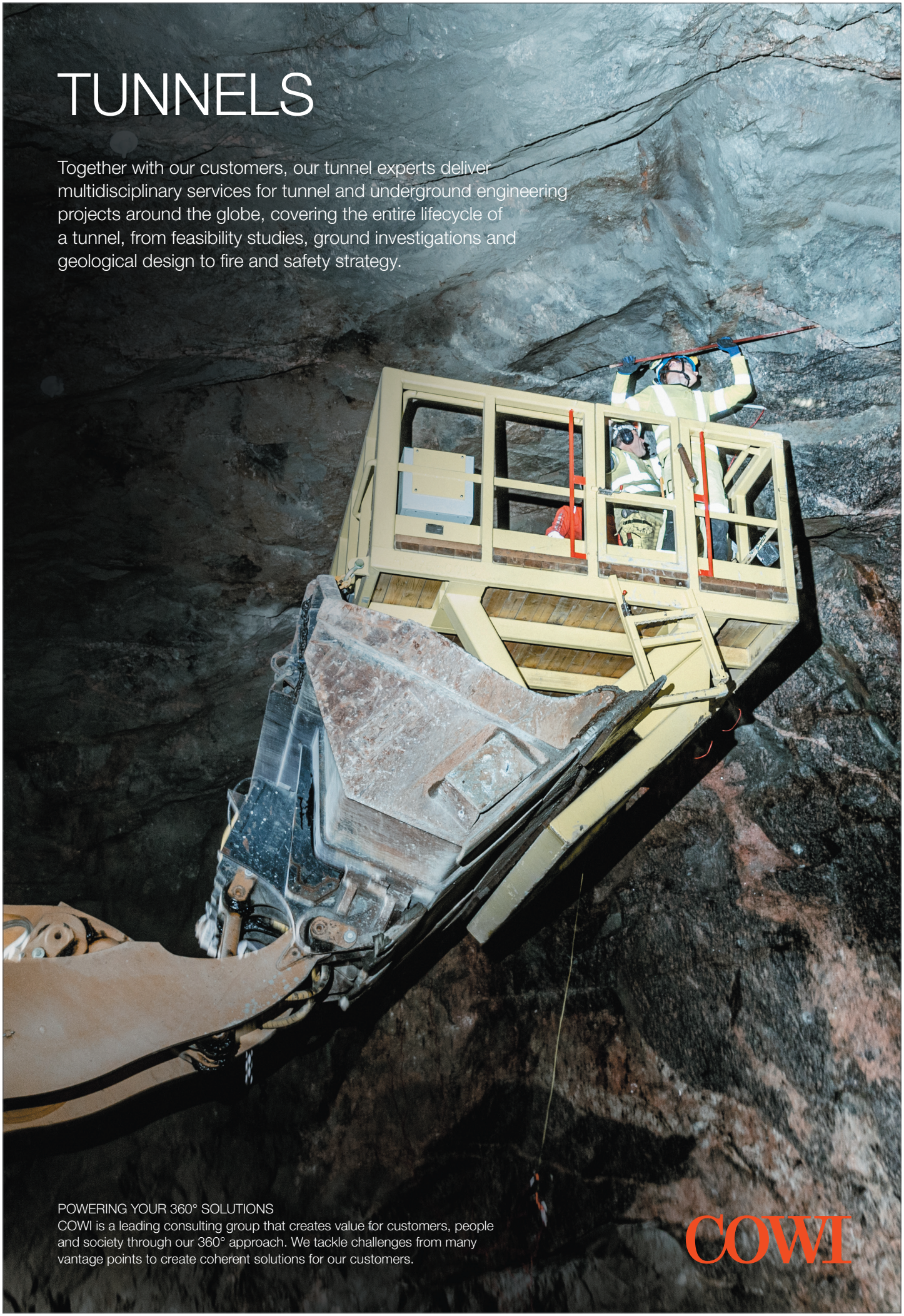
Figure 4.4.33. An example of contaminated masses.

We solved this issue with a dedicated reception controller, who regularly followed up the loads that came in. Humus samples were taken, and the contaminants were sorted out, while some heavily contaminated loads were returned. Therefore, we were finally able to provide a sufficiently high quality to the customer, while also keeping this stone from having to be deposited.

Example – Oslo mass hub

The Municipality of Oslo has decided that the handling of masses from projects within the municipality shall take place within the boundaries of Oslo. Franzefoss has therefore established a connection to several forums, in which we are examining how Franzefoss can contribute to the circular handling of mass in the Municipality of Oslo. Bondkall has been suggested as one of the places in which such a hub can be placed, so that we can be an intermediate storage for all types of masses, before they are processed further and sold again, or deposited.

Figure 4.4.34. Suggested area for mass handling.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