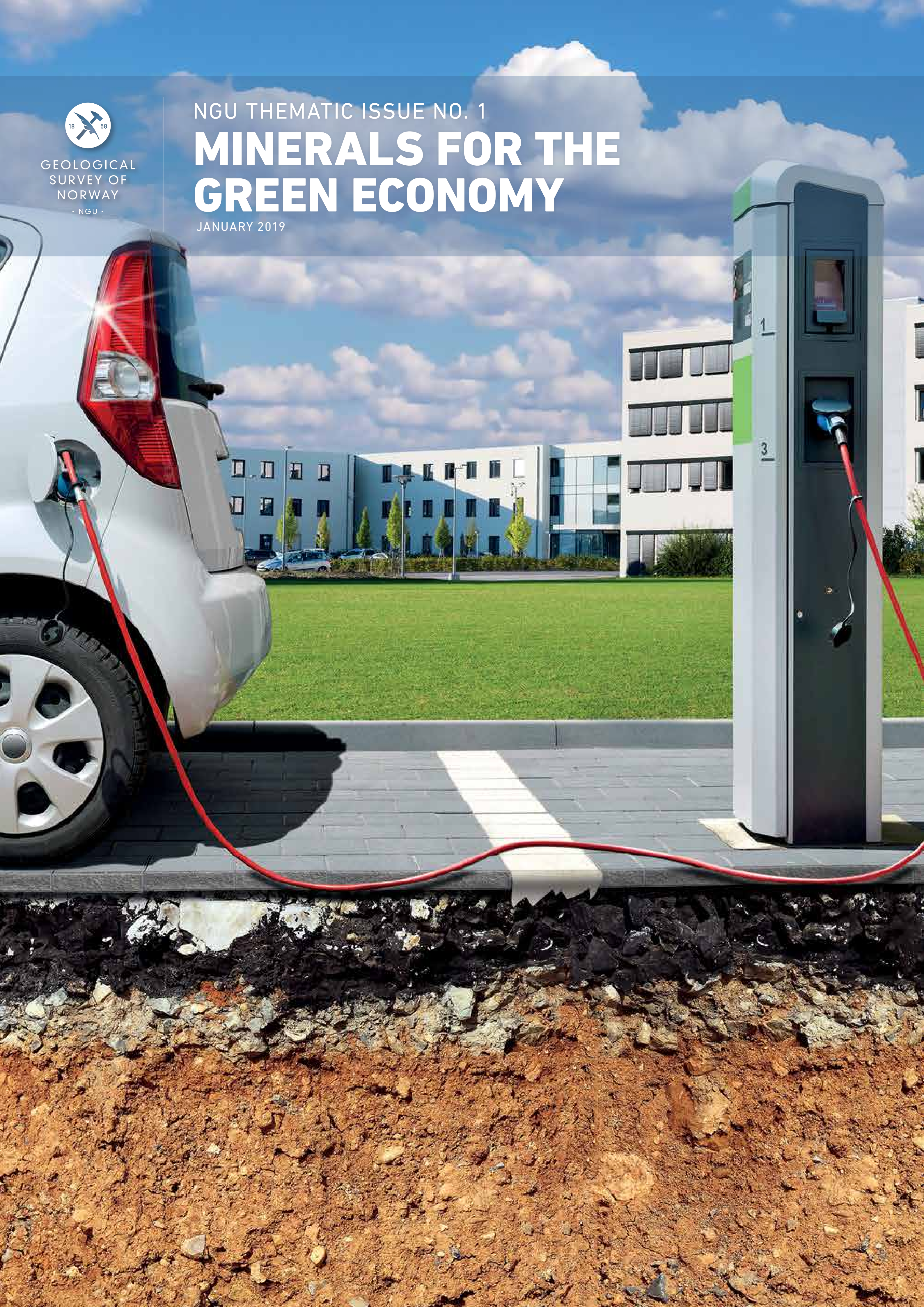
GEOLOGICAL SURVEY OF NORWAY
- NGU -

NGU THEMATIC ISSUE NO. 1

MINERALS FOR THE GREEN ECONOMY

JANUARY 2019



NGU THEMATIC ISSUE NO.1
ISSN 2535-7042, printed edition
ISSN 2535-7050, online edition
MINERALS FOR THE GREEN ECONOMY
Cover and layout: NGU, Communication & Public Relations
Text: Tom Heldal, Henrik Schiellerup & Kari Aslaksen Aasly.
Translated by Rognvald Boyd
First edition november 2016
Edited edition january 2019

REFERENCES

1) EU 2016: European Innovation Partnership on Raw Materials: Raw Materials Scoreboard.
(http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=8955&lang=en)

2) The European Innovation Partnership (EIP) on Raw Materials
(https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en)

3) EU, 2014: Communication from the Commission: On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative
(http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014DC0297)

4) Mineralressurser i Norge 2015. Mineralstatistikk og bergindustriberetning.
Norges geologiske undersøkelse og Direktoratet for mineralforvaltning, 2016

5) UNEP, 2011. Recycling rates of metals
(http://www.unep.org/resourcepanel/portals/24102/pdfs/metals_recycling_rates_110412-1.pdf)

6) International Copper Study Group: The World Copper Factbook 2015
(http://www.icsg.org/index.php/component/jdownloads/finish/170publications-press-releses/2092-2015-10-03-icsg-factbook-2015?Itemid=0)

7) Pedersen & Bjerkgård: Sea-floor massive sulphides in Arctic waters
(Mineral resources in the Arctic)

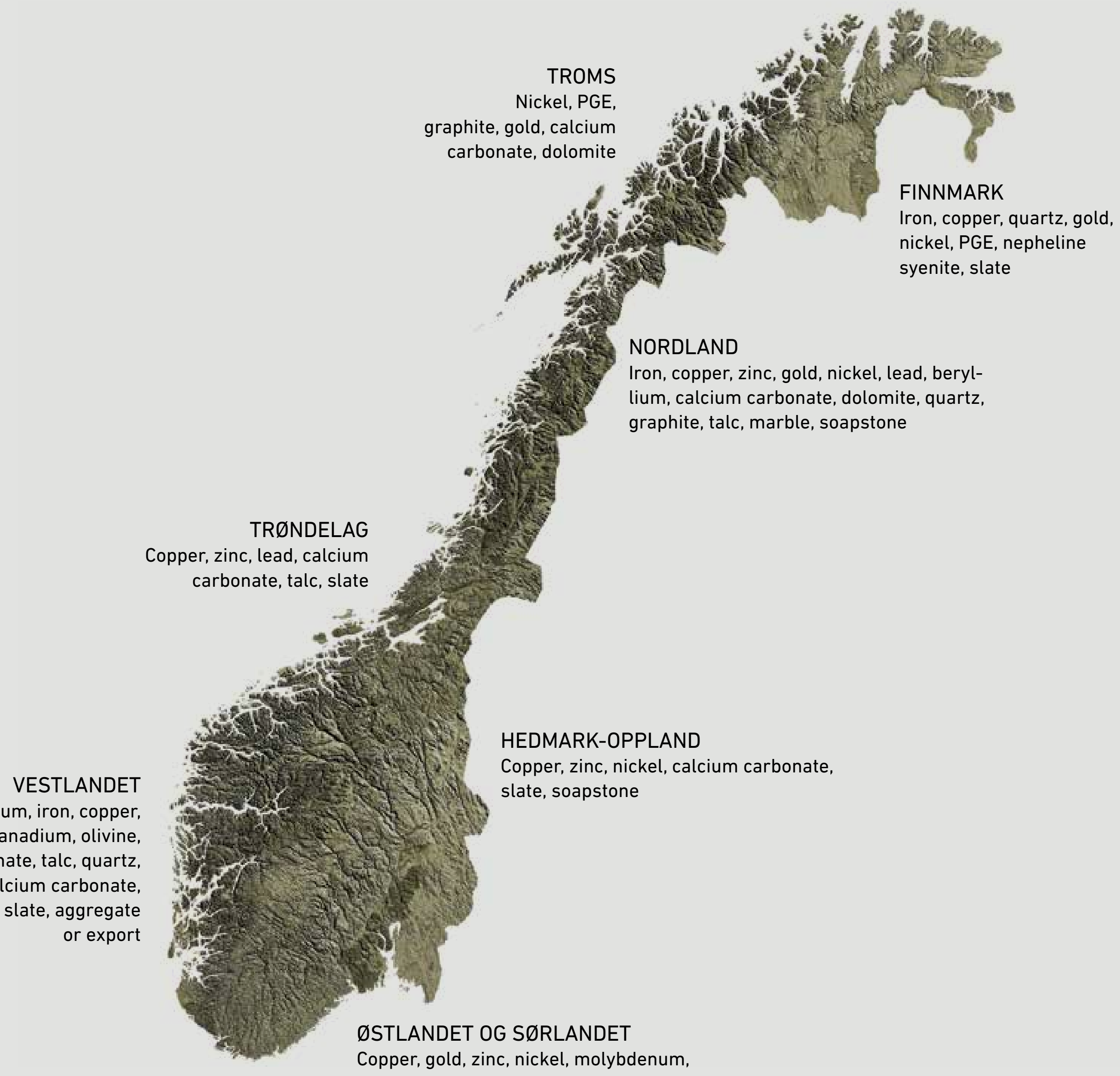
8) Müller, A. 2013. The chemistry of the mobile phones Nokia Nuron 5230, Nokia 5130 and Sony Ericsson W595. NGU rapport 2013-026, 23p

9) 17 Goals to Transform Our World: http://www.un.org/sustainabledevelopment/

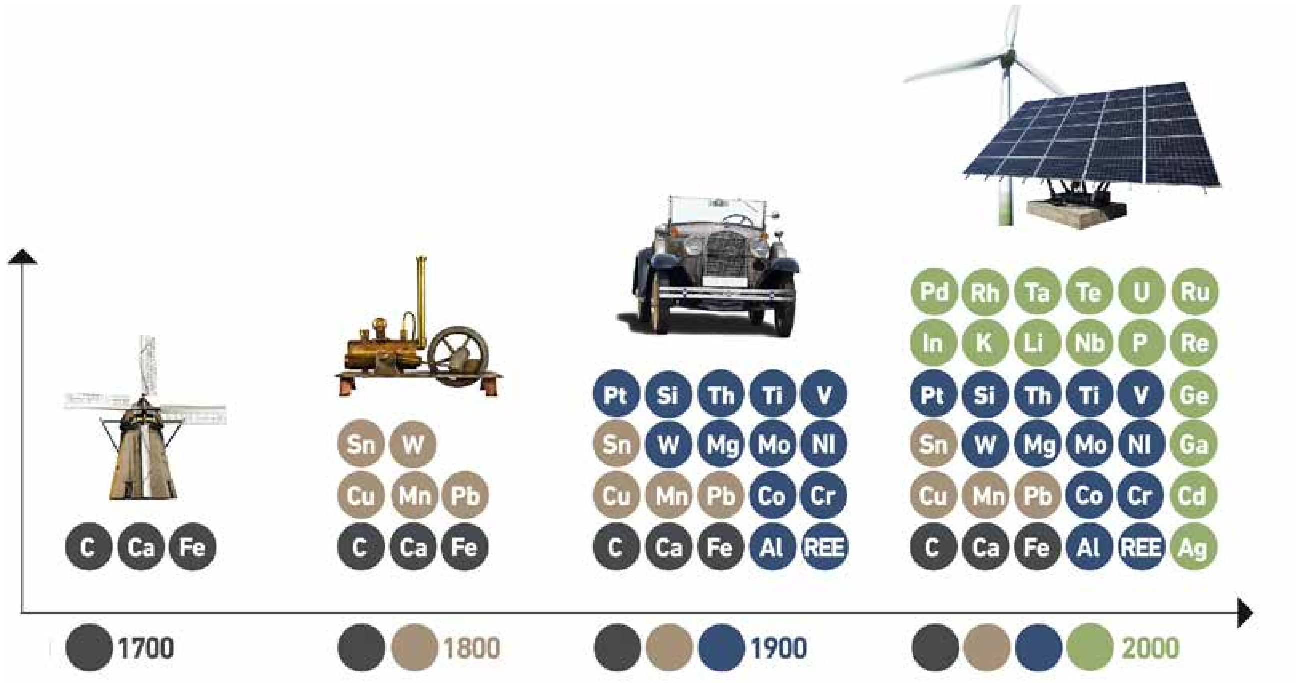
CONTENTS

GREEN ECONOMIES NEED MINERALS....................5
NORWAY, THE EUROPEAN UNION AND THE UNITED NATIONS....................7
GREEN MINERALS....................8
LOCAL USE OF ROCK MATERIAL....................14
GREEN PRODUCTION....................16
MINERALS IN THE CIRCULAR ECONOMY....................18
RESOURCES IN NORWAY....................20
THE MINERAL INDUSTRY IN NORWAY – STATUS AND FUTURE....................24
PUBLIC-PRIVATE COOPERATION....................26
TEN POINTS TO FOLLOW UP AND ACHIEVE....................27

Mainland Norway has a varied geology with possibilities for the discovery of many types of mineral resource. Each region has potential for particular types of resource. Known and indicated resources in the ground have a possible value of close to NOK 2,500 billion.



MINERALS – A NECESSITY FOR THE GREEN ECONOMY



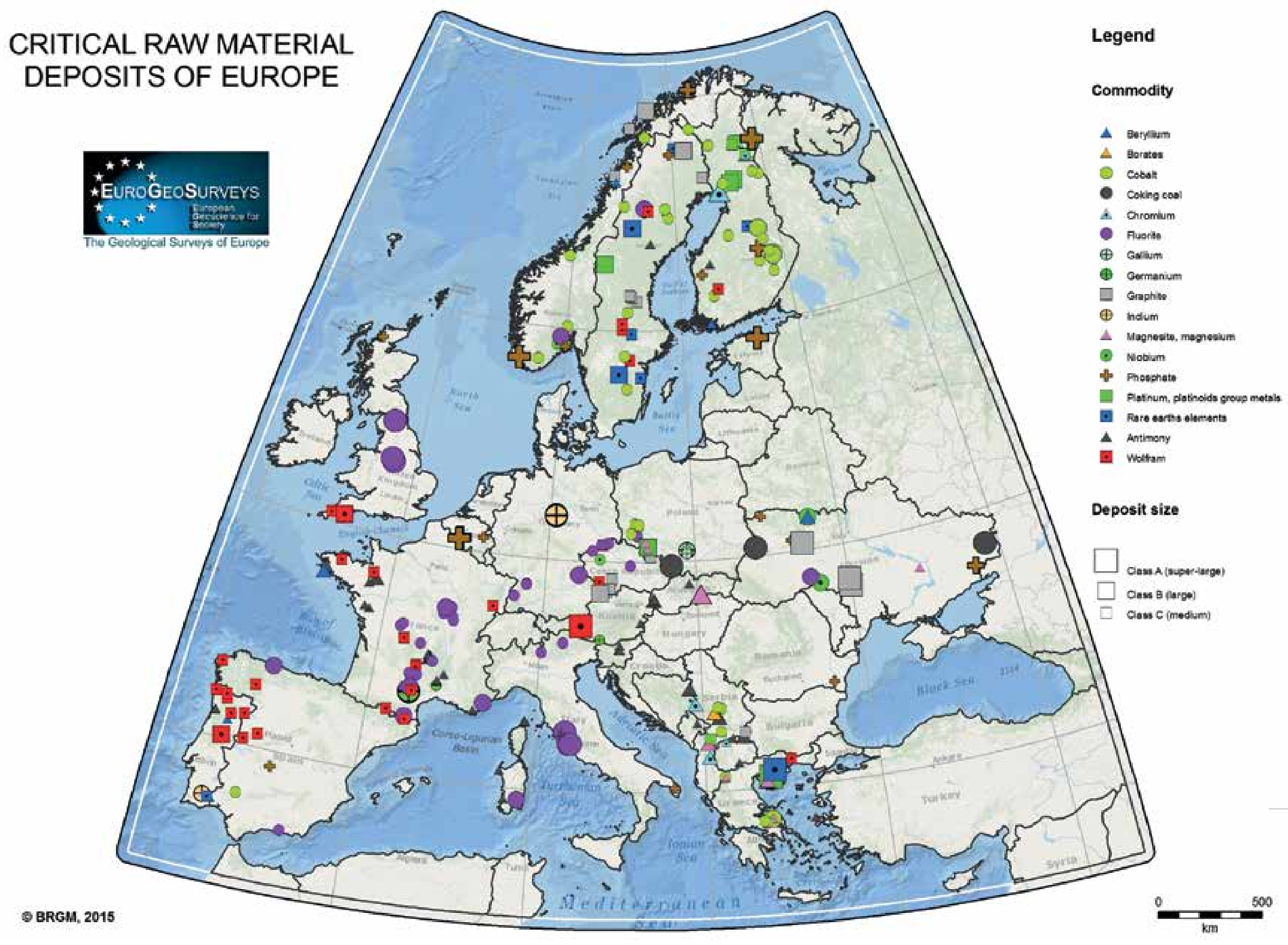
Global industrialisation has always been followed by an increasing demand for both the volume and type of raw materials. The high-technological revolution and the transition to a green economy have led to a need for use of a steadily increasing part of the Periodic Table – here illustrated by the development in the number of elements needed in core technologies in the last three hundred years. Figure based on [1].

The development of a green economy will, like all the major changes in history, require more use of mineral resources.

Mineral resources have, throughout the history of mankind, been decisive for wellbeing and development. Each new epoch has been characterised by the availability of new mineral resources for use in mankind's toolkit, which, in turn, led to new technological developments. The Stone Age was replaced by the Bronze Age in the same way as green energy will replace the use of fossil fuels. Almost all useful elements in the Periodic Table are now, in modern society, available to us, a development which allows use of ever more advanced technologies. Resources for which there was little use 20 years ago are now absolute necessities for high-technology applications which we all use.

The transition to a green economy will necessitate a major focus on green technology. The main focus will be on renewable energy (bio-energy, hydrogen, water, wind and sun), better storage and less loss of energy (batteries and energy transport), reduction in the use of fossil energy (electrification of vehicles, lighter materials) and advanced, smart technology.

Most of these sectors are mineral-intensive. In the long term it should be possible to facilitate recirculation of a large part of the resources we use. Population growth and, not least, improvements in standards of living, will, however, lead to further increases in demand which cannot, in the short term, be met by recirculated materials. We must thus, for the foreseeable future, meet our needs by extracting most of the necessary resources from rocks and surficial sediments, until the available store of recyclable material in society is large enough to be significant and the recycling technology good enough to process it. We will, in the following chapters, examine different aspects of the minerals needed in a green economy, Norway's potential and challenges, and also sketch ways in which private-public partnerships can contribute to achieving key goals.



Eurogeosurveys, the European cooperative organisation for national geological surveys, published, in 2015, a map showing the known deposits of minerals and metals which are critical for European industry and the European economy. The project demonstrates Europe's own potential for averting political or strategically motivated supply crises in a continent which is heavily dependent on import of mineral raw materials.

NORWAY, THE EUROPEAN UNION AND THE UNITED NATIONS

The green transition will necessitate an ever more effective and cleaner mineral extraction and processing industry. This means that emissions during production must be reduced and that resources and tailings must be utilised better. There will also be major challenges in making our enormous consumption of construction raw materials greener, by thinking of "short transport" solutions.

Norway and the European Union are well equipped for a green transition. The mineral industry has made much progress in development of sustainable solutions[1] and Europe leads in terms of both development of technology and solutions for collecting materials for recycling. We may add that Europe has a demographic development and standard of living profile which is favourable for a gradual transition to a circular economy.

Norway and the other Nordic countries are world leaders in mining technology, and the region leads Europe in terms of production of both mineral raw materials and refined metals. Access to resources, stable political government, the will to regulate and focus on both innovation and the environment mean that Norway and the other Nordic countries can contribute with both production and technology to a greener world in the coming decades.

There are, however, some stumbling blocks. Resources which are vitally important for development of, and supply to Europe's ever greener value chains can be difficult to access. This is not due to a lack of such resources in Earth's crust, but because their availability is governed by national and/or private monopolies, in addition to the fact that restrictions on exports of important raw materials have become increasingly common in the world in recent decades[1].

This was the starting point for the European Union's Raw Materials Initiative in 2008: it described three main axes: secure good and sustainable trade regimes for raw materials, secure supply of raw materials in Europe and stimulate effective resource utilisation and recycling. The Commission presents, at regular intervals, an updated list of raw materials which are particularly important and vulnerable, so-called critical raw materials[3].

The Commission has, in addition to establishing research programmes linked to the Raw Materials Initiative, via Horizon 2020, established public-private industry partnerships aimed at strengthening the three axes. Every second year an analysis containing a set of 24 indicators ("Raw materials score board"[1]) is produced in order to monitor progress in the EU's overall activity in this field. These analyses have a broad profile, from the future demand for raw materials, via exploration, investigation of deposits and extraction in Europe, to recirculation and sustainability in the industry. The analyses form an important foundation for development of political action plans in the EU.

The member countries of the United Nations approved, in autumn 2015, a set of shared sustainability goals. The 17 goals and 169 subsidiary goals are a shared work plan for elimination of poverty, combating discrimination and terminating climate change by 2030. Achievement of the green transition and improved social conditions are core concepts for achieving these goals. Questions related to minerals will thus be important in the work aimed at reaching these goals[9].

Norway participates in many of the actions and initiatives which are implemented at European level, via NGU, the universities and research institutes. Norway does not, however, participate in the part which covers analyses and indicators. These are reserved for EU member states. The connection between R&D and policy development is therefore weaker in Norway than in the EU. The visibility of Norway's role in the European context as well as initiatives for public-private cooperation, are weakened. Thus, even though Norway's role in the basic activities in the Raw Materials Initiative is strong, implementation at the national level is in suspense, pending possible new directives which Norway will be committed to following.

GREEN MINERALS

Several metals and minerals are of particular importance in implementing the green transition. This applies to materials which, with minimal encroachment and consumption, are absolutely critical in climate- and environmentally friendly energy production, minerals which are used directly in environmental applications, and materials which are of vital importance for modern technology. Many elements and minerals with unique properties are necessary for the increasing degree of electrification in the transport sector, and these are needed in steadily increasing quantities. We call them "green minerals" and will describe some of them here.

COPPER

Demand for copper is increasing and has increased exponentially throughout history. Copper has many applications but 75% of the copper which is mined is used for transport of electric current in one or other context. Everything which is to be electrified requires copper and copper is completely indispensable in the green transition. Increased prosperity, urbanisation and population growth have always driven the global increase in demand for copper. The need for copper in the green transition is a new, important and additional "driver". The green transition and the increase in the global middle class from 1,800 million in 2009 to 4,900 million already in 2030 will double the demand for copper in less than 20 years. There is a great need for discovery and development of new copper deposits in order to secure the development of prosperity and the transition to a greener society. Norway has, historically, been a very important producer of copper and active exploration for copper continues in Norway today. Large resources may still lie in the bedrock in Norway, but there is also a potential for economically mineable deposits on the seabed in Norwegian territorial waters. The important copper deposits, Nussir and Ulveryggen, in Repparfjord in Finnmark county are being developed for production within a few years.

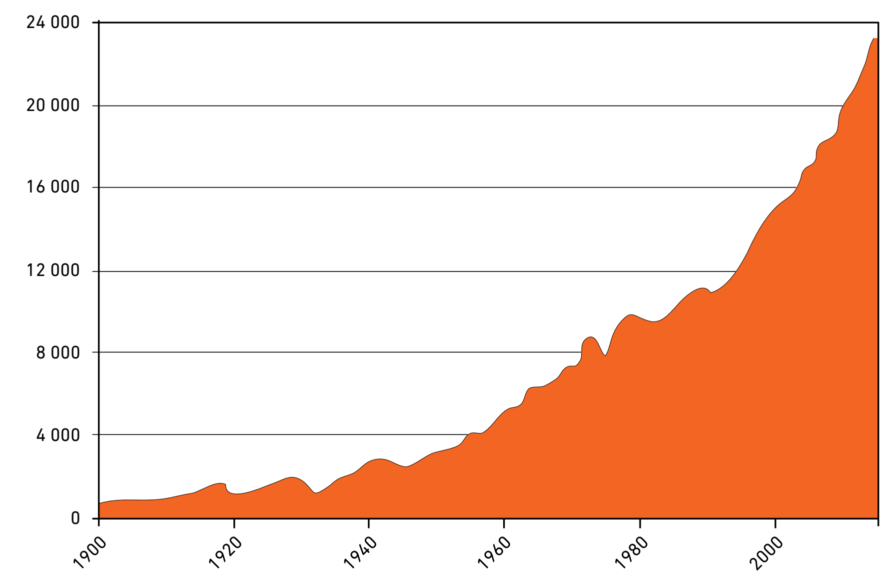
- **An electric car needs 3 times as much copper as a conventional car – about 80 kg.**
- **3,600 tons of copper is required for building a wind park with a capacity of 1000 MW, the size which is being planned in Trøndelag county: this is equivalent to the area of a football pitch covered with a 5 cm-thick plate of copper.**
- **Two new wind turbines were set up every single hour in China in 2015.**

Increasing need for resources

We are efficient in recirculating copper but demand for copper is increasing exponentially as a result of population growth and increased prosperity.

The world is therefore dependent on a steady increase in the number of new copper mines, even though we recirculate over half the amount of metal used6. Global copper consumption increased by 3.4% annually between 1900 and 2014. Consumption is expected to pass 50 million tons annually during the 2040s.

World consumption of refined copper, 1900 – 2014. Data in 1000 tons.



PHOSPHATE

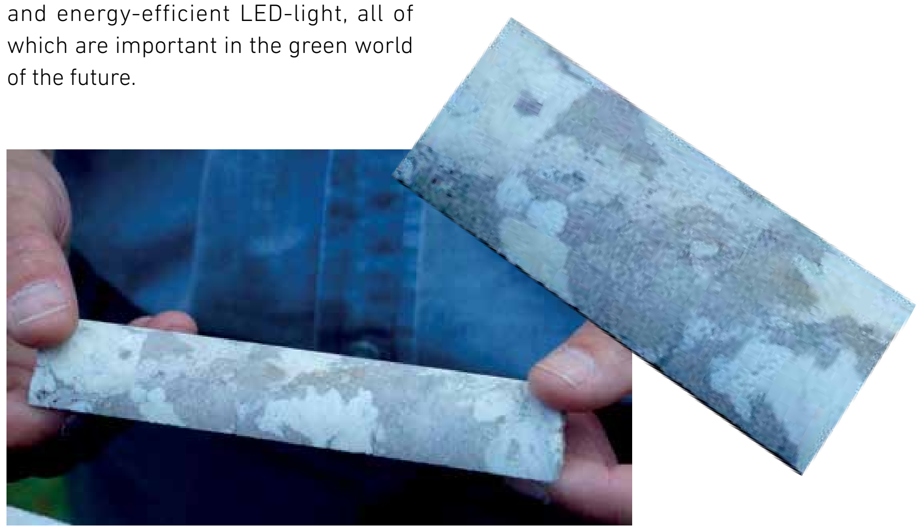
The global population and efforts to achieve greater prosperity are increasing. The world must have more food. Mineral fertiliser has an enormous effect on the yield of agricultural soil and is essential for maintenance of food production in many parts of the world. Phosphate, nitrogen and potassium are the most important nutrients for the world's corn. The largest deposits are, and the greatest production of phosphate come from the phosphorite deposits in North Africa, partly in areas in which there is political conflict. The phosphate in this area is mined from deposits which are also enriched in uranium and cadmium. The heavy metals have, over the years, either followed the fertiliser onto agricultural soil or have accumulated in waste heaps at the mining sites. "Green phosphate" will be important for the future and Norway has considerable resources which may be suitable for exploitation – the largest deposit is located east of Egersund in Rogal

RARE EARTH METALS (REE)

Rare earth metals (Rare Earth Elements, REE) are the collective names used for 16 elements (the lanthanoids and yttrium) which have quite unique properties in relation to modern technology. The elements commonly occur together in "rare earth minerals": very advanced processes are required in order to separate the metals from each other. China completely dominates world production. Norway and the remainder of Europe have to import all we need.

The rare earth metals have been the subject of much attention in recent years because China has exploited it's production monopoly for political purposes. The different metals have many, varied applications: particularly important sectors include batteries, electric motors, wind turbines, catalysers, screen technology and energy-efficient LED-light, all of which are important in the green world of the future.

Norway has several small deposits, and one single, very large deposit of rare earth metals. It is located at Ulefoss in Telemark county and is one of Europe's largest.



GRAPHITE

Graphite is a soft, grey mineral which consists solely of the element carbon. Everyone has related to graphite because the "lead" in a pencil consists of graphite, typically blended with clay to adjust the writing hardness. Graphite has, however, unique properties in relation to the green transition: in the future ultra-thin layers of graphite, called "graphene", may form the basis for a new technological revolution. Lithium-ion batteries, which are the central energy source in almost all portable electronic items, contain twice as much graphite as lithium, and it is estimated that the development of fuel-cell technology will cause a major increase in demand for natural graphite. The quality of the natural graphite is critical for an application in high technology, and many known deposits on Norway meet the necessary quality standard. Skaland Graphite's mine on Senja is the most important producer of high-quality natural graphite in Europe.

LITHIUM

Lithium is the lightest metal which exists and, in the Periodic System, is element no. 3. Lithium is used in many contexts, but most of it ends up either in ceramic products or in batteries. Demand for lithium continues to increase because of increasing electrification in the transport sector and growth in consumer technology, which requires effective, light batteries. Lithium is, in fact, one of the few raw materials for which prices have increased throughout the global raw material price collapse in recent years. A small electric car, such as a Nissan Leaf, has a battery which contains 4 kg. lithium, while the battery in a Tesla is much larger and requires much more lithium. Norway has, at the present, no known mineable deposits of lithium, but a Norwegian company, Nordic Mining, has ownership involvement in a lithium deposit in Finland.

TITAN

Titanium, in the form of TiO2 - titanium dioxide – was part of an earlier phase of green development which took place in the last century. Lead had, until then, been the main additive for giving paint a white colour. Old lead-based white paint can contain up to several tens of % of lead and remain as an important source of pollution in the soil, especially in our cities. Norway has very large resources of titanium and Titania's mine in Hauge i Dalane is responsible for 6% of world production. A new titanium project on Engebøfjellet in Førdefjor may, with time, further increase Norway's importance as a titanium producer.

- **Titanium is stronger than steel but is 42% lighter and is therefore used in aircraft fuselages. A Boeing 787 Dreamliner contains 15% titanium.**
- **Titanium, is a metal which our bodies tolerate: it is therefore used in implants and in artificial limbs.**
- **Titanium dioxide is a non-poisonous pigment which makes paint, foods and other products white. You will find titanium dioxide in soft ice cream, sun cream and in toothpaste.**

OLIVINE

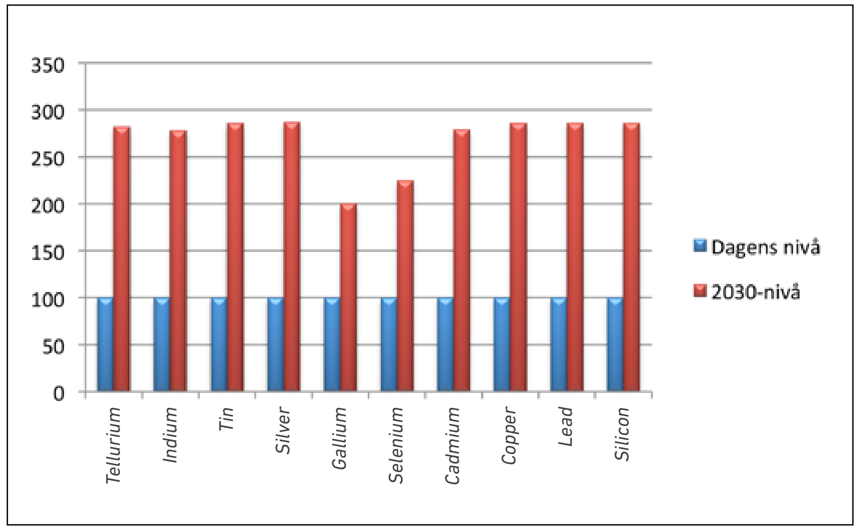
Olivine is, in fact, a green mineral – also when you find it in nature. Olivine is one of our most important industrial minerals and Norway produces almost half of the global production. Most of the olivine is used as a flux in iron pellets in blast furnaces, but olivine also has a green side. Olivine has special properties in adsorption of heavy metals and is, to an increasing extent, used in removing heavy metals from soil or water or for covering polluted ground, e.g. in harbour areas. Sibelco Europe's olivine mine at Åheim is the world's largest and the region has several other deposits of world class.

QUARTZ AND OTHER SOLAR CELL RAW MATERIALS

Extremely pure quartz is a vitally important resource, for, among others, solar cell producers and in the semiconductor industry. The solar cell industry requires highly refined raw materials, even though the initial resource is very pure quartz. The company Quartz Corp AS produces, in Norway, ultra-pure quartz at their plant at Drag, south of Narvik. The path from a deposit of ultra-pure quartz to a saleable raw material for solar cell production is, however, demanding: Quartz Corp's technological solutions are critical for the value of the mineral product.

Solar cell production requires, in addition to quartz, like much high technology otherwise, numerous other elements with special properties, which contribute to the solar cells being effective and economic to produce. Several of the elements, for example indium, do not occur as single- or main-resource deposits but are extracted as by-products from deposits being mined primarily for other components. Geological knowledge, understanding of the resources, political will and regulations are necessary in order to ensure that the World's increasing need for elements of this kind can be met with a minimum of encroachment on nature and culture.

SOLAR ENERGY



Estimate of the percentage increase in demand in for selected elements for solar energy up to 2030[1].

	TODAY	2030
Tellurium	100	282
Indium	100	278
Tin	100	286
Silver	100	287
Gallium	100	200
Selenium	100	225
Cadmium	100	279
Copper	100	286
Lead	100	286
Silicon	100	286

LOCAL USE OF ROCK MATERIALS

Norway needs large quantities of stone for construction of infrastructure such as roads, railway lines and other large constructions. Norwegian consumption is equivalent to one truckload of sand, gravel and hard-rock aggregate/person/year.

Construction materials should be supplied locally. Transport costs for delivery of these heavy materials for distances of over 30 kilometres will exceed the price for the construction materials. Most construction materials are therefore transported for short distances. Local sourcing of stone is environmentally favourable, as is the case also for food. The population of the cities will increase strongly in the coming years. This will lead to increased demand for construction materials and greater difficulty in ensuring local supplies of these materials. This trend necessitates long-term planning: planners

must ensure that society does not build on top of the materials needed for the actual buildings.

Freight of stone from the location where it is extracted to the location where it is to be used involves the use of heavy trucks which have impacts on the road network and the environment and also cause increased pollution. It will be necessary, in the future, to look for solutions which minimise the environmental impact from both extraction and transport of construction materials. We anticipate that a larger proportion of construction materials for areas with intensive development will, in the future, be transported by sea from deposits on the coast.

A larger proportion of raw materials of this type is transported, in other countries, by railway. Several of the largest deposits which can meet the future needs of the Oslo region are located near available infrastructure for railway transport. Studies from Great Britain show that railway freight reduces carbon dioxide emissions by at least 80% compared with road freight. Several of the largest hard-rock aggregate deposits in Norway are based on freight by sea. Transport by ship can also be important for cities close to the sea. The challenge in using trains or ships is the need for large areas for receipt and temporary storage of the construction materials, before they can be freighted onwards to the market.

Planning for and establishment of areas for temporary storage of construction materials near a harbour or railway will constitute appropriate steps for increasing transport by railway or by ship.

Large road- and railway-projects are being planned for future development in Norway. Achieving a mass balance in these projects by planned use of construction-site material as construction material will reduce the environmental impact of such projects. This must be used by mapping the quality of the rock bodies as construction resources in an early phase of planning, and by development of extraction techniques and production methods which secure more high-value use of construction materials.

Good, long-term plans for management of construction materials will be an important measure for reduction of the load on the environment and for society. Such plans can form the basis for securing raw-material needs, both nationally and locally, for securing that the material used is of sufficient quality, so that other raw-materials with unique qualities are not used where there is no need for their specific qualities.

The anticipated population increase in the Oslo region will lead to an approximate need for. 339 million tons of construction raw materials up to 2040.

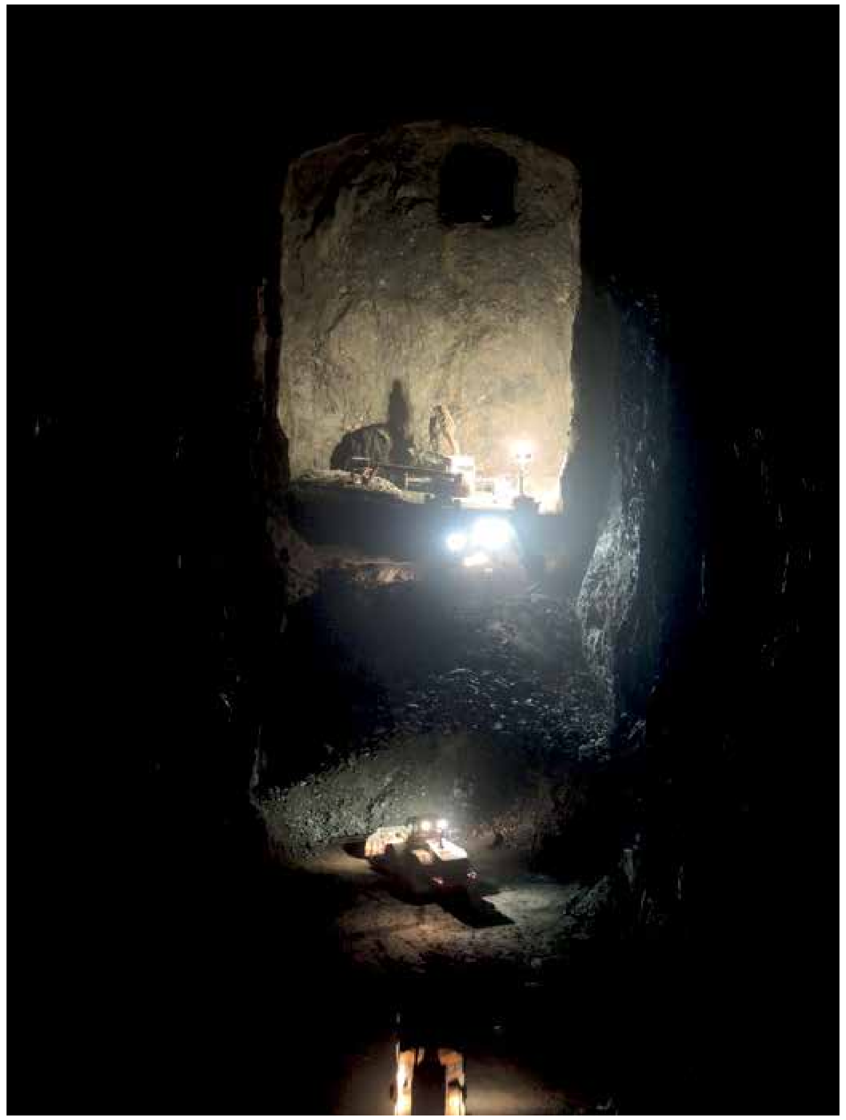
This corresponds to the top of Gaustatoppen. Where is all the rock going to come from?

- **20% of all heavy transport on roads in Norway consists of trucks loaded with gravel and hard-rock aggregate**
- **4 million truckloads of construction raw materials are transported every year in Norway. Every additional kilometre of transport distance results in an additional 4 million extra truck-kilometres on Norwegian roads.**
- **120,000 tons of hard-rock aggregate are needed to build 1 kilometre of four-lane motorway.**
- **50,000 tons of hard-rock aggregate are needed to build 1 kilometre of double-track railway.**
- **3,000 tons of hard-rock aggregate, or 250 truck-loads, are needed to build a school.**

GREEN PRODUCTION

Greener mines will reduce the environmental foot print in the future, but it is not certain that this can be done without waste tipping.

Hard-rock aggregate deposits are traditionally operated as open pits. Underground operation is a good alternative where this is operation-technically possible. Underground operation means a less environmentally disfigured landscape, and less dust and noise for which the industry is commonly criticised. The rock caverns which remain when the aggregate has been blasted out can easily be used for tipping of waste rock. There are many advantages in going underground for rock even though underground operation costs more than open-pit operation. In addition, an integrated operation with several production processes within the same area will be very advantageous. An aggregate operation with, for example, integrated plants for concrete- and asphalt production and –recirculation will reduce transport costs considerably.



Fana Stein & Gjenvinning in Bergen operate a combined recycling plant and aggregate works underground. This type of operation reduces the environmental impact in the local environment and also reduces the transport needs, in that fewer empty trucks have to drive in and out of the plant
Foto: Lars Libach

Reuse of rock materials is an important supplement to ordinary construction materials, but will not meet the demand alone. Over 9 million tons is used annually in Greater Oslo alone – the capital plus the 45 nearby municipalities.

It is inevitable that extraction and processing of mineral raw materials set a footprint on the external environment. The green transition presupposes the greatest possible reduction in the negative impact on nature. Norway has a mineral industry which is among the foremost internationally as regards environmental footprint, and is comparable with European standards. Norway has, in addition, a mineral industry which uses renewable energy: this is an important, positive factor compared with most other countries in the world. Norwegian industry is also among the foremost in the world in reduction of emissions to the atmosphere, a sector in which development is moving in the right direction. There are, nevertheless, challenges: these are primarily related to utilisation of the raw materials.

Rich and easily accessible metallic resources are, to a large extent, used up. Mines are being established globally on ever-lower grade but large deposits, and the deposits are at increasing depths. Fifty years ago it was not commonly payable to open a copper mine with a grade of less than 1.5% Cu: there are, today, mines operating at 0.3% Cu. This type of operation results in very large tonnages of waste rock material. This leads to a low degree of utilisation, higher energy consumption and large tips of mineral waste. We can envisage several ways in which such footprints can be reduced.

It is of great importance to assess whether many of the old mine tips on which the government expends many millions of NOK every year, in order to minimise environmental damage, could be exploited commercially. The metal content in parts of the tips close to several disused mines is higher than what could, today, be considered to be mineable rock. The need is therefore great for mapping and characterisation of these waste tips. Technology exists for increased use of secondary resources from aggregate production as fine fractions in concrete- and asphalt production. The raw material has traditionally been adapted to concrete and asphalt recipes. It can be anticipated that there will, in the future, be a greater degree of adaptation of the recipe to the raw material which is available, in order to achieve optimal us of the resources.

It is, despite various innovative solutions which may become economically viable in the future, probable that deposition of surplus rock material is a factor with which we will have to live so long as resources are being extracted from rocks. Even if it may be theoretically possible to use this waste rock for a practical purpose, this does not necessarily mean that it is desirable relative to the market or the environment to do so. Good sustainability does not necessarily mean total utilisation of all deposits, but there may, nevertheless, be a considerable potential in innovative thinking on use of major sources of waste materials, and, if possible, establishment of new value chains based on mine waste.

When mine waste must ultimately be deposited this should be done in a way which has the least possible impact on the local environment. There are several ways in which mine waste can be deposited.

Marine disposal of mine waste has the advantage that the waste is literally laid on the seabed and is therefore much less exposed to slides. Such submarine waste deposits will, in some cases, be consolidated quite rapidly, in such a way that the material becomes inert and stable. Marine waste deposits will, however, influence the biodiversity of the waters. It is thus important that the consequences of marine disposal are assessed thoroughly and that the disposal site is monitored systematically.

Waste disposal on land is, in many cases, the only possible solution. The waste disposal sites require large areas. We have, in Norway, a great deal of negative experience from acidification and leakage of heavy metals from old mine-waste tips. A financially responsible mining company will not, in our times, abandon waste tips which are as rich in sulphides and metals as was done in the past, but it can still be a problem that possible reactive materials are left, exposed to air and running water for a very long time. Slumping and slides from waste disposal sites on land have caused several environmental catastrophes in the world. This risk may increase as a result of more extreme weather in the future.

A third form of waste disposal is backfilling of mineral waste production into the mine cavity or open pit as the operation progresses. This is a solution which may be appropriate for certain types of mining operation, but not for all.

Whether the one or other type of deposition is best in a given situation depends on many factors. The best practice in one area may be the worst in another area. We must therefore aim for thorough research and smart planning, and secure good regulation and monitoring of the deposition process so that defined limits are not exceeded.

Walling stones are produced at this stone quarry in Larvik from rock which is surplus to the requirements for larvikite production.
Foto: Peer Richard Neeb

- **New technology involving robotification of mining may make it profitable to exploit small and rich deposits to a greater extent than previously.**

- **Future technology may make it simpler, technically, to exploit deposits which contain a blend of metals and industrial minerals. This can lead to economically viable production, better utilisation of the resources and reduced waste from deposits with several valuable components.**

- **Certain minerals, such as olivine, may, in time, and with the right technology, be used in mineral production, in a process where CO2 is, at the same time, bound in the residual products. The result will be a combination of resource extraction and storage of greenhouse gases.**

MINERALS IN THE CIRCULAR ECONOMY

Most non-renewable resources will, in the long term, become renewable, through recirculation.

A typical cell phone contains ca. 0.02 g. of gold. If all the gold in iPhones sold in 2013 had been extracted from a single mine this would leave a hole corresponding to a 6 km. long road tunnel. This example gives a modest perspective on the quantity of resources required to manufacture the products with which we surround ourselves. It is obvious that such a level of consumption cannot be sustainable in the long term if it is based solely on extraction of the resources from rock.

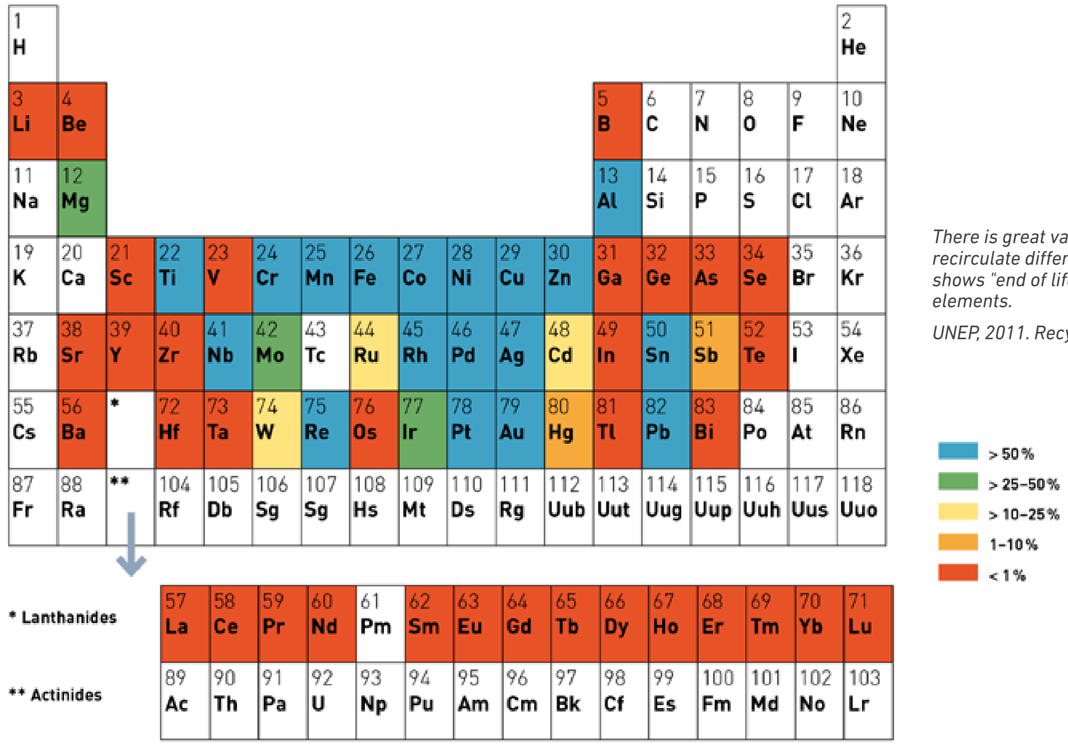
Gold:	0,04 %
Silver:	0,15 %
Copper:	24,9 %
Nickel:	3,10 %
Zinc:	2,74 %
Tin:	0,74 %
Cobalt:	0,09 %
Chronium:	0,44 %

Mobile-phone high technology depends on very many mineral resources. The example above shows a selection of metals, analysed in a crushed Nokia 5230 cell phone.[8]

Europe is approaching a zero growth-level in population. This will lead to some metals (especially iron, copper, gold and other major metals) being increasingly supplied by recirculation in the future. The technology is in place and has been implemented in commercial applications and we are skilful in recirculation of these metals. At a global level however, the growth in demand for copper will exceed the growth in recycled copper for several decades to come.

The situation is different for other raw materials. Technology has, so far, not advanced sufficiently as to allow easy recirculation of special metals. Much research and innovation in both private and publicly funded organisations will, however, improve this situation.

There is, in addition, focus on increased effort by the producers of electronic products to design these so as to facilitate recirculation.



There is great variation in how effectively we recirculate different materials. The figure shows "end of life" recirculation rates for 60 elements.

UNEP, 2011. Recycling rates of metals [5]

The aggregate plant at the Velde AS stone quarry at Sandnes is integrated with the concrete and asphalt station and a modern recipient plant for construction materials. This reduces the transport needs and the environmental impact.
Foto: Velde AS

RESOURCES IN NORWAY

Norway is a historically important producer of numerous important metals and industrial minerals and the potential for new discoveries is still large.

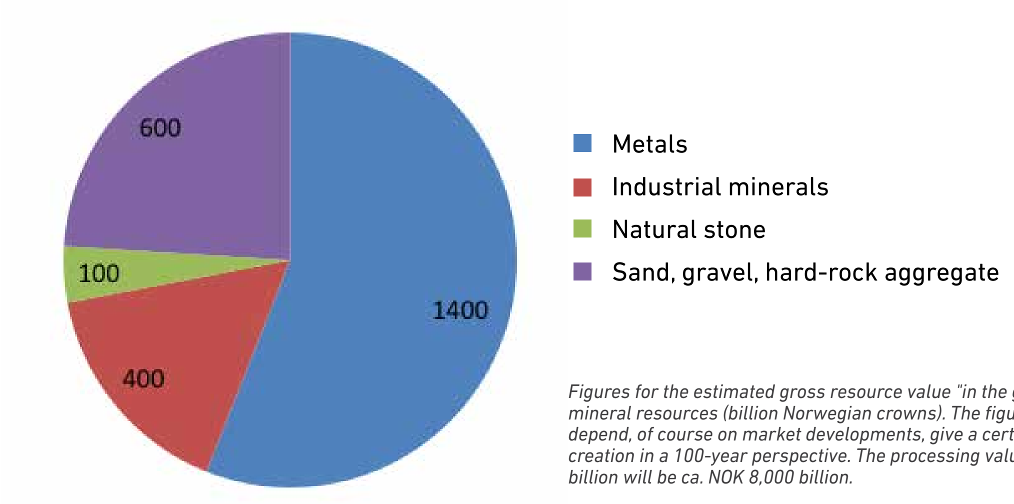
The Fennoscandian Shield which encompasses Norway, Sweden, Finland and northwest Russia is considered to be Europe's most prospective area and new world-class deposits are still being found in the Shield. Sweden and Finland have both focussed major efforts, using the national geological surveys and other national institutional systems, on their mining industries, work very intensively on creating favourable conditions for exploration activity and on attracting international capital to the industry. Norway has, through the special allocations MINN and MINS focussed on mineral resource investigations in North- and South-Norway succeeded in establishing a similar framework for collection of data. The data basis available in Norway is still, however, weaker than those which exist in the neighbouring countries. On the other hand the potential in Norway is correspondingly large: the challenge now is to discover the deposits concealed under overburden or at greater depths – or, perhaps, on the seabed.

Norway also has known deposits which can, we believe, be suitable for exploitation in the future. These are deposits of a type for which we see that the global trend in grades (the percentage content of minerals or metals) is gradually approaching the levels in known deposits in Norway, or trends relating to particular qualities which can make deposits economically viable. Advances in process technology are another factor which can bring known deposits into play, and additional benefits such as disposal of CO2 may also increase profitability. The potential for continued exploitation, development and process improvement is, in any case, considerable. It is thus important in land use planning to know as much as possible about where the potential is regarded as significant.

FUTURE POTENTIAL	RESOURCE TYPES
Existing and potential exploitation possibilities: Large resources, established value chains and technology	Titanium, copper, iron, olivine, quartz/silica, carbonate rocks, nepheline syenite, graphite, aggregate, natural stone
Major potential for the future: large resources and potential for new discoveries, in addition to increasing demand	Rare earth metals (REE), zinc, nickel, lead, molybdenum, magnesium, phosphate, talc
Limited potential for future exploitation:	Cobalt, silver, vanadium, niobium, gold, beryllium, fluorspar, feldspar, garnet, mica, sand and gravel
less resources and potential for new discoveries	Wolfram, chromium, aluminium, PGE, scandium, tantalum, gallium, indium, aluminosilicates

We have, even though we cannot foresee the future markets for mineral resources, grouped those resources which we can find in mainland-Norway into four groups according to: presumed future potential, our knowledge of them and their importance for society.
Resources which are critical according to the EU classification of 2014 are indicated in red font, while green underlining indicates resources which are particularly important for green energy.

The prices of most of the resources are governed by a global market: China's explosive economic growth and resource needs from 2000 up to 2012 dictated the agenda in the mineral industry throughout the globe. The prices of both energy and mineral resources rose constantly, except for the short-lived effect of the financial crisis in 2008. Prices have, however, fallen from 2012 to 2015 and exploration companies which are dependent on risk capital have had difficult circumstances. There has been a strong increase in activity in our neighbouring countries, which suggests a belief in an upturn in the trends, and we expect that we will, in time, see the same effects in Norway. Exploration companies and investors must, however, be cultivated and fed with basic information and data so that they can implement their object investigations in the right places, with the required permits and the necessary predictability.



Figures for the estimated gross resource value "in the ground" for groups of Norwegian mineral resources (billion Norwegian crowns). The figures, though they are speculative and depend, of course on market developments, give a certain image of the possibilities for value creation in a 100-year perspective. The processing value for a resource value of NOK 2,500 billion will be ca. NOK 8,000 billion.

Value chains in the mineral industry can be complex and are often international. The three examples below illustrate this. Zinc production in Norway is based on imported raw materials. Super-pure quartz combines both Norwegian and imported raw materials, as does the value chain for titanium dioxide.

VALUE CHAIN ULTRA-PURE QUARTZ

EXTRACTION
Quartz, (feldspar, mica)

IMPORT
Quartz concentrate

→ PRODUCTION
Super-pure quartz
Feldspar
Mica

→ EXPORT
Semiconductors, solar energy, optics, fibre optics, halogen lamps, ceramic products, filler in paint, plastic, rubber

VALUE CHAIN ILMENITE/TITANIUM DIOXIDE

EXTRACTION
Ilmenite (Hauge i Dalane

→ PROCESSING
lmenite concentrate
(Hauge i Dalane)

→ PURIFICATION
TiO_2 (Fredrikstad)

IMPORT
Ilmenite concentrate
(Senegal)

→ PURIFICATION
TiO_2 and pig iron
(Tyssedal)

→ EXPORT
White paint, cosmetics, plastic, food, etc.

VALUE CHAIN ZINC

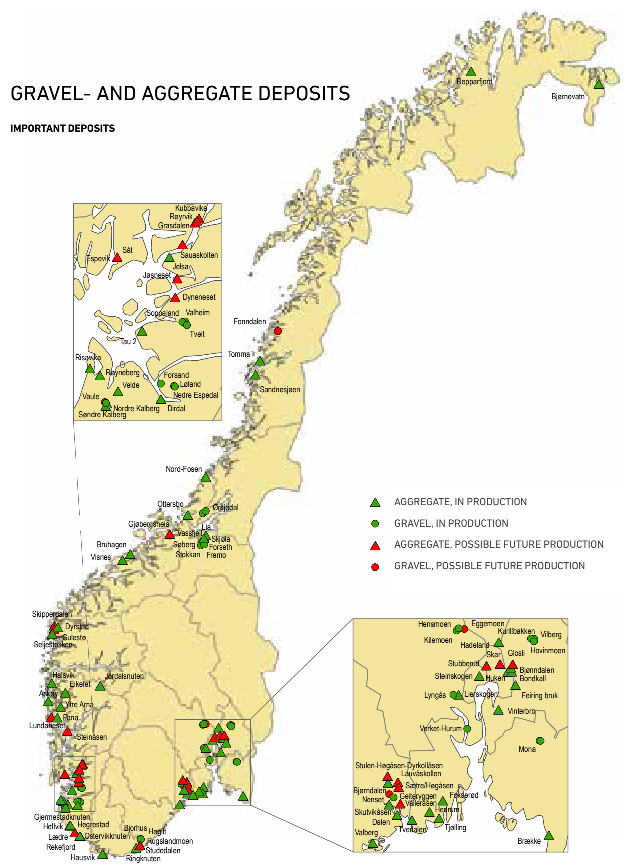
IMPORT
Zinc concentrate from mines, zinc clinker from smelters, fluorspar, aluminium hydrate

→ PRODUCTION
Zinc metal, zinc alloys, sulphuric acid, aluminium fluoride anhydrit

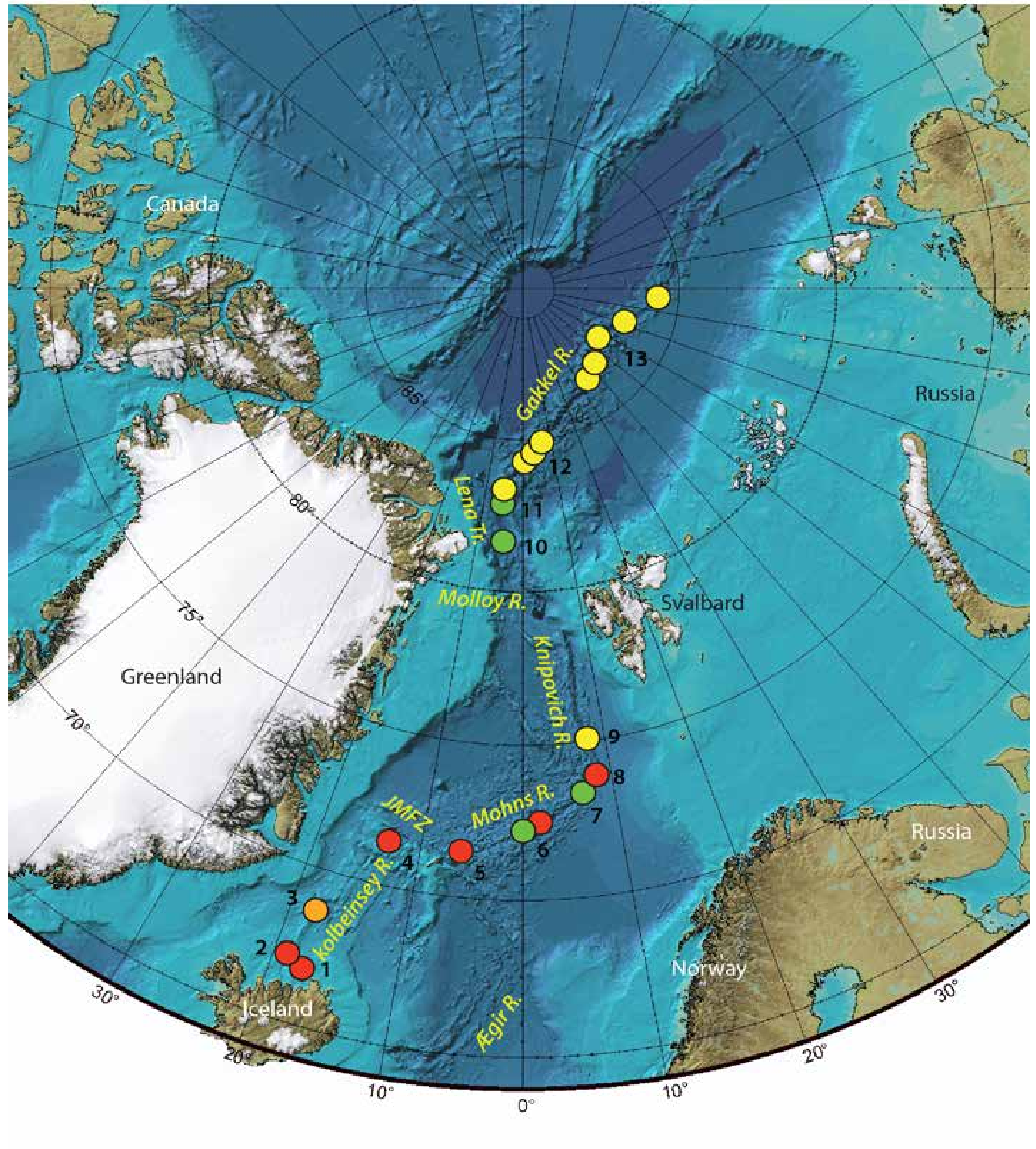
→ USED IN NORWAY
Aluminium industry

→ EXPORT
Steel industry, foundry products, mineral fertiliser

The potential for mineral deposits of all types is still large in Norway and these resources, with the right framework conditions, can yield both profit on extraction and downstream value creation in a world in development.



Norway's territorial waters encompass many hundred kilometres of the Mid-Atlantic Ridge along which active formation of metal deposits takes place from so-called "black smokers". Bothe the University of Bergen and NTNU have had expeditions to the Mid-Atlantic Ridge in order to study both the geology and the biology around these active metal sources. The deposits on the seabed are of interest primarily because of their content of copper, but also zinc, gold and other metals can be found in deep-marine deposits. The potential for major discoveries considerable for the marine territories: several hydrothermal fields with black smokers have been identified, but mapping has only just begun and will require considerable resources. The potential for exploitation and value creation from possible deposits is large, because the Norwegian oil industry is a world-leader in marine technology.

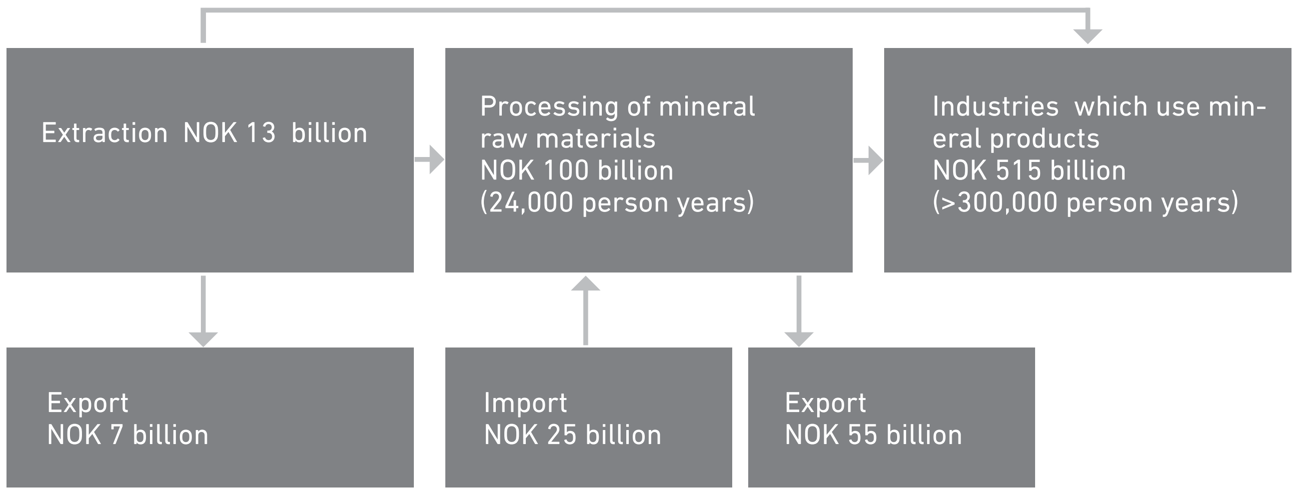


Deep marine resources. Known fields with active metal precipitation from black smokers along the Mid-Atlantic Ridge.[7]

THE MINERAL INDUSTRY IN NORWAY – STATUS AND FUTURE

The mining industry in Norway had a turnover of NOK 12.5 billion in 2015, of which the export component amounted to 52%. 97.6 million tons of mineral resources were sold in Norway last year, of which 89% was hard-rock aggregate and gravel. It was reported for 2015 that employment in the mining industry amounted to 5,551 person-years.

Metals, industrial minerals and construction raw materials have been exploited continually from the Middle Ages to the present and have formed the basis for paid employment, value creation and exports. Operation of Norway's mineral resources has been the origin of the Norwegian process- and metallurgical industry which currently employs 24,000 Norwegians[4].



Mineral value chain, Norway 2014

Norwegian mineral deposits have, over time, been exploited for a large range of metals. The list encompasses: copper, zinc, lead, iron, titanium, chromium, nickel, cobalt, vanadium, molybdenum, wolfram, niobium, silver, and gold. Metal production at the present is mainly limited to iron and titanium from the large mines, respectively of Rana Gruber and Titania, but there is still a limited production of iron from Sydvaranger Gruve, following the bankruptcy in 2015, and of molybdenum from Knaben Gruve in Vest Agder county. New mining projects are, however, being developed and Norway may, in the near future, again become a copper producer, with operation of the large Nussir deposit in Finnmark county, and a planned mine at Engebøfjell in Førdefjord may be a new producer of titanium minerals.

Metallic ores dominated production in past centuries but industrial minerals are the most important of the two types of resource at the present. The industrial mineral sector is dominant in number of operations, production and number of employees by carbonate minerals such as limestone and dolomite. Norway has, in addition, production of olivine, nepheline syenite, quartz of many different qualities, feldspar and graphite.

Natural stone and construction raw materials have become an increasingly important sector. In West Norway there are several large aggregate deposits with a quality which is attractive on the European market. In addition to domestic consumption we export aggregate to a value of NOK 1.3 billion and natural stone (mainly larvikite) to a value of NOK 670 million.

Extraction of minerals, metals and construction material resources, processing and beneficiation as well as shipping create and have created, possibilities for settlement and for value-creating industry in many Norwegian cities and districts. A large number of Norwegian cities and towns have their origins precisely in activities related to the mineral industry.

The slag tips at Røros give a good illustration of the enormous volumes of rock which have been extracted from the mines. The picture shows the clear traces of extraction of ballast material.

The Norwegian mineral industry has, over time, been favoured with a considerable density of exploitable resources, a feature which has formed the basis for industry, technological advances and an innovative thinking, which are used to this day. About 90% of the value creation occurs within 5 km. of the coastline. Clean, renewable water power forms ca. 96% of the production capacity in Norway and the availability of green energy is a major Norwegian advantage for a highly energy-intensive process industry.

Precisely the abundance of resources and renewable energy are the most important nature-given advantages of the Norwegian mineral industry in the future. We have many of the types of resources which the future will demand more of, and we have a great potential for creation of new, innovative value chains. We have process-technology and –knowledge, and the petroleum industry has been responsible for development of competence centres which can certainly serve other natural resource industries as well as oil and gas.

There is therefore no reason to believe that the mineral industry (including processing) will be smaller than at present in the future, given that our own and the world's need for such resources will certainly not decline for a long time.

Our consumption of construction raw materials is also increasing. Development in this sector will concentrate on use of local resources in a broad sense: the CO_2 footprint must be reduced in this part of the branch and both primary and recirculated materials must be used more efficiently. This places requirements on both those who use the resources and those who manage them. It is bad environmental policy to contribute to increased road transport for construction raw materials by closing a city-near aggregate plant, and an industry which must develop an ever more sustainable production needs both good land areas and a long time horizon for planning.

PUBLIC-PRIVATE CO-OPERATION

Good public-private co-operation has great importance for the green transition. It can take place in several arenas.

We have, in Norway, good traditions for public-private co-operation in relation to important challenges for society. We can also achieve this in relation to the green transition. There are, in addition to industrial policy framework conditions of a more general nature, several specific areas in which a focussed co-operation can lead to major benefits.

KNOWLEDGE-INFRASTRUCTURE

Public authorities, through governmental bodies and universities, have a responsibility for production of basic knowledge which is of benefit to industry. Knowledge of natural resources – where they are to be found and how they can best be utilised is important for the development of industry, just as the physical infrastructure is important for increasing communication and transport possibilities.

Many initiatives in Norway lead in the direction of "open government". These will increase the possibilities for industry to utilise knowledge from mapping and research. This encompasses in general modern geological and geophysical maps of the whole country, good interpretations of the geology in important deposit areas, together with open, good downloading solutions. NGU has responsibility for the mapping, and, together with the universities, carries out research which leads to better interpretations of deposit areas at depth. In order to make the "bridge" between knowledge production and the application of the knowledge in industry more sound, it would be positive to involve industry to a greater extent in these activities.

APPLIED RESEARCH AND DEVELOPMENT

There are several good systems for public-private co-operation on applied research. The mineral industry, however, has not been a major user of these systems. The applied research groups which have a focus on the mineralindustry (mainly NTNU, NGU, SINTEF and the University of Tromsø) have good co-operative relationships with each other, in the case of NGU-NTNU structured in a formal co-operation encompassing laboratories and students. The cluster co-operation, Mineral Cluster Norway, is also positive: it functions as a co-operative arena for industry and the public research centres. Much of the Norwegian mineral industry, both within extraction and especially within exploration, consists of small or medium-sized companies with limited resources relative to the cost of major, strategic efforts. The cluster co-operation can, in this context, contribute to project development and greater use of R&D services.

LAND AREA- AND RESOURCE MANAGEMENT

Ensuring a sustainable, good management of our land areas and resources is a public responsibility. Much work is being carried out at present to focus attention within land area management on potentially important resources for the future. A great deal of land area management is locally based: this commonly leads to strong divergence in practice from place to place, and the level of knowledge of planners and decision makers is variable. A specific initiative to strengthen this component in land management would be to develop good guides which take as a starting point: "Best practice" for a sustainable development in relation to minerals.

SUSTAINABILITY GOALS

The European Innovation Partnership on Raw Materials (EIP-RM) is a large initiative in Europe in which public and private organisations in Norway also participate. Within the EU there has been a considerable effort to develop a so-called "scoreboard" for mineral resources so as to raise the level of the co-operation closer to decision makers. This encompasses numerous indicators which can be useful in assessing possibilities and challenges along the whole value chain for mineral resources, also in relation to recycling and sustainable management. Development and future updating and maintenance are a co-operation between the EU Commission and industry. Norway is not a participant in this part of the EU project. "Scoreboard" is being developed without data from Norway. Consideration should therefore be given to development of a similar national co-operation which can provide us with a corresponding overview of developments at the national level and a sound basis for comparison with the rest of Europe.

TEN POINTS FOR FOLLOW-UP AND ACHIEVEMENT

MAP THE RAW MATERIALS

Increase geophysical, geological and geochemical mapping until we have complete national-coverage data sets. Develop 3-dimensional models for areas with deep-seated deposits.
Stimulate exploration activity.

SECURE THE RAW MATERIALS

National-coverage data sets for land-area management which show the distribution of mineral deposits, their importance and the potential for new discoveries. Increased consideration of mineral resources in land-area management.

USE THE RAW MATERIALS

More use of surplus materials. Make the surplus materials and their application areas better known in a larger market. Aim for total utilization in the production.

WEAKER FOOTPRINT

Reduce the footprint in the external environment: lower energy consumption, electrification, zero-emission of poisonous materials. "Best possible" practice for waste disposal, better knowledge of the long-term effects in various type of waste disposal facility. Monitoring of waste facilities.

NEW VALUE CHAINS

New, greener value chains for processing of mineral raw materials combined with value chains for better utilization of surplus materials. Research on mineral beneficiation processes which consume CO_2.

MANAGEMENT FOR SUSTAINABILITY

Better management of resources and operation by incorporation of indicators for sustainability and better guidance for land-area managers and decision makers.

SHORT TRANSPORT OF CONSTRUCTION MATERIALS

Shrewd management and utilisation of construction raw materials with the aim of reducing emissions, especially related to transport.

OUT IN THE WORLD

Participation in international, especially European, co-operative platforms related to resources and sustainability.

OUT IN THE BLUE

National mapping of mineral resources and biological diversity in the deep ocean.

OUT TO THE PEOPLE

Better, broader communication on the importance of minerals and construction raw materials in the green transition.

GEOLOGICAL
SURVEY OF
NORWAY
- NGU -

Visiting Address:
Leiv Eirikssons vei 39
7040 Trondheim
Norway

phone: +47 73 90 40 00

E-mail: ngu@ngu.no
www.ngu.no