RYSTAD ENERGY

# MARINE MINERALS

## *NORWEGIAN VALUE CREATION POTENTIAL*

REPORT 20TH NOVEMBER 2020

# Positioning of the report

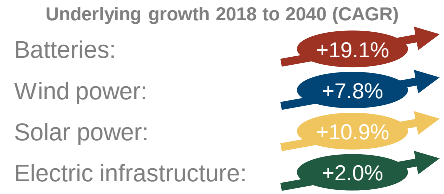
| | |
|---|---|
| Mandate | Rystad Energy has been engaged by a consortium of sponsors to evaluate the potential for a marine minerals industry in Norway. Scope of work includes;<br>▪ an overview of trends driven by the ongoing energy transition affecting selected metals markets<br>▪ a description of the supply chains for a selection of selected metals<br>▪ an introduction to a production concept for marine minerals extraction<br>▪ a high-level assessment commenting on synergies between the oil and gas industry and a marine minerals industry<br>▪ a technical-economical model based on the production concept and corresponding assumptions on mineral enrichment, prices, timing etc. which are used to illustrate possible impacts on Norway from a marine minerals industry in various future scenarios |
| System boundaries | When building a technical-economical model as part of the work, we define our system/project to only contain the offshore portion. The associated onshore processing part of the value chain is not assessed in this report. Economically, we have accounted for the latter by implying a discount to the product prices achieved. Hence, the report only discusses the impact from the offshore extraction of marine minerals. |
| Prices | When building a technical-economical model as part of the work, we make assumptions that forward prices for metals will stay at the average level observed in 2020 year to date. We acknowledge there is uncertainty to future prices. Given current expected trends and increasing metal demand, prices may increase. However, downside to metal prices is also present depending on future development of onshore mining and technological breakthroughs using substitutes for the metals as outlined in the report. |
| Uncertainties | The key uncertainty for this industry lies in the geological potential, and depending on the outcome of future exploration, the potential may be significant, or the potential may be zero. We define 4 stylistic scenarios that all build on the assumption that there exist commercially producible resources. However, we acknowledge that there are scenarios in which there is no commercially viable industry. Such scenarios, and the likelihood thereof, has not been substantiated in this report.<br><br>All cost estimates in the technical-economical model are subject to significant uncertainty: Assumptions have been made on the capex portion based on industry interviews and building on analogies from the oil and gas industry. There are upsides and downsides to these estimates, and the appendix provides for some ranges in addition to the mid-point estimates that the main report builds on. For operational expenditures, we have also built our assumptions on analogies from the oil and gas industry. While we have acknowledged this in our estimates, the remoteness and potential harshness of the geographical locations in question, may pose additional upside to the operational expenditures. |
| Scalability of costs | The cost estimates of the technical-economical model represent a scenario where a moderate industry have been built. As such, the costs reaps benefits from having more than one project developed. As such, costs should be expected higher for a single first project and cost may trend even lower if the industry develops more critical mass. |

# Content

# Executive summary

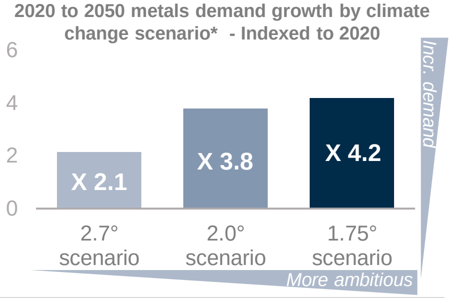
**Ongoing global energy transition**

The global energy transition is driven by technology forces and society coping with externalities such as global warming and local pollution. These forces are fueling the growth of new value chains. We nominate 4 such key value chains in (1) batteries, (2) wind- and (3) solar power as well as (4) electric infrastructure. The rapid growth of these industries will require significantly higher supply of minerals in the coming decades.




**Metal consumption will increase - marine minerals part of the solution**

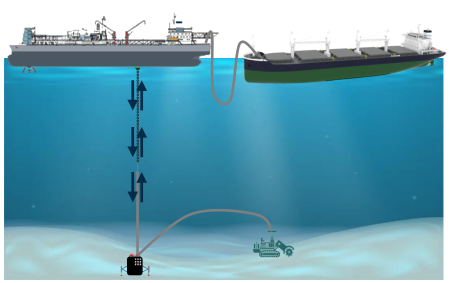
The four value chains nominated above all call for significant metals demand: While the cathode of Li-ion batteries currently requires nickel, cobalt and lithium, the photovoltaic solar panels are primarily made up of aluminum and copper. The more aggressive society fights climate change, the more metals demand will increase. Improved recycling efforts can only supply parts of the growing metals demand, mined minerals must supply the remaining. Currently producing onshore mines are challenged by controversial working conditions and put severe stress on resources and the environment. A low carbon future calls for additional metals supply, which can be met by marine minerals extraction.




**Well-positioned NCS marine minerals could be a metal supply source**

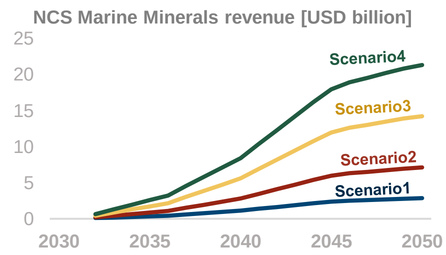
The world's spreading ridges host massive sulfides containing especially copper, cobalt and zinc. After Fiji, Norway is the country with economic rights to most of these ridges. Marine minerals extraction's good overlap with oil and gas technologies and competence gives Norway a strong competitive advantage over its peers. With the establishment of a Norwegian marine minerals legislation in 2019, in addition to the 2018-2020 NCS impact studies performed by the NPD, Norway is well positioned for the next and crucial steps towards a marine minerals industry with both great export and domestic value creation potential. A potential extraction concept builds on proven technologies from Oil & Gas and onshore mining, including a mining production vessel (similar to FPSOs), wet bulk shuttle tankers, a vertical riser transportation system and subsea mining machines/ROVs.

Potential marine minerals extraction concept



**High value creation potential, but time critical**

We nominate four scenarios which color how a marine minerals industry could evolve in Norway over the next 30 years. In our most constructive scenario, we estimate that such an industry could create annual revenues worth of USD 20 billion with corresponding annual employment up to 21 thousand FTEs. This sets the stage for building an industry based on a home-market with significant export potential, like Norway has done in deepwater Oil & Gas: A key ingredient to building the 120 bNOK export industry that we currently have in deepwater Oil & Gas was to create a leading local industry while the global market was in its infancy. That timing is now for marine minerals.




*See appendix for climate change scenario details, in line with the IEA Energy Technology Perspectives Scenarios. Demand for 17 of the core clean energy technology metals and elements, plus steel.
Source: Rystad Energy research and analysis; World Bank

# Content

# The four key drivers of the Energy Transition

Cost & Performance of Oil substitutes

Cost of renewable power generation

Global warming & Climate change

Local pollution

Source: Rystad Energy research and analysis

# Energy Transition drives emerging value chains providing opportunities for marine minerals

| The forces of the Energy Transition… | …drives new, emerging value chains | Description and rationale | Underlying growth 2018-2040 (CAGR) |
|---|---|---|---|
| 1. | Batteries | The evolving trends of electric vehicles (EVs) are fueling an explosive demand for battery production on a global scale. With demand for battery capacity estimated to grow at an annual rate of ~18% going into 2050, regions like the Nordic countries are investing heavily in large scale production capacity. | + 26.0 % |
| 2. | Wind power | Wind power is an increasingly important electricity provider across the world. Despite onshore wind maturing in some markets, offshore wind capacity enters a period of extensive advancement, and wind power's growth potential remains vast. | + 7.8 % |
| 3. | Solar power | The solar PV* industry is already fairly mature in some markets while emerging in others. The currently known pipeline of new capacity represents >250% of current capacity in operations, largely driven by Australia, China, India and the United States. | + 10.9 % |
| 4. | Electric infrastructure (Cables) | Rapidly increasing supply of renewable energy, electrification of industries such as transportation and improved access to electricity in rural regions will require significant upscaling of capacity and reliability of current electric infrastructure around the world. | + 2.0 % |

*Solar photovoltaic (PV) - sunlight directly converted to electricity by use of semiconductor PV cells. Not the same as concentrated solar power (CSP) which concentrates the sun's energy by use of mirrors panels or reflective troughs to produce heat and then drive a heat engine and electric generators. Source: Rystad Energy research and analysis; International Energy Agency (IEA)

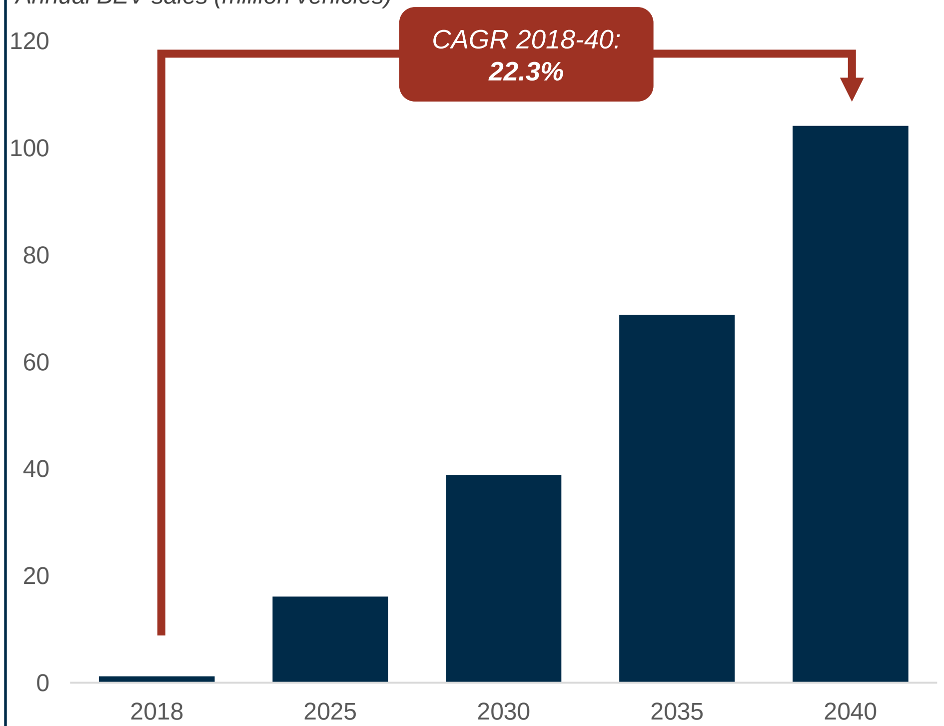
# 1. EV sales to fuel a rapid explosion in battery demand – Norway could be well positioned

## Battery demand outlook

Looking at the land transportation sector development, demand for battery capacity is estimated growth at a staggering annual rate of ~26% from 2020-40. This is largely driven by a surge in battery electric vehicles (BEVs) illustrated in the graph in the lower left corner.

In response to the growing need for battery capacity countries like Norway, with its substantial green energy supply, are in a unique position to take part in an increasingly important industry addressing the energy transition. This is already evident as the past months and years have seen multiple newly founded battery companies and proposed production facilities in the Nordic countries.

## Electric vehicle market to grow substantially*




## …and Nordic industry positions to take advantage

**Corvus Energy** – Batteries for the maritime industry

- Canadian/Norwegian company with 10 years experience of providing energy storage capacity to the maritime industry from smaller vessels all the way up to cruise ships.

**Morrow Batteries** – New battery venture

- Founded in 2020 and planning a giga-scale battery factory in Southern Norway expected to be in production by 2024.

**Freyer** – Government backed battery factory

- Planning a 32+2 GWh (battery cells for up to 1 million EVs and additional applications) giga-factory in Norway with production estimated to commence in 2023.

**Northvolt** – Swedish company looking to expand capacity

- Significant battery production pipeline planned and under construction across Europe, including a 32 GWh giga-factory planned in Sweden with production to commence from 2021.

*Based on car manufacturers' communicated ambitions for Battery Electric Vehicle production
Source: Rystad Energy research and analysis

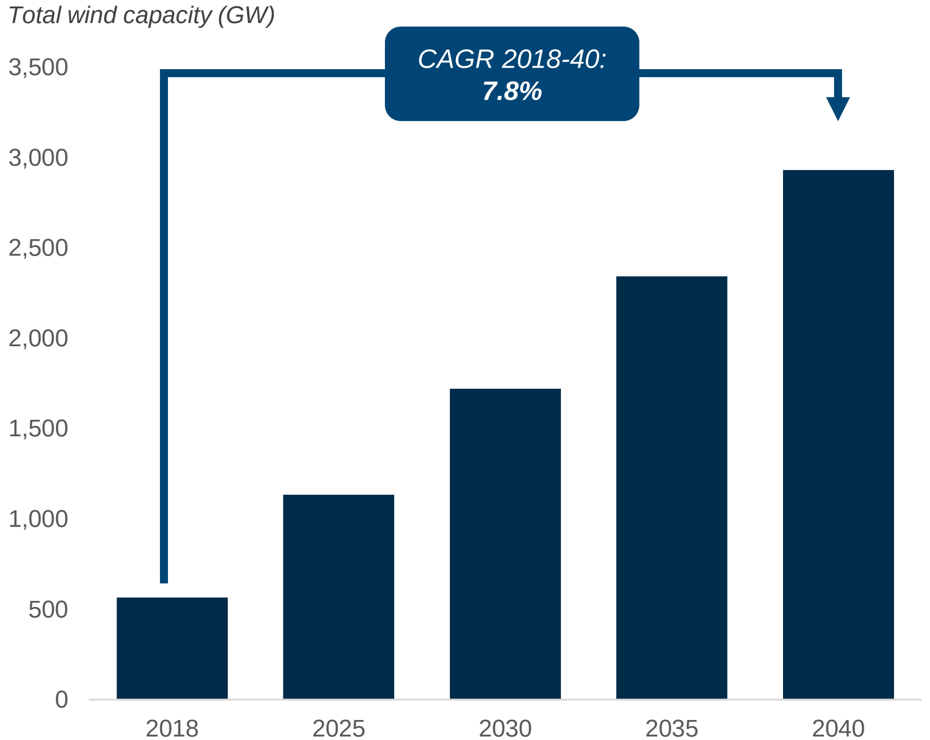
# 2. Nordic countries well positioned to take part in the rapidly expanding wind power market

## Wind power outlook

IEA's "Sustainable Development Scenario" depicts a steady growth in wind power capacity at ~8% annually towards 2040, implying more than 2,000 GW of new capacity to come online within the next 20 years.

From Denmark to Norway, the Nordic region is well situated to tap into the abundant power of wind both onshore and offshore. While parts of the Nordics have already invested significantly in the potential of wind, others are in the process of developing this industry.

## Wind power capacity to grow substantially*




## and Nordic industry positioned with offshore focus

**Hywind Tampen** – O&G offshore electrification by wind power

- Norwegian floating offshore wind project of 11 turbines at 8 MW capacity a piece to cover 35% of annual energy demand from the five oil platforms Snorre A and B and Gullfaks A, B and C.

**Sydkustens Vind** – 500 MW Swedish offshore wind project

- Norwegian and Swedish companies Magnora and Kustvind are in the development phase of a shallow water offshore wind project in the Baltic Sea.

**Vestas** – Leading Danish provider of wind turbines

- Designing, manufacturing, installing and servicing wind turbines across 81 countries.
- Has provided wind turbines accounting for 17% of globally installed capacity.

*"Sustainable Development Scenario"
Source: Rystad Energy research and analysis; IEA World Energy Outlook 2019

# 3. Focus on sustainability could imply >4,000 GW of new solar PV capacity by 2040

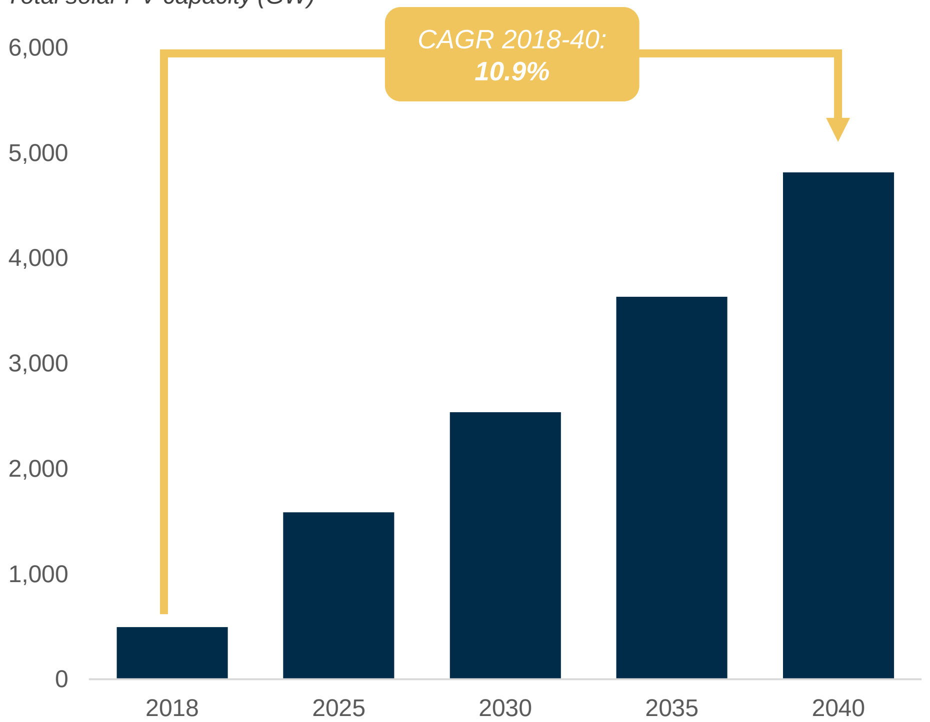
## Solar PV outlook

IEA's "Sustainable Development Scenario" depicts a steady growth in solar PV capacity at ~11% annually towards 2040, implying more than 4,000 GW of new capacity to come online within the next 20 years.

Despite the limited application of large-scale solar power generation in the Nordic countries, there are multiple examples of large investments in this industry on a global scale from this region.

## Solar PV outputs with double-digit growth*

*Total solar PV capacity (GW)*




## ...and Nordic industry is forming

**Scatec Solar** – Becoming a Norwegian giant

- Currently operating 16 solar PV plants in 10 countries with a total capacity of >1.5 GW.
- Announced acquisition of SN Power in the fall of 2020, expanding its renewables footprint and more than doubling capacity by 2021.

**REC Silicon** – Norway-based high-purity silicon supplier

- Operates two U.S. based production plants with a combined capacity of >20,000 MT of high-purity polysilicon, supplying the solar and electronics industries worldwide.

**BayWa** – German solar panels to Sweden

- Has secured ~1 square km in Sweden to construct a solar PV facility of at least 100 MW, with plans for further future expansion in the country.

*"Sustainable Development Scenario"
Source: Rystad Energy research and analysis; IEA World Energy Outlook 2019

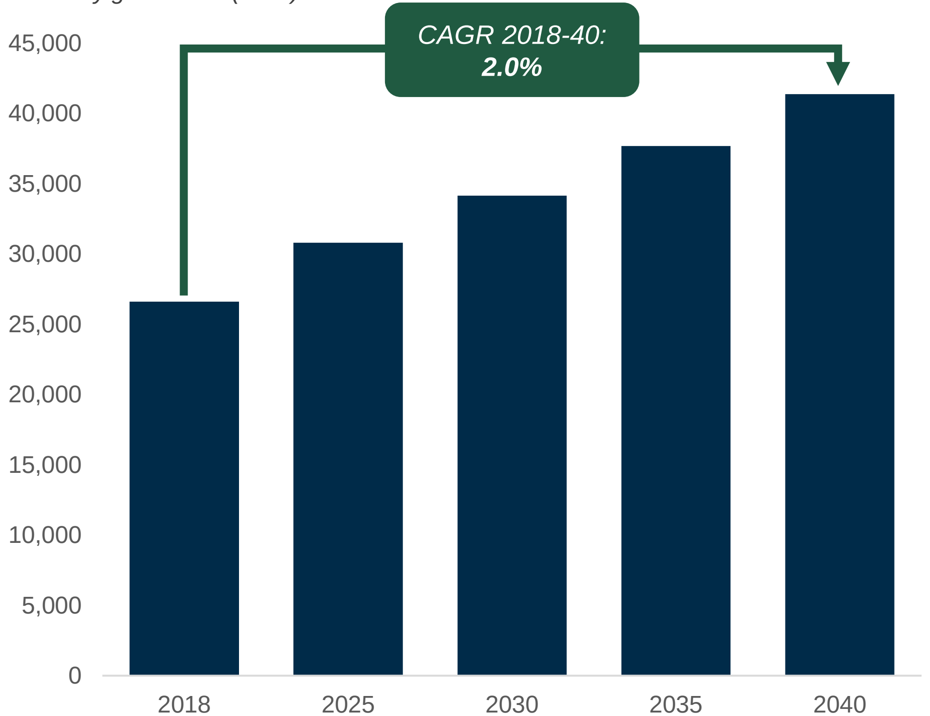
# 4. Rapidly increasing electricity generation requires significant upscaling of global grids

## Electric infrastructure outlook

Rapidly increasing supply of renewable energy, electrification of industries such as transportation and improved access to electricity in rural regions will require significant upscaling of capacity and reliability of current electric infrastructure around the world.

The IEA World Energy Outlook of 2019 estimates >55% increase in global electricity generation in its “Stated Policies Scenario” with India and Africa leading the growth race. Additionally, regions such as UK could see significant infrastructure development to account for the transition from fossil fuels (such as natural gas) to electricity.

## Electricity is the backbone of Energy Transition*




## …with a global footprint (here: anecdotes)

**United Kingdom** – From gas to electricity

- UK has an extensive gas pipeline system, providing power to households and industries
- Increased electrification of these activities could require meaningful improvements to the current grid.

**India** – Ripe for expansion and upgrades

- A rapidly expanding economy of almost 1.4 bn inhabitants and extensive efforts for village electrification require significant expansion and upgrades of the nation’s power grid.

**Africa** – Rapidly growing electricity consumer

- With nearly 600 million people without access to electricity, the expansion potential for electric infrastructure is extensive.

**Norway** – Early adopters

- With the abundance of established renewable electricity generation by Norwegian hydro power, the country is not likely to require significant upscaling of the electric infrastructure in the near-term future.

*“IEA Stated Policies Scenario”
Source: Rystad Energy research and analysis; IEA World Energy Outlook 2019

# Content

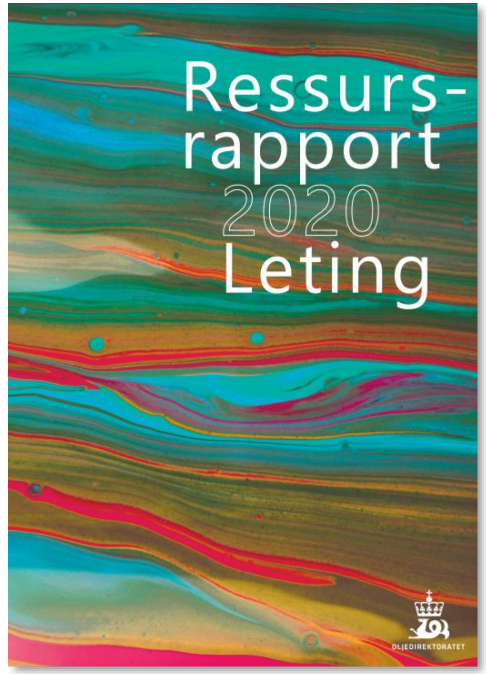
# NCS mineral exploration reveals copper, cobalt, zinc, manganese and REE potential

NORWEGIAN PETROLEUM DIRECTORATE

## Analysis reveals extensive seabed minerals


Sampling from sulphide-deposit, 3500 meters water depth in the Norwegian Sea. (Photo: The Norwegian Petroleum Directorate)

07/06/2019 The Norwegian Petroleum Directorate's chemical analyses of sulphides and manganese crusts from the Norwegian shelf reveal that the sulphides contain a high content of copper, zinc and cobalt.




### Havbunnsmineraler på norsk sokkel inneholder grunnstoffer som vil være viktige i energiomstillingen og det digitale skiftet

**Betydelige ressurser på norsk sokkel**

Sulfidene inneholder hovedsakelig bly, sink, barium, kobber, kobolt, gull og sølv. De er knyttet til varme kilder på vulkanske spredningsrygger, også kalt «Black Smokers», svarte skorsteiner. I tillegg til de aktive skorsteinene finnes metallene i kollapsede skorsteiner, som grushauger på havbunnen. Størstedelen av sulfidforekomstene antas å ligge i disse grushaugene.

Manganskorper inneholder mest mangan og jern og mindre mengder av metaller som kobolt, nikkel, titan og andre mer sjeldne metaller. Manganskorpene vokser som laminerte belegg på fast fjell som stikker opp av havbunnen.

REE = Rare Earth Elements

Source: Rystad Energy research and analysis; Norwegian Petroleum Directorate (NPD)

# Introduction to key metals and their green technology applications

| KEY METALS | | | METALS USAGE IN GREEN TECHNOLOGIES | | | | COMMENT |
|---|---|---|---|---|---|---|---|
| **Importance** | **Metals and elements** | **Earth crust abundance** *[ppm]** | **Wind power** | **Solar power** | **Batteries** | **Electric infrastructure** | **Metals and elements properties and their applications in green technologies** |
| **Core** | **Copper** (Cu) | **55** | ✓ | ✓ | ✓ | ✓ | Copper, with its unmatched ability to conduct heat and electric currents, is one of the most widely used and needed metals in a low-carbon future. E.g. used in cabling to enable electricity transmission from wind and solar farms, to generally lead electricity in power grids and for batteries. |
| | **Cobalt** (Co) | **25** | | | ✓ | | Hard and highly temperature resistant cobalt superalloys are used in extreme environments such as jet engines or space vehicles. On the note of green technologies, cobalt plays a vital role as cathode material in Li-ion batteries. |
| | **Zinc** (Zn) | **70** | ✓ | ✓ | ✓ | | For clean energy technologies, zinc is predominantly used for protecting wind turbines from corrosion. Smaller amounts of the metal are also demanded for solar panels (for solar energy conversion) and batteries (e.g. zinc-air). |
| **Secondary** | **Iron** (Fe) | **56,300** | ✓ | | ✓ | | Iron is used in both wind farm foundations (as steel) and e.g. large amounts needed in wind turbine generators (in generator core, mainframe and rotor hubs). Iron-based flow batteries are further a rapidly emerging alternative to Li-ion. |
| | **Manganese** (Mn) | **950** | ✓ | | ✓ | | In terms of clean energy technologies, manganese steel is modestly utilized in wind turbines as structural material while more commonly used as cathode material in Li-ion batteries in combination with nickel and cobalt. |
| | **Silver** (Ag) | **0.075** | | ✓ | | | Silver is the most reflective metal and has the highest electrical and thermal conductivity. Consequently used in both mirrors, tele- and microscopes, and solar cells (PV)**. Electrons are generated when sunlight hits the cell, and silver collects the electrons and form electric currents. |
| | **Gold** (Au) | **0.004** | | | | | Precious metal-gold today not vital for green technologies. |
| | **Rare Earth Elements (REE)** | **9** | ✓ | | ✓ | | REEs' electron structure gives them unusual magnetic and optical properties. E.g. neodymium and dysprosium are widely used in wind turbines (for generators with permanent magnets) due to their magnetic properties. |

*Parts per million = ppm **Silver is a primary ingredient in photovoltaic (PV) solar cells, the most common type of solar panels
Source: Rystad Energy research and analysis; World Bank

# Introduction to key metals and their global market

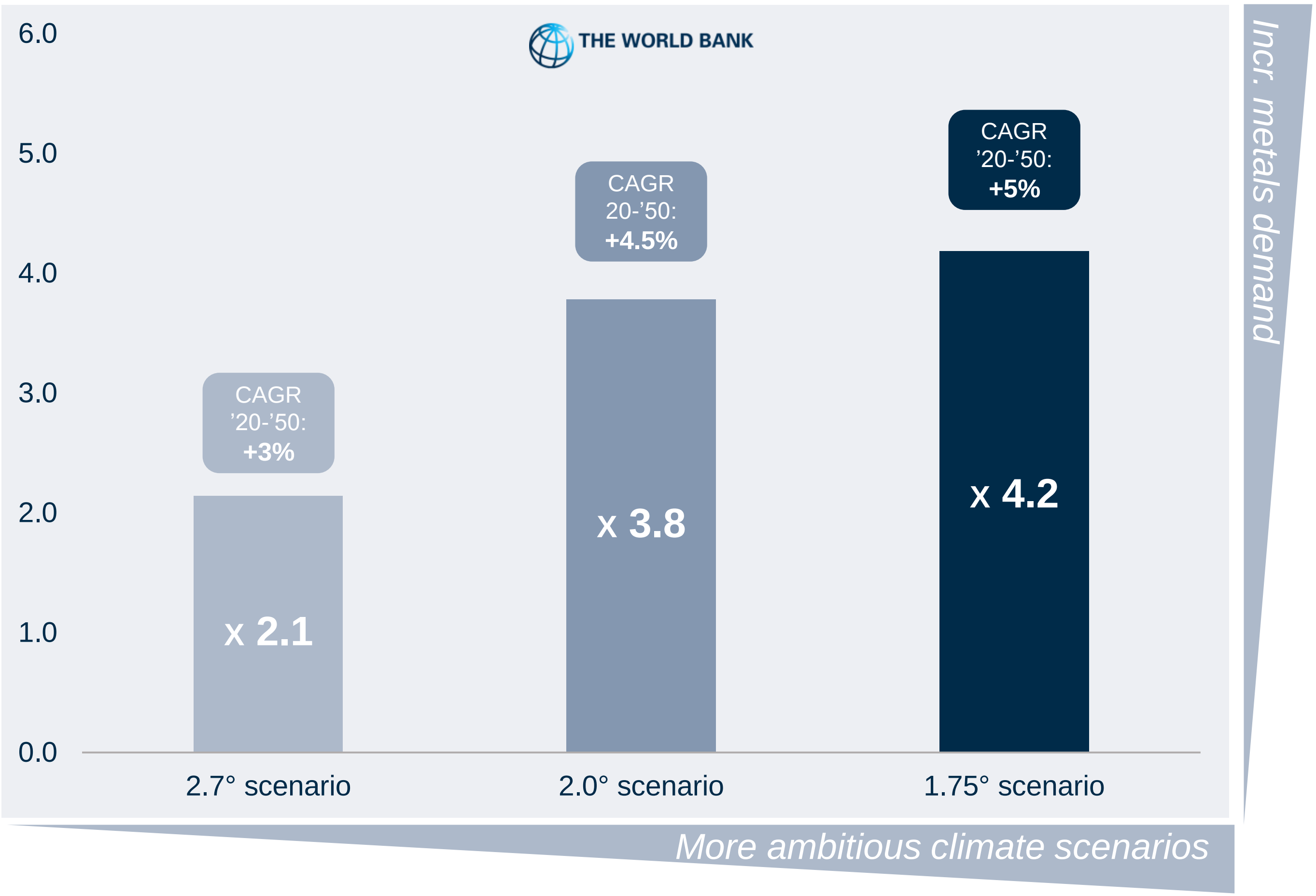
| KEY METALS | | | GLOBAL MARKET DETAILS | | | COMMENT |
|---|---|---|---|---|---|---|
| Importance | Metals and elements | Earth crust abundance *[ppm]* 1) | 2018 global production (mine) *[Thousand mt/year]* (X) | 2018 unit price (refined) *[kUSD/mt]* (=) | Indicative market size *[Billion USD]* | Metals and elements facts and details |
| **Core** | **Copper** (Cu) | 55 | 20,500 | 6.53 | 134 | Copper is a non-ferrous (contains no iron) base metal that is an essential element for all known living organisms, arising in various compounds. It is characterized by its reddish brown color. |
| | **Cobalt** (Co) | 25 | 162 | 38 | 6 | Cobalt pigments have for thousands of years been used to create blue colored glass. It does not exist in its pure form in nature and is mostly a by-product from copper and nickel mining. Today mainly used in Li-ion batteries and to make powerful magnets and superalloys (e.g. for jet engines). |
| | **Zinc** (Zn) | 70 | 12,500 | 2.92 | 37 | Zinc is mainly used as a galvanic anode in galvanizing iron and steel to prevent corrosion. It is the second most common metal (after iron) naturally found in a human body. |
| **Secondary** | **Iron** (Fe) | 56,300 | 2,920,000 2) | 0.07 2) | 204 | Iron is the fourth most common element in Earth's crust by weight, with its concentration of 56,300 ppm. The metal is mostly used to produce steel (an iron and carbon alloy). |
| | **Manganese** (Mn) | 950 | 53,000 3) | 0.007 3) | 0.4 | Manganese is a very hard and brittle metal, one of the most common elements in the earth's crust, but never found on its own. Mainly used in alloys for steel production. |
| | **Silver** (Ag) | 0.075 | 28 | 505 5) | 14 | Silver is among the low reactive metals and is easy to form. Application areas range from jewelry, currency, silverware, dentistry, photography and electronics. |
| | **Gold** (Au) | 0.004 | 3.4 | 40,820 5) | 137 | Gold is the only yellow metal. It is very ductile and can be rolled to foils of 0.0001 mm and stretched to threads of 3000 m per gram. Used for e.g. jewelry, gold bars, dentistry. |
| | **Rare Earth Elements (REE)** | 9 | 190 4) | 18 | 3 | REE is a common term for 17 chemically similar metallic elements. The term *rare earth* is a misnomer arising from the rarity of the minerals from which they were originally isolated (in reality a ~9 ppm abundance). China dominated across both mining, processing and magnet production. |

1) Parts per million; 2) Iron ore production and iron ore cfr spot price per dry metric ton; 3) Manganese ore production and cif spot price (metallurgical-grade 44% Mn content); 4) Rare earth minerals and oxides; 5) Standard silver and gold prices in USD per Troy Ounces (3.1E-5 mt), converted for comparison. Source: Rystad Energy research and analysis; World Bank; British Geological Survey, United States Geological Survey, World Mining Data

# Future metals demand increases with stricter climate change targets

**Indicative 2020 to 2050 metals demand growth by climate change scenarios***

*2050 metals demand indexed to 2020*




2050 metals demand** (indexed to 2020) is displayed to the left by three commonly communicated climate change targets. A 2.7°, 2.0° and 1.75° average global temperature increase by 2100 represent IEA's *Reference Technology Scenario****, *2-degree* and *Beyond 2-degree* scenarios.

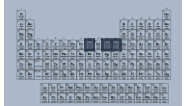
Growth in global metals demand from 2020 to 2050 range from a multiplication factor of 2.1 (the 2.7° scenario) to 4.2 (the 1.75° scenario), while the annual growth rate over the next 30 years (CAGR) vary from +3% to +5%. In comparison, global copper production increased with a factor of 2.2 from 1990 to 2020, similar to the 2.7° scenario's growth to 2050.

A low-carbon future will regardless of realized climate change target (outlined by the Paris Agreement) lead to an extensive growth in metals demand as green technologies are more material intensive than fossil-fueled electricity generation. The stricter the climate change target, the higher the implementation of clean energy technologies which require more metals. A sufficient minerals supply will be pivotal for the energy transition and hence reaching any of the outlined climate goals.

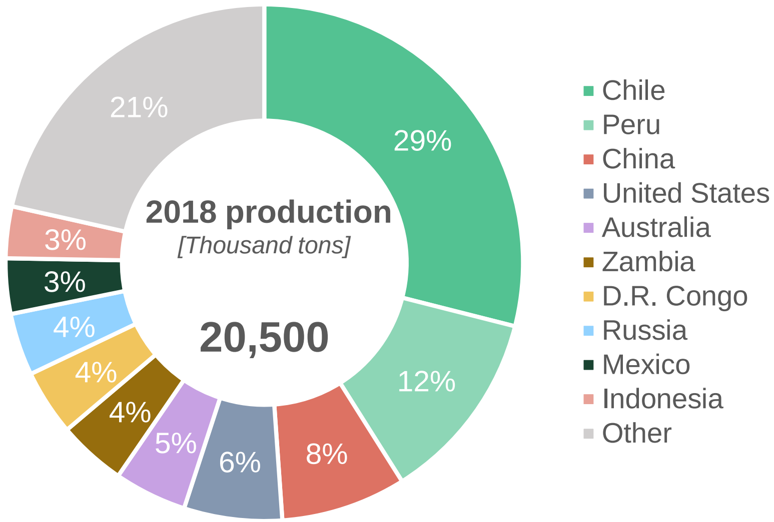
*Climate change scenarios in line with IEA Energy Technology Perspectives Scenarios. See appendix for details **Metals demand based on 17 of the core clean energy technology metals and elements, plus steel. Figures from The World Bank ***Assumes all countries implement their determined contributions outlined by the Paris Agreement, resulting in an avg. global temperature increase of 2.7° by 2100.
Source: Rystad Energy research and analysis; International Energy Agency (IEA); World Bank

# Future copper production challenged by declining ore quality and high climate stress

| KEY METALS | |
|---|---|
| **Importance** | **Metals and elements** |
| **Core** | **Copper** (Cu) |
| | **Cobalt** (Co) |
| | **Zinc** (Zn) |
| **Secondary** | **Iron** (Fe) |
| | **Manganese** (Mn) |
| | **Silver** (Ag) |
| | **Gold** (Au) |
| | **Rare Earth Elements (REE)** |



**2018 global copper production split by main producers**





BBC (2020/09/17)

**Rio Tinto: Mining giant accused of poisoning rivers in Papua New Guinea**


*28.5% of demand currently supplied by recycled copper*

Out of global 2018 copper production of 20.5 million tons, 80% is split on top ten producers. Chile and Peru, defined by political instability, together stood for 40% of 2018 production, while the next 20% were coming from China, the USA and Australia.

Future supply from producing mines is uncertain as copper ore quality is steadily declining. Some of the world's oldest copper mines have been in operation since the end of the 19$^{th}$ century and are nearing their peak as reserves are exhausted. Some examples of the oldest still producing mines are found in Chile - the Chuquicamata mine (est. 1879), and in the USA – the Bingham Canyon (est. 1906).

Another challenge with the current copper value chain is its negative environmental impact on local surroundings. Copper mining and processing requires vast amounts of water which threatens drinking water supply for local populations, and additionally, the use of chemicals for e.g. concentration processes pollute downstream water bodies.

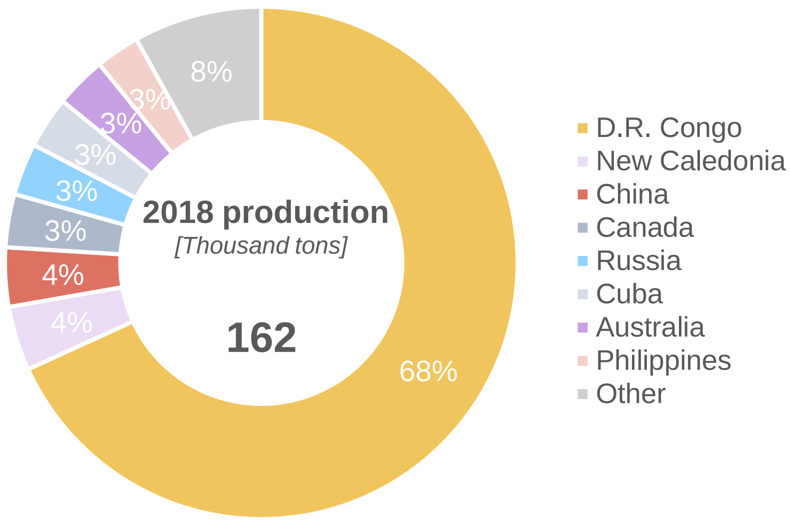
According to UNEP the current copper end-of-life recycling rate** is 50% on average, while 28.5% is the percentage of end-use demand supplied by recycled copper.

*Fiscal year 2020 **End-of-life recycling rate: How much of a metal is recycled at the end of its use in a product
Source: Rystad Energy research and analysis; British Geological Survey (BGS); World Mining Data (Austrian Federal Ministry of Sustainability and Tourism); UN Environment Program (UNEP)

# Current cobalt supply highly reliant on controversial Congolese production

| KEY METALS | |
|---|---|
| **Importance** | **Metals and elements** |
| **Core** | Copper (Cu) |
| | **Cobalt** (Co) |
| | Zinc (Zn) |
| Secondary | Iron (Fe) |
| | Manganese (Mn) |
| | Silver (Ag) |
| | Gold (Au) |
| | Rare Earth Elements (REE) |

**2018 global cobalt production split by main producers**




ALJAZEERA *(2019/12/17)*

**US tech giants sued over DRC cobalt mine child labour deaths**

*Legal complaint lists Apple, Dell, Microsoft, Tesla and Google's parent company Alphabet as defendants.*

**Forbes**
*(2020/10/07)*
How Tesla Should Combat Child Labor In The Democratic Republic Of The Congo

Cobalt is generally a by-product from copper and nickel mining (~90% of produced volumes), and cobalt production consequently correlates with the latter two. The Democratic Republic of Congo is the world's main producer, and stood for as much as 68% of 2018 cobalt production. The second and third largest producers are New Caledonia and China with scarcely 4% in comparison.

There are several controversial sides to the near monopolistic cobalt supply, and according to the IEA there are only a few new projects outside Congo under development. D.R. Congo firstly has a long history of both political unrest with violent confrontations between ethic groups and militia, and refugee and humanitarian crises characterized by hunger and disease outbreaks (e.g. ebola, malaria and measles). Adding poor and unsafe working conditions and child labor to the list, questions whether future cobalt production and hence the EV revolution (its main demand) can be sustainable without any additional supply sources.

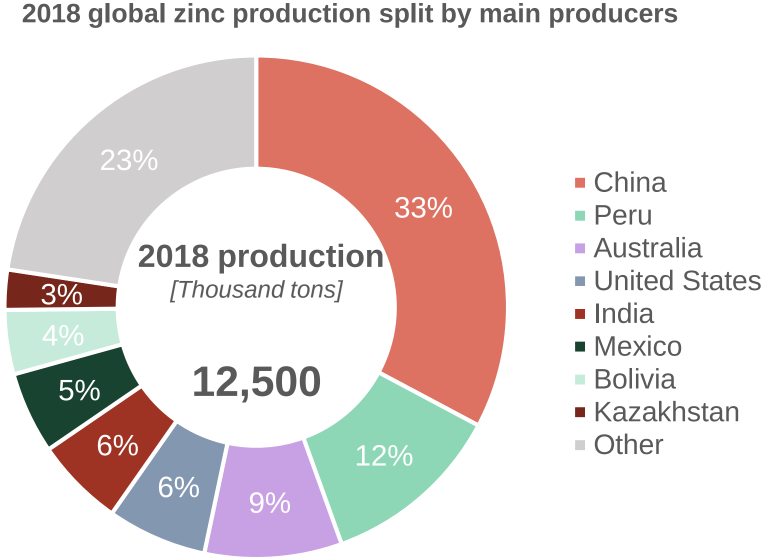
Cobalt has a current 68% end-of-life recycling rate* and a 32% recycled content rate**, hence only about one third of cobalt demand is supplied by recycled metal (e.g. driven by purity requirements in Li-ion batteries).

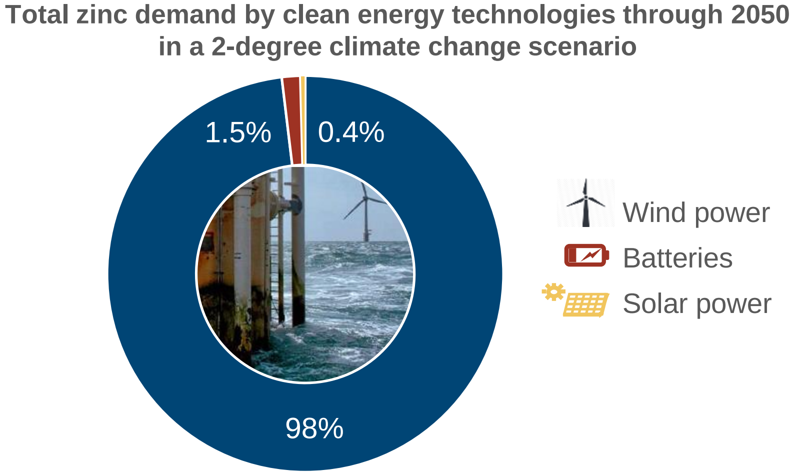
*End-of-life recycling rate: How much of a metal is recycled at the end of its use in a product **Recycled content rate: Percentage of demand for a metal supplied by recycled material
Source: Rystad Energy research and analysis; British Geological Survey (BGS); World Mining Data (Austrian Federal Ministry of Sustainability and Tourism); International Energy Agency (IEA); UN Environment Program (UNEP)

# Zinc demand in a low-carbon environment dependent on wind energy expansion

**KEY METALS**

| Importance | Metals and elements |
|---|---|
| Core | Copper (Cu) |
| | Cobalt (Co) |
| | **Zinc** (Zn) |
| Secondary | Iron (Fe) |
| | Manganese (Mn) |
| | Silver (Ag) |
| | Gold (Au) |
| | Rare Earth Elements (REE) |




Around 75% of zinc production was supplied by top eight largest producing countries in 2018. China with as much as one third of produced volumes, followed by Peru (12%) and Australia (9%) make top three.

In a low-carbon future, zinc will predominantly play a role for wind-generated electricity production. The metal's corrosion preventive characteristics make it vital as a coating layer on wind turbines. The lower left pie chart shows The World Bank's indicative zinc demand forecast by green technologies through 2050 in a 2-degree climate change scenario. Unlike other key metals needed for wind turbine production (e.g. iron, copper, aluminum, nickel and chromium), zinc is the only element that is not used in any of the other low-carbon technologies (<2% demand from batteries and solar). As such, future zinc demand in an energy transition perspective is reliant on installed wind turbine capacity to evolve in the foreseen strongly upwards direction (mainly growing in Asia, North America and Europe).

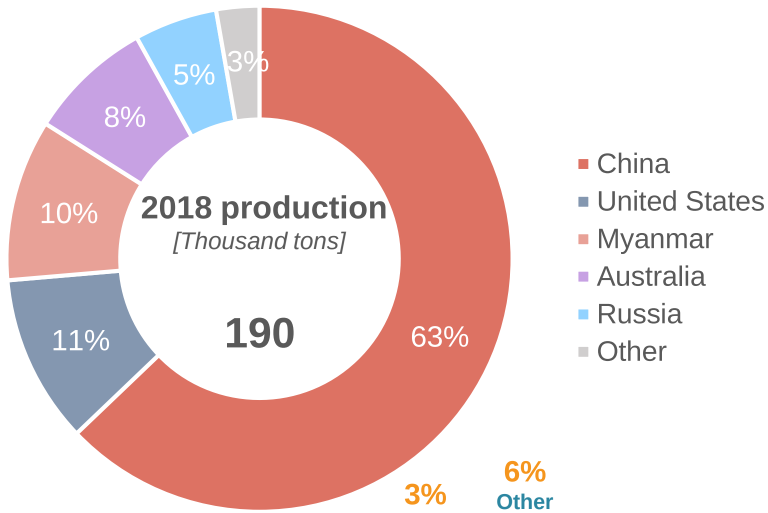
Recycling of zinc make up a relatively small contribution to supply, about half of zinc is recycled, whereas the recycled metal supply contribution to demand of zinc is in the 22% figures.

Source: Rystad Energy research and analysis; British Geological Survey (BGS); World Mining Data (Austrian Federal Ministry of Sustainability and Tourism); World Bank

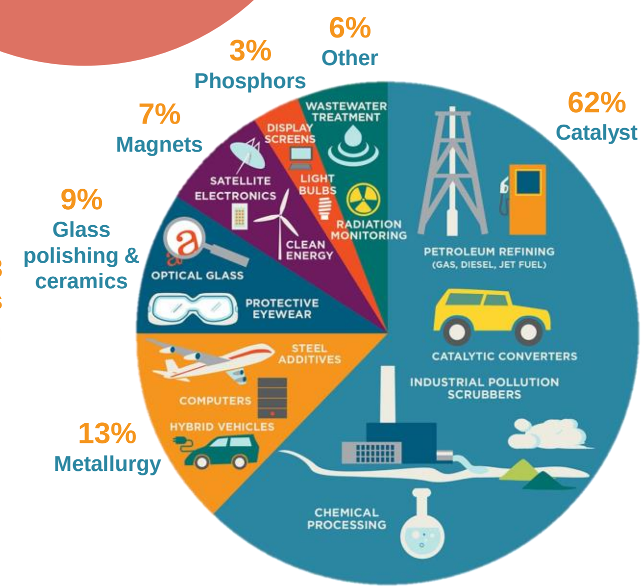
# Low fragmentation in unique rare earth elements supply – China is leader of the pack

| KEY METALS | |
|---|---|
| **Importance** | **Metals and elements** |
| Core | Copper (Cu) |
| | Cobalt (Co) |
| | Zinc (Zn) |
| **Secondary** | Iron (Fe) |
| | Manganese (Mn) |
| | Silver (Ag) |
| | Gold (Au) |
|  | **Rare Earth Elements (REE)** |

**2018 global REE production split by main producers**




**United States 2013 rare earth elements usage by category:**




The rare earth elements, also called the rare earth minerals, consist of the 15 lanthanides in addition to scandium and yttrium, all sharing a similar chemical structure especially known for their magnetic properties. Due to their similarity, the REEs can often substitute one another, while their unique properties seldom can be replaced by other metals outside the REE group. The REEs are amongst other important contributors in both batteries and wind turbine generators.

Similarly to cobalt's dependence on D.R. Congo, China is the sovereign rare earth elements (REEs) producer, where most comes from the Bayan Obo mine as a by-product from iron mining. In 2018 China produced over 60% of the annual REE output, approximately 120 thousand tons. The next four countries almost made up the reminder of 2018 REE production, namely the US, Myanmar, Australia and Russia, totaling 34%.

In addition to China's large share of produced volumes, they hold as much as 85% of the world's REE processing capacity according to Adams Intelligence. REEs could be a bottleneck for clean energy disruption due to their property uniqueness and limitations related to a concentrated supply, which currently is Chinese dominated with only a few others.

Source: Rystad Energy research and analysis; British Geological Survey (BGS); World Mining Data (Austrian Federal Ministry of Sustainability and Tourism); United States Geological Survey (USGS)

# Controversial and centralized minerals extraction stresses environment and resources

## Challenges with the existing mineral mining industry

### ENVIRONMENTAL STRESS

Existing onshore mineral mining poses stress on its surroundings both in terms of resource need and environmental destruction. Onshore mining and mineral processing require vast amounts of both water and land, e.g. limiting the local populations' access to drinking water. Remote locations, currently not connected to existing electricity grids, further demand electricity production from fossil-fueled generators which increases carbon footprint. Additionally, the use of chemicals for processing pollutes downstream water bodies.

### DECLINING ORE QUALITIES

The oldest onshore mines have been in operations since the late 19th century and are under depletion. Declining ore qualities, meaning the ore's metal concentrations, demand new mineral supply sources.

### GEOPOLITICAL RISKS

Today's leading suppliers of core metals used in clean energy technologies are generally African, American or Asian countries. For example are the top producers of copper from the South American continent, while cobalt is mainly supplied by D.R. Congo and rare earth elements by China. Whereas metals supply is rather centralized around these regions, metals are consumed worldwide. Future supply of metals to European countries might be challenged by new emerging geopolitical strategies involving self-sufficiency and political independence. This trend has been observed over recent years in e.g. the EU, US and China (the "Made in China 2025"-strategy launched in 2015*), emerging in line with trade wars and rising tension between developed nations. With European copper ore imports of ~5 mmtons in 2016 compared to a mine production of ~1 mmtons within the union the same year, we could suffice from more local content.

### CONTROVERSIAL SUPPLY

Global metals demand is currently supplied by rather few nations, ~80% of global copper production is split on top 10 producers, while ~75% of zinc is produced by top 8. Scarce competition has somewhat limited the pressure on requirements to operational practices and working conditions, exemplified by the Democratic Republic of Congo's continued use of child labor for onshore mining of cobalt. The latter being one of the main metals in modern Li-ion batteries is a controversy. Going to extremes - child labor is in this way fueling the Western world's electric vehicle revolution, and while the metal demanders' local pollution is reduced, the producers' resources and environment are under stress and destruction.

*The «Made in China 2025» industrial policy was launched by the Chinese government in 2015, a ten year plan aiming at a shift from being a low-end manufacturer to becoming dominant in global high-tech manufacturing. Source: Rystad Energy research and analysis; Minerals4EU – The Minerals Intelligence Network for Europe (part-financed by the European Union)

# Content

# Increased metal demand needs a combo of onshore mining, recycling and marine minerals

**ONSHORE MINING**

**Increased exctraction rates at onshore mines are likely to further increase exploitation of populations and impact on the environment in challanged countires**

**RECYCLING**

**Recycling will be key in order to meet increased demand for metals, but will not in itself be able to cover expected growth**

**MARINE MINERALS**

**New sources of metals supply will be increasingly needed in order to meet future demand growth and limit both environmental and social consequences globally**

*Marine minerals represent a metal supply source with potential low social and environmental impact*

Source: Rystad Energy research and analysis

# Even very ambitious recycling efforts cannot solely supply the growing metals demand

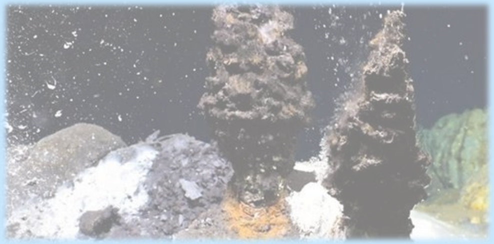
## ONSHORE MINING

**Increased exctraction rates at onshore mines are likely to further increase exploitation of populations and impact on the environment in challanged countires**

## RECYCLING

**Recycling will be key in order to meet increased demand for metals, but will not in itself be able to cover expected growth**

## MARINE MINERALS

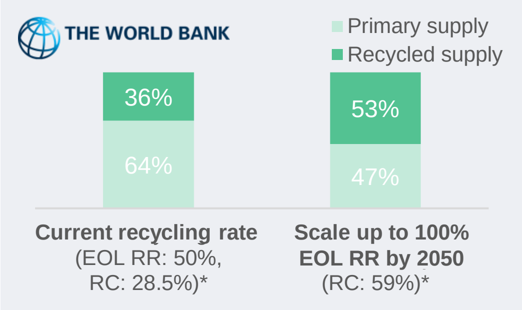


**New sources of metals supply will be increasingly needed in order to meet future demand growth and limit both environmental and social consequences globally**

***Metal recycling can offset parts of future demand growth***

There are two commonly reported rates for recycling of metals*, the end-of-life recycling rate (EOL RR) – how much of a metal is recycled, and the recycled content (RC) rate – how much of a specific metal's demand is supplied by recycled material. For copper, these figures are currently 50% and 28.5% respectively. The EOL and the RC rates are not equal, the latter is lower than the former, mainly driven by low availability of scrap compared to overall metals demand. In addition, there are often losses associated with recycling processes, and recycled metal is often of poorer quality than directly mined (e.g. high purity requirements for cobalt used in Li-ion batteries limit content of recycled metal in manufactured batteries).

**Impact of recycling on cumulative copper demand from energy technologies through 2050 in a 2-degree climate change scenario**




Recycling efforts' impact on metals demand from green technologies is illustrated to the left by the means of copper (through 2050 in a 2-degree scenario). With copper recycling rates remaining the same, the result would be a 64%-36% split between primary (mined copper) and recycled supply through 2050 according to the World Bank, where some of the metal is assumed to be recycled multiple rounds. Foreseeing ambitious recycling efforts with EOL RR reaching 100% by 2050 (all copper scrap is captured, recycled and reused), supply through 2050 would near a 50-50 split between primary and recycled, still strictly reliant on mined copper. Nearing 100% copper RC rate would require significant demand reductions.

*EOL RR = End-Of-Life Recycling Rate: How much of a metal is recycled at the end of its use in a product. RC = Recycled Content, percentage of end-use demand for a metal supplied by recycled material
Source: Rystad Energy research and analysis; UN Environment Program (UNEP); World Bank


RYSTAD ENERGY

# Massive sulfides are the marine mineral type with likely highest commercial potential

## ONSHORE MINING

Increased exctraction rates at onshore mines are likely to further increase exploitation of populations and impact on the environment in challanged countires

## RECYCLING

Recycling will be key in order to meet increased demand for metals, but will not in itself be able to cover expected growth

## MARINE MINERALS

New sources of metals supply will be increasingly needed in order to meet future demand growth and limit both environmental and social consequences globally

***Three main types of marine minerals,***
*the NCS holds massive sulfides and crusts*

### SULFIDES

Massive sulfides originate at hot vents in the ocean where sulfide-enriched water flows out of the seabed. They occur around the world at plate boundaries, typically at 2000-3000 meters depths. The first deposits were discovered in the Pacific in 1979. They are now known to occur worldwide.

***Metals: Cu, Co, Zn, Fe, Au, Ag, Pb***

### NODULES

Manganese nodules (polymetallic) are rock concretations on the seabed formed of concentric layers of iron and manganese hydroxides around a core.

Typically located in water depths of 4000-6000 meters.

**Metals: Fe, Mn, Ni, Co, Cu**

### CRUSTS

Cobalt crusts (polymetallic) are rock-hard, metallic layers that form on the flanks of submarine volcanoes, called seamounts. Like manganese nodules, these crusts form over millions of years as metal compounds in the water are precipitated. On average located in water depths of 800-2500 meters.

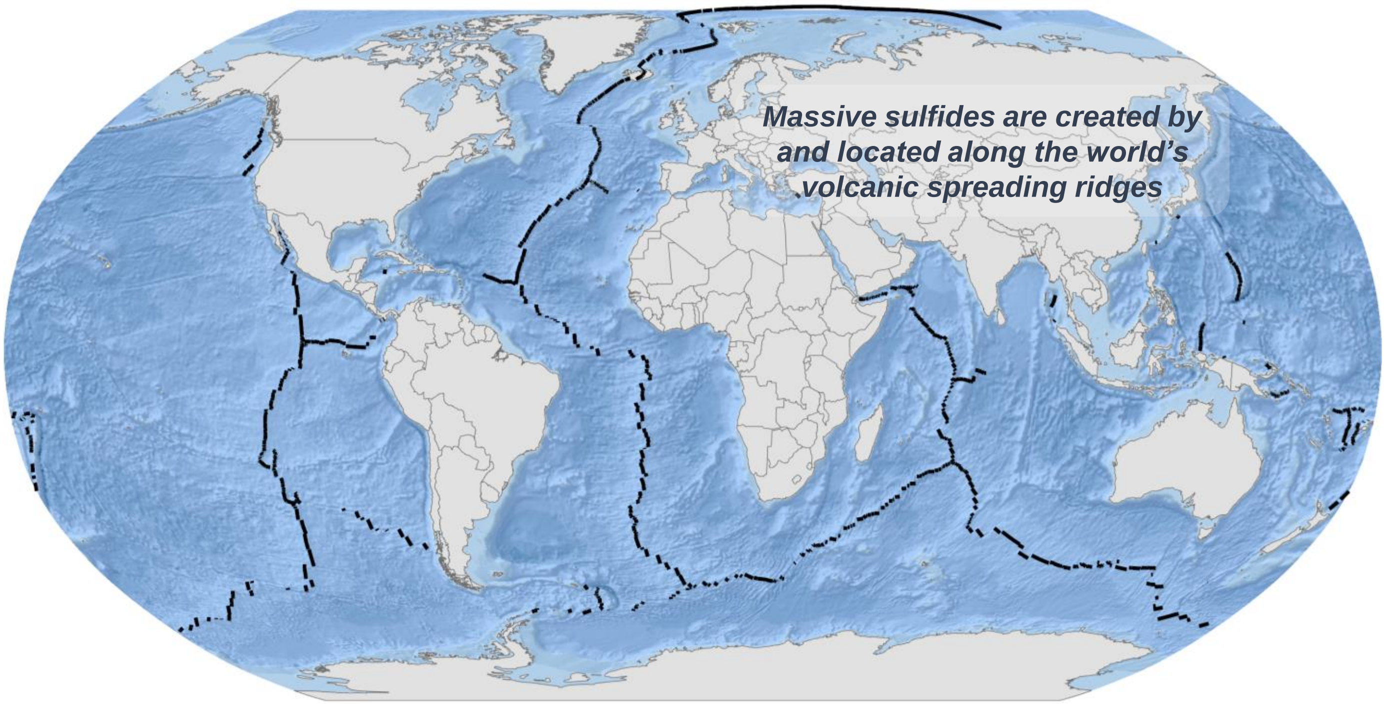
***Metals: Mn, Fe, Co, Ni, Ti, Te, REE***

Source: Rystad Energy research and analysis; United States Geological Survey (USGS); World Ocean Review

# 64% of global active spreading ridges located in international waters – Norway with 2%

**Global active spreading ridge formations**

— Spreading ridge




**Global spreading ridge by 2020 ownership**
%


The world's active (volcanic) spreading ridges host the concentrations of massive sulfides. The total length of these global ridges is ~67,000 kilometers, carved out on the map to the left.

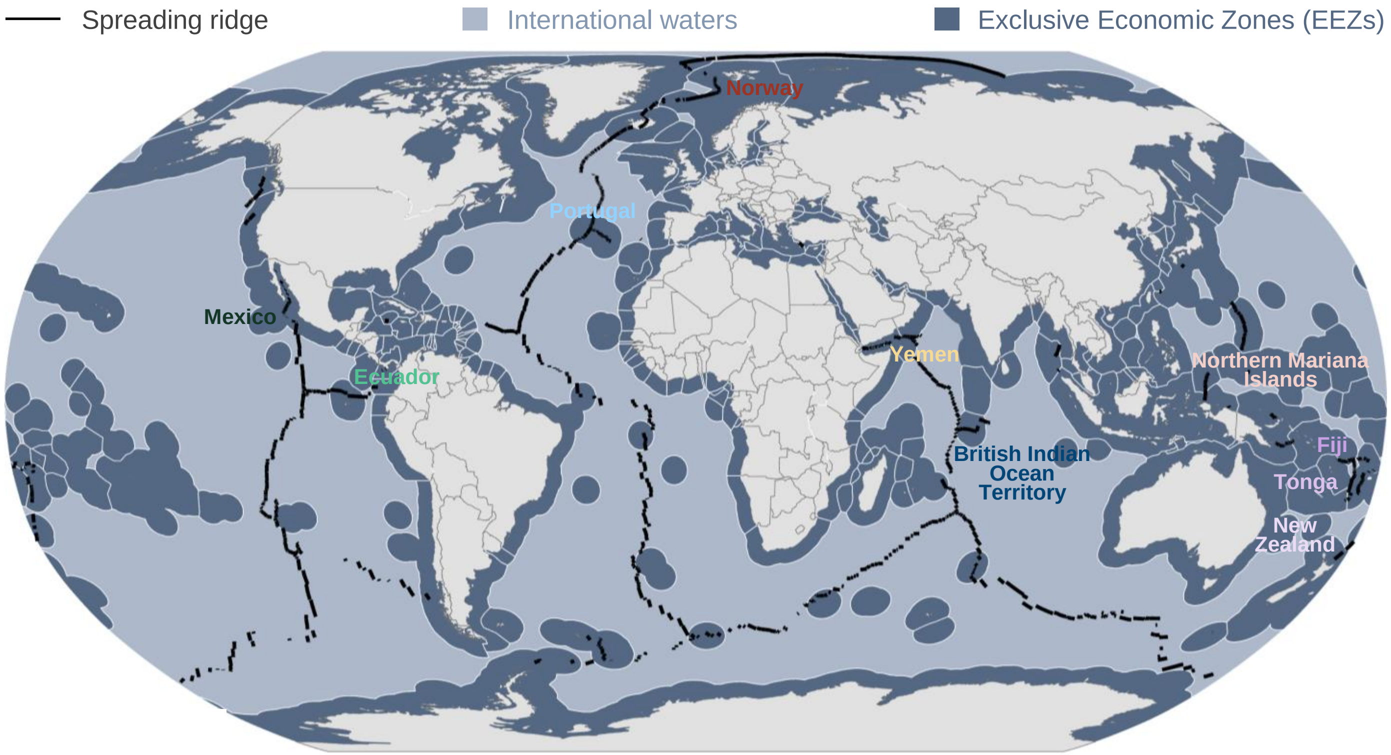
Most parts (64%) of the global spreading ridges are located in international waters, meaning waters beyond the territorial sea of any state. 36% of the global ridges are within exclusive economic zones, so called EEZs, defined by the United Nations Convention on the Law of the Sea (UNCLOS) from 1982. By definition, the costal state has sovereign rights for the purpose of both exploring, conserving and managing the marine resources within its EEZ, including energy production from water, currents and winds.

Norway is well positioned with regards to potential marine minerals extraction from massive sulfides as 2% of the world's active spreading ridges are located within our exclusive economic zone.

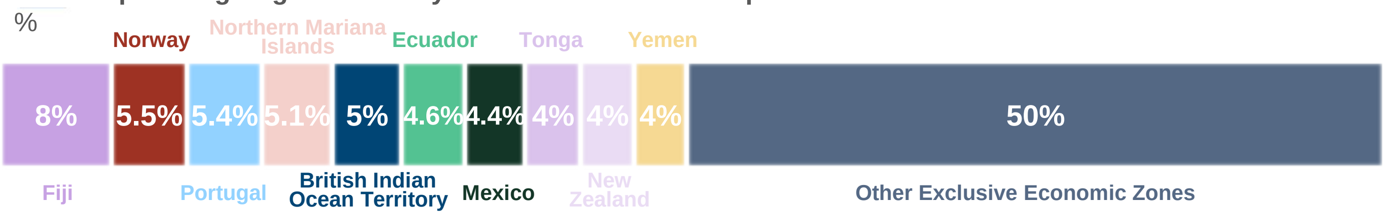
Source: Rystad Energy research and analysis; United Nations

# Only Fiji beats Norway on economic rights to spreading ridges – large export potential

## Global active spreading ridge formations by ownership




**Global spreading ridge in EEZs by 2020 national ownership**




The map to the left indicates global active spreading ridges by national and international ownership, while the lower bar displays ownership of the ridges in exclusive economic zones by top ten countries and remaining.

Norway holds as much as 5.5% of the world's active spreading ridges, with only Fiji having resource rights to more (8%). However, only Mexico and the UK (represented by the British Indian Ocean Territory) compare to Norway in terms of having a well-established oil and gas industry. The latter is a strong Norwegian competitive advantage as we hold eminent oil and gas competence and technology (from exploration to operations) which overlap well with potential marine minerals extraction.

Norway is further one of few countries with a marine mineral legislation already in place (est. in 2019), and our resource and impact studies being led by authorities shows signs of political willingness and stability. With few comparable players among top ten, a first-mover Norwegian marine minerals industry (including developed technology) have great export potential.

Source: Rystad Energy research and analysis

# Key preparations for new Norwegian offshore industry

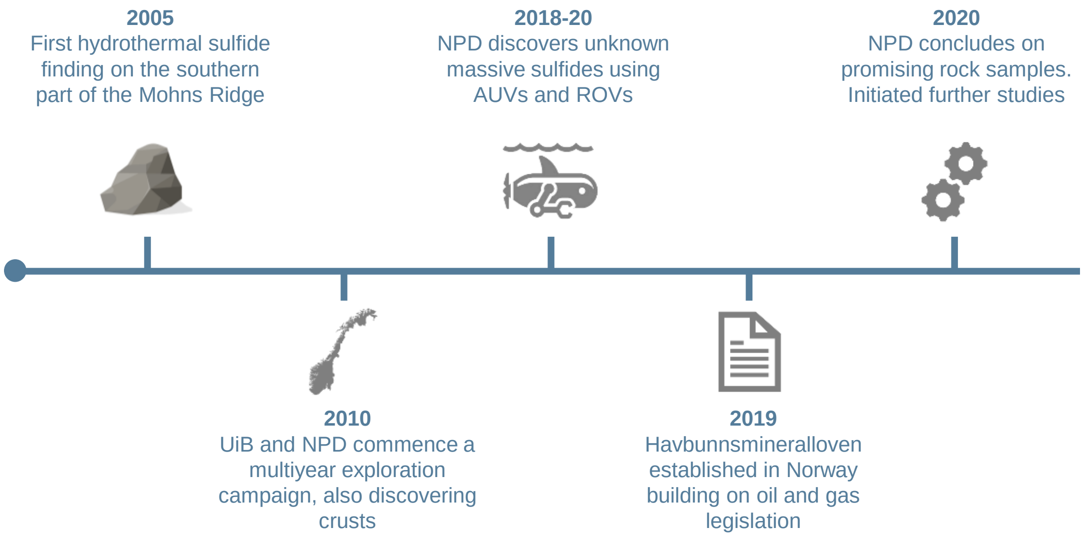
## The history of Norwegian marine mineral exploration and legislation

Since the late 1990s, UiB and later NPD, have explored mineral compositions on the sea-bed across the Norwegian part of the Mid-Atlantic ridge. Their exploration has discovered previously unknown massive sulfides and crusts rich on copper, zinc, cobalt, iron, manganese, rare earth elements (REE) and other important minerals.

Utilizing a combination of autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs) they have explored areas with a combination of geochemical, geophysical and rock sampling methods at depths of up to 3,000 meters.

On 22 March 2019, Havbunnsmineralloven, a law for mineral activities on the Norwegian Continental Shelf (NCS), was passed, building on the experience from the oil and gas industry. The law facilitates further exploration and production of marine minerals on the NCS, providing the foundation for a new potential industry. In 2020, NPD commenced further assessments related to this potential industry.

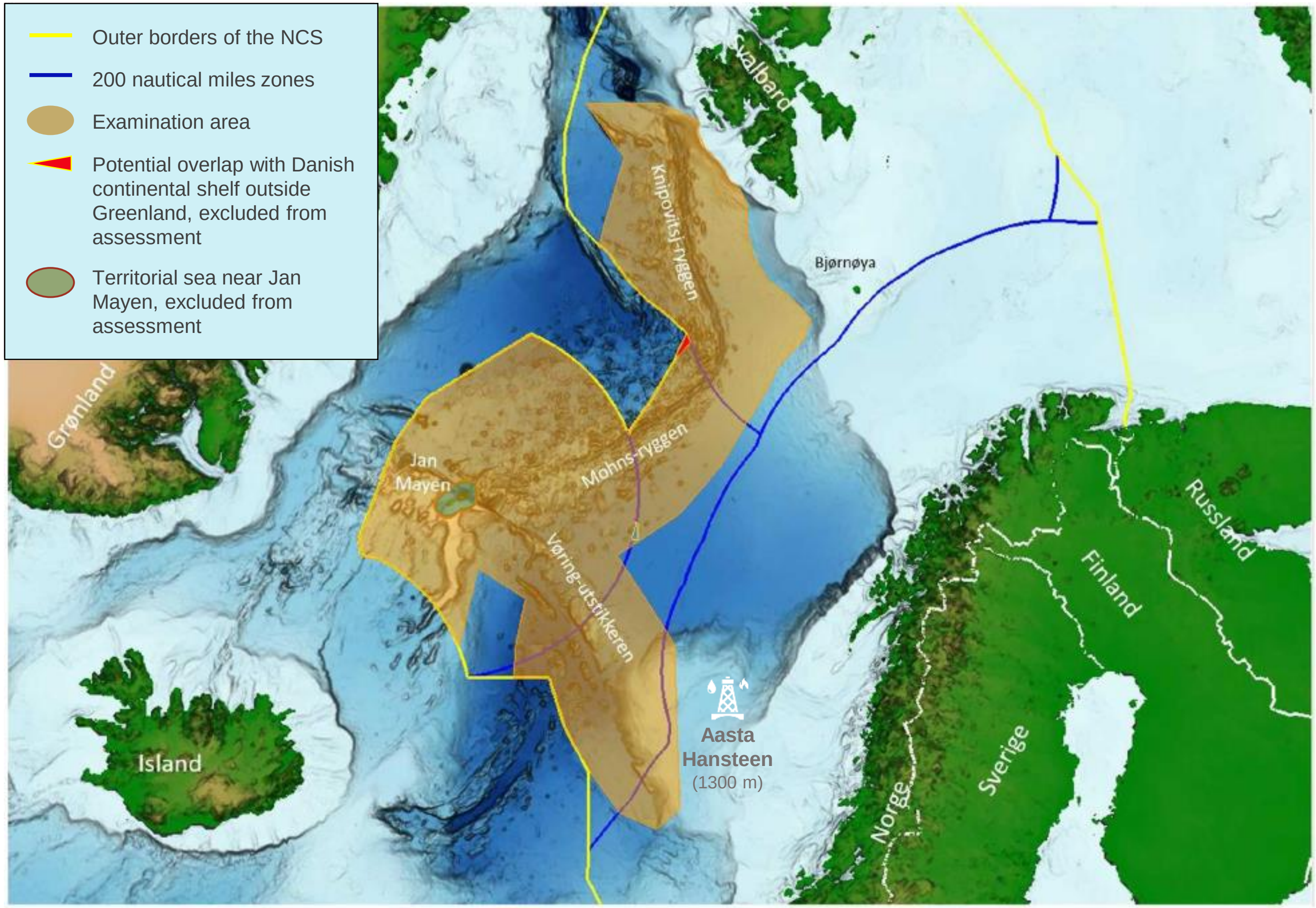
### Key historical events




Source: Rystad Energy research and analysis; Norwegian Petroleum Directorate (NPD)

# Ultra deepwater Norwegian spreading ridge located between Jan Mayen and Svalbard

**The Norwegian spreading ridge**




The Norwegian territorial spreading ridge (ca. 1300 km long) is located between Svalbard and Jan Mayen, with the Knipovich Ridge up north and the Mohns Ridge further south. NPD's resource mapping studies over the 2018 to 2020 period have been made along the Mohns Ridge.

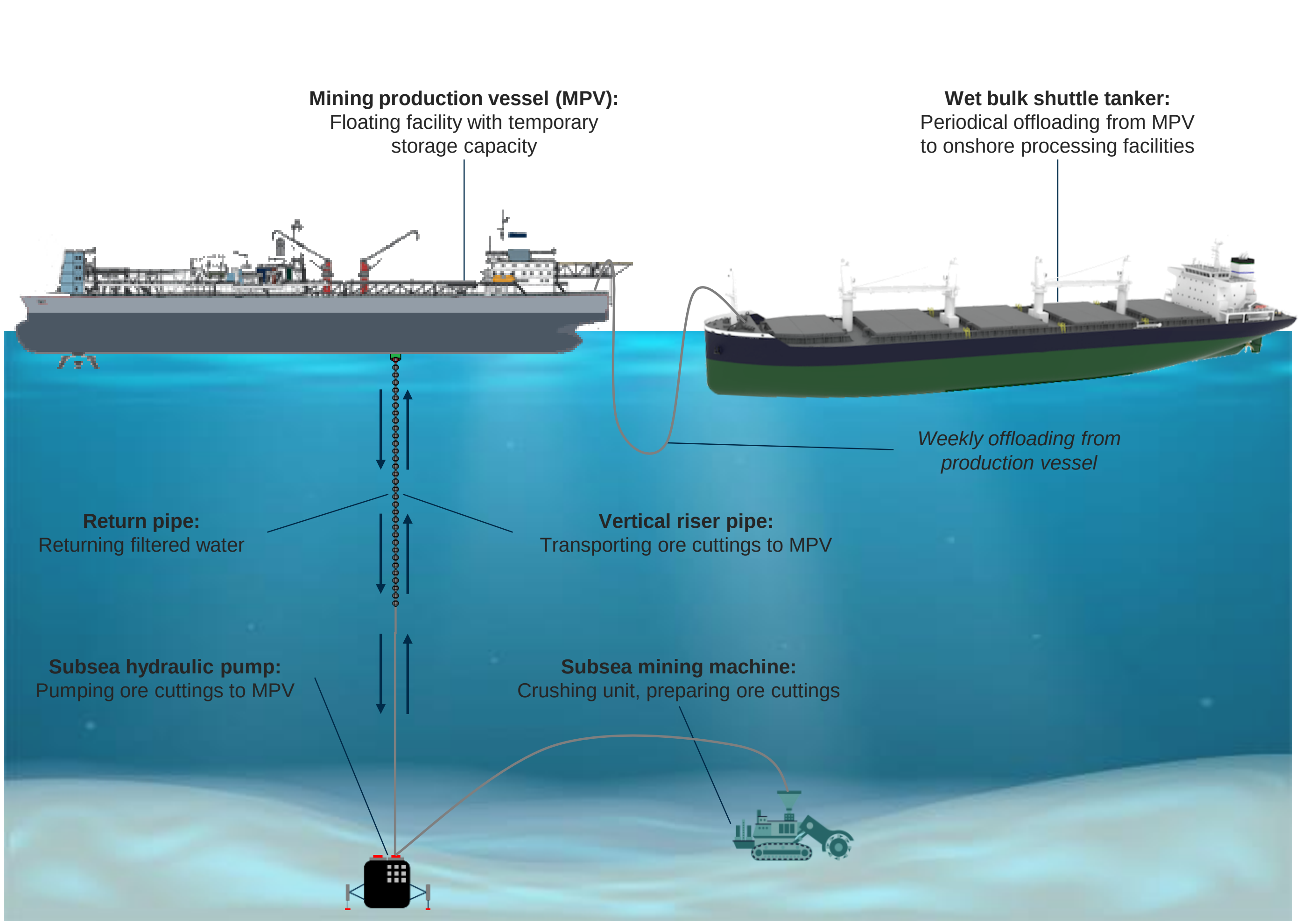
The approximate distance from the Norwegian mainland (from Tromsø) to the mid of the Norwegian spreading ridge is 700 km (~380 nautical miles). Located at such distances away from the Norwegian coastline (mainland), the waters reach depths in the range of 2000 to 3000 meters. While the most southern parts of the Mohns Ridge and furthest north on the Knipovich Ridge have some water depths in the 1000 to 2000 meters range, most of the Norwegian spreading ridge is located thousand meters deeper. In comparison the water depth at Aasta Hansteen in the Norwegian Sea, the NCS' currently deepest operated oil and gas field, is 1300 meters.

Source: Rystad Energy research and analysis; Norwegian Petroleum Directorate (NPD)

# Content

# Numerous opportunities for application of oil and gas technology

**Illustration of potential concept for offshore marine minerals extraction***




**Technical concept explained:**

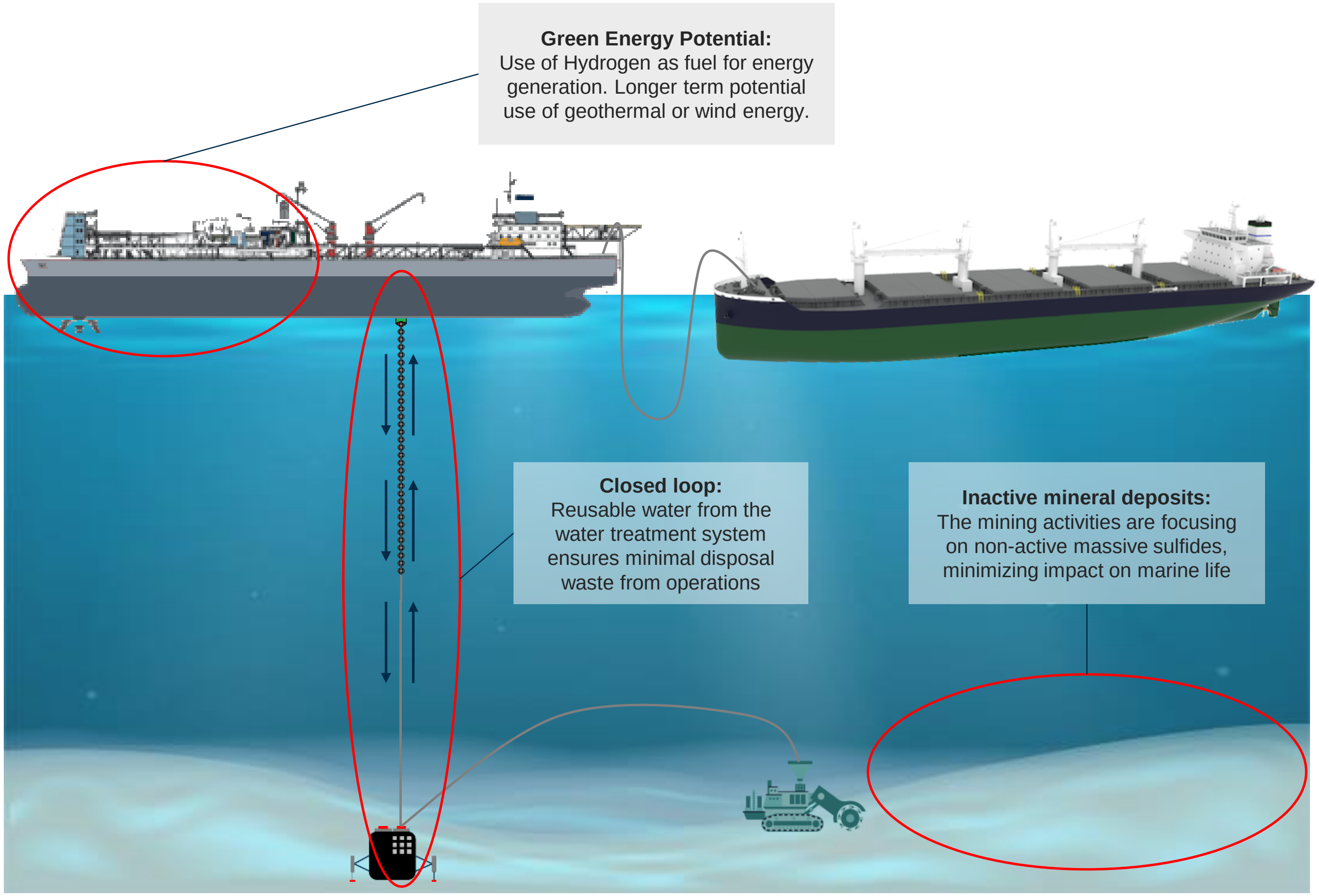
- **Subsea mining machine** crushes mineral rich rocks from inactive massive sulfides on the sea floor, providing ore cuttings
- **Subsea hydraulic pump** unit lifting the ore cuttings to the mining production vessel (MPV)
- **Vertical riser pipeline** system transports the ore cuttings from mining operations to the MPV for temporary storage
- **Water filtering system** on the MPV sorts minerals from the water
- **Return pipeline** pumps clean water back down to the subsea hydraulic pump unit in a closed loop system
- **Wet bulk shuttle tanker** arrives periodically to transport the temporarily stored wet bulk mineral mix from the MPV to an onshore processing facility

*The concept is focusing on the offshore extraction process and does currently not account for any onshore facilities.*

*Illustration not to be considered as technical drawing
Source: Rystad Energy research and analysis

# Sustainability measures embedded in production concept

**Environmental footprint in focus***




Strict regulations on the Norwegian Continental Shelf (NCS) has driven oil and gas operators to become leading in low environmental impact operations on a global scale.

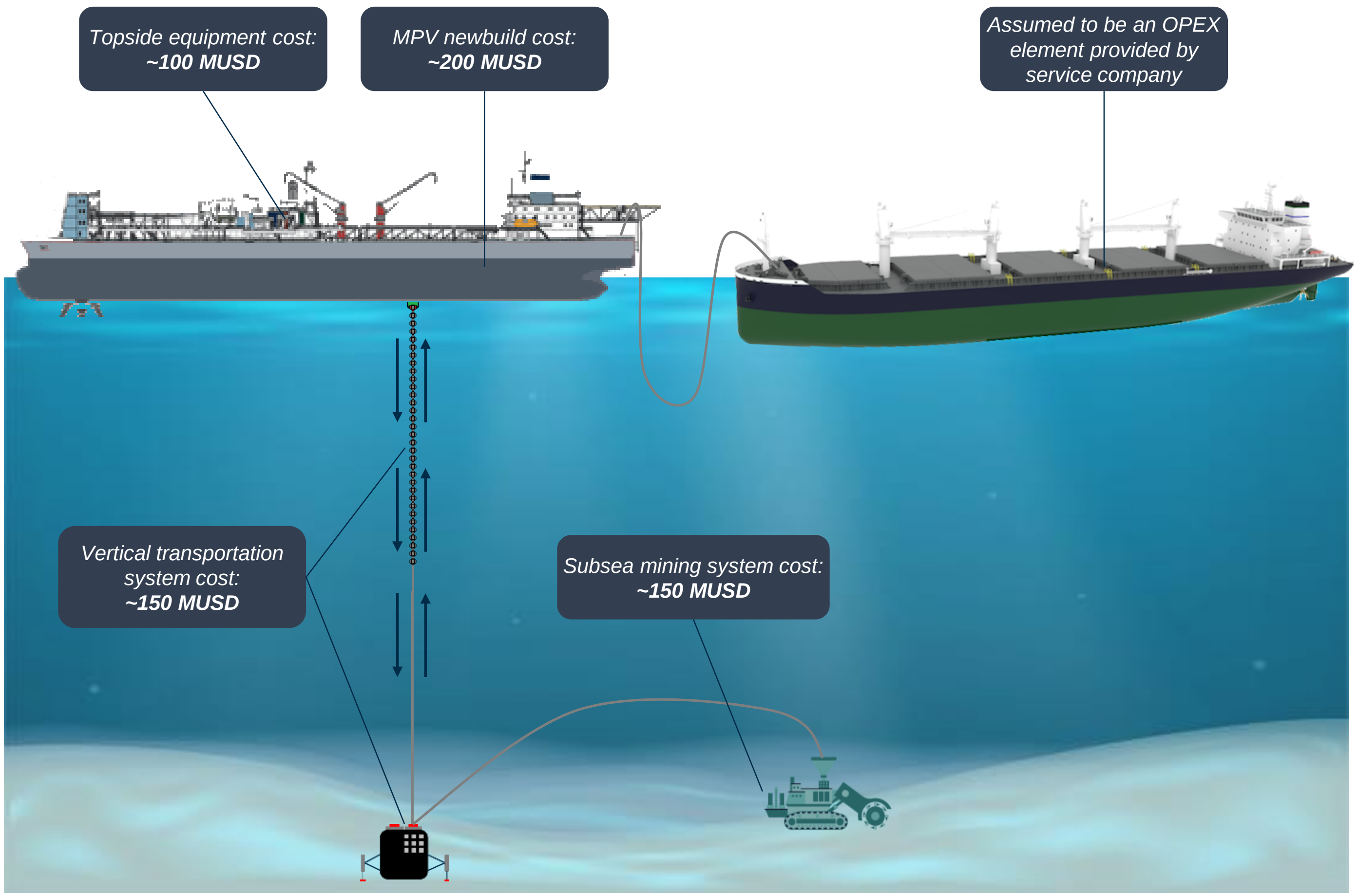
With significant focus on the environmental footprint of operations from the start, marine mineral mining on the NCS could become a leading sustainable provider of key minerals.

Some of the key sustainability measures are; electrification through local **renewable energy supply**, curtailing disposal waste through a **closed loop water treatment system,** targeting **inactive mineral deposits** to minimize impact on marine life and use of suction box behind the cutter of the mining tool to **minimize sediment plume**.

*Illustration not to be considered as technical drawing
Source: Rystad Energy research and analysis

# Total project CAPEX of ~780 MUSD in base case scenario

**Case example: Production CAPEX***




**Cost drivers:**

Topside equipment

- Launch and Recovery
- Riser handling
- De-Watering
- Storage

MPV newbuild

- Production vessel

Vertical transportation system

- Subsea Pumping
- Vertical Riser

Subsea mining system

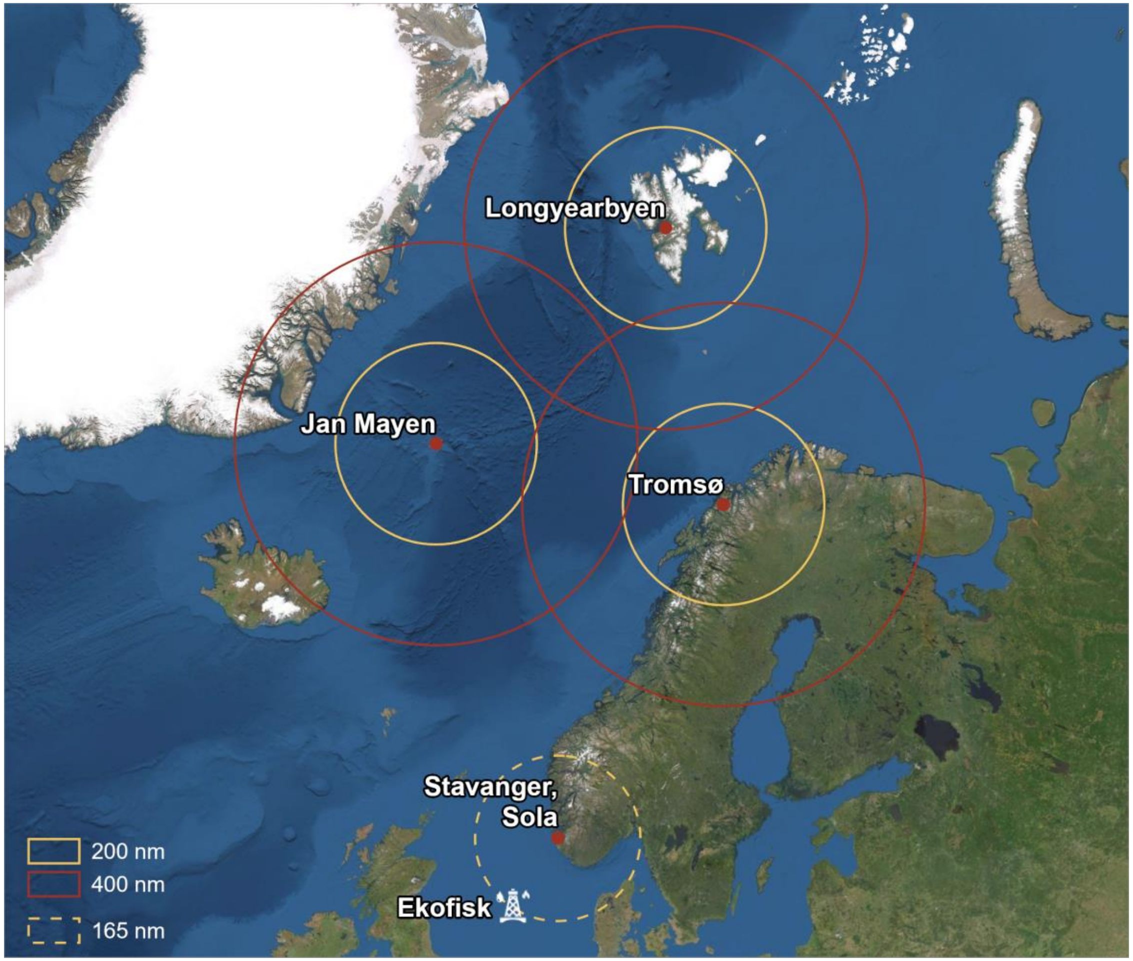
- Mining machines

*Current concept assumes power supply from diesel turbines but could also utilize future offshore wind power or local thermal energy.*

*CAPEX estimates include an assumed 20% contingency *Illustration not to be considered as technical drawing
Source: Rystad Energy research and analysis

# Operational costs might be challenged by the spreading ridge's remote location

**The Norwegian spreading ridge with distances* to main logistic centers**




Distances from the Norwegian spreading ridge to the three key mainland logistics centers are represented by the red (400 nm*) and yellow circles (200 nm) on the map. Jan Mayen is a nature reserve and currently functions only as a military base with no permanent residents. Svalbard (Longyearbyen) and Tromsø will be the likely main logistic points for a potential marine minerals industry.

Notice that the 400 nm-circles cover the complete spreading ridge, whereas the yellow ones approximately reach two thirds. The 200 nm-circles are an indication of current NCS oil and gas-operation helicopter routes. Ekofisk is located 165 nautical miles from the helicopter base at Sola, while Wisting in the Barents Sea is located at a similar distance from Hammerfest.

Helicopter reach knowingly increases with lower pax as this allows for more fuel. Today's S92 helicopters are generally said to reach up to 300 nm carrying 8 passengers**. Reaching 400 nm in a future scenario cannot be ruled out given new technologies or fewer pax.

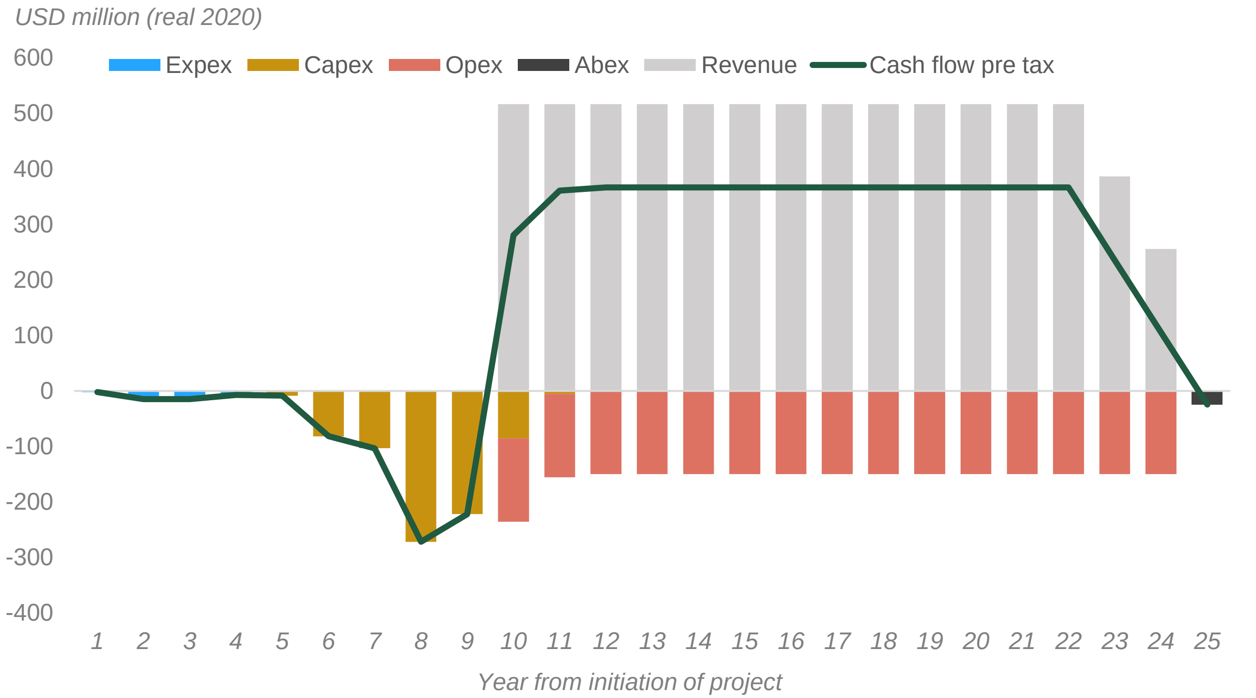
*One nautical mile (nm) = 1852 kilometers (km) **Current NCS regulations set maximum helicopter travelling distance to half of the unit's reach – returning to base must be an option. In practice, reaching 300 nm means that the helicopter has a capacity of 2x300 nm. Source: Rystad Energy research and analysis

# A type project is modelled based on current information on costs and enrichment

## Description of the type project

A type project is modelled to assess possible impact from a marine mineral industry in Norway. The type project is utilized in all four scenarios of this report.
The project is based on the concept with a Mining Production Vessel (incl. de-watering), a Vertical Transportation System (risers and pumping) and a Subsea Mining Tool. These production units are assumed to have a lifetime of around 14-15 years enabling extraction of 30 million tons of sulfide minerals (similar to the "TAG" accumulations). Investments in the production units are estimated to around USD 780 million including 20% contingency.
Operational costs include wet bulk shuttle tanker, offshore and onshore manning, logistics, maintenance and power consumption. Yearly operational costs are estimated to around USD 150 million.
The pre-tax NPV given a 10% discount rate is USD 746 million with a project IRR of 29%.

## Cash flow




## Key metrics*

| | | |
|---|---|---|
| **Mineral resources** | **30** | *Million tons* |
| **Enrichment (CuEq)** | **5.3** | *%* |
| **Sum Revenue** | **7,360** | *USD million* |
| **Sum Expex** | **40** | *USD million* |
| **Sum Capex** | **780** | *USD million* |
| **Sum Opex** | **2,250** | *USD million* |
| **Sum Abex** | **100** | *USD million* |
| **Unit cost (CuEq)**** | **2.0** | *USD/kg CuEq* |
| **Lifting cost (CuEq)**** | **1.4** | *USD/kg CuEq* |
| **Pre-tax NPV0** | **4,260** | *USD million* |
| **Pre-tax NPV10** | **746** | *USD million* |
| **Pre-tax IRR** | **29** | *%* |

*For more granular breakdown of revenue and cost assumptions see Appendix. CuEq = Copper equivalent **Unit cost includes capex, opex, expex and abex. Lifting cost includes opex
Source: Rystad Energy research and analysis; Loke Marine Minerals

# A potential road to becoming the leading global supplier of marine minerals

## The history and potential future of Norwegian marine mineral production

Awaiting the results of the ongoing impact study of marine mineral production on the NCS, private companies and partner organizations are preparing for what could be the next Norwegian offshore adventure. The timeline below depicts what such a potential industry development could look like.

Due to the accumulated offshore expertise from the oil and gas sector, Norway is well positioned for a rapid deployment of seismic and geological exploration on the NCS. Additionally, the Norwegian competence within the offshore service industry could become critical in developing a professional and efficient industry to address the growing mineral demand driven by the energy transition and digitalization processes unfolding across the globe.

### Key historical events

**2005**
First hydrothermal sulfide finding on the southern part of the Mohns Ridge

**2010**
UiB and NPD commence a multiyear exploration campaign, also discovering crusts

**2018-20**
NPD discovers unknown massive sulfides using AUVs and ROVs

**2019**
Havbunnsmineralloven established in Norway building on oil and gas legislation

**2020**
NPD concludes on promising rock samples. Initiated further studies

### Potential future development

**2023-24**
First round of licensing

**2025**
Commercial exploration triggering development

**~2030-35**
First project in commercial production

**~2050**
An estimated +20 projects in production

Source: Rystad Energy research and analysis; Norwegian Petroleum Directorate (NPD)

# Four scenarios for a marine mineral NCS future are described in this report

**A scenario framework for resource availability***

**Resource concentration**

| Total resource potential | Low *(fragmented)* | High *(concentrated)* |
|---|---|---|
| Low | **Scenario 1.** 10 projects | **Scenario 3.** 50 projects |
| High | **Scenario 2.** 25 projects | **Scenario 4.** 75 projects |

Four scenarios describing possible developments of a marine mineral industry on the NCS are explored in this report.

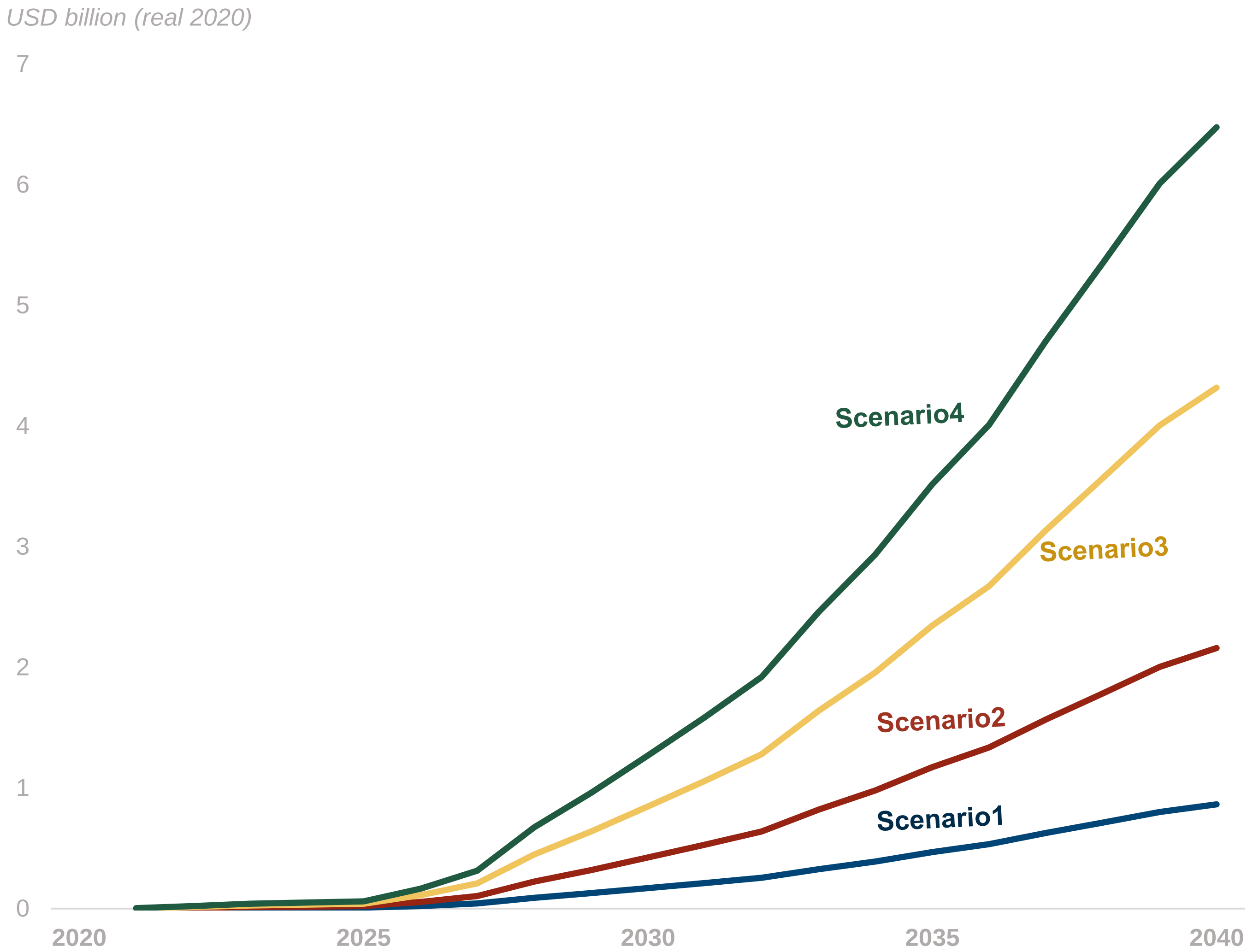
The scenarios are defined by characteristics of the marine mineral resource accumulations. A "low" and a "high" outcome for the total resource potential (amount) and the concentration of these resources (commerciality) give four scenario permutations.

Each scenario represents a given number of projects being initiated in a **30-year time period** from the assumed start of a Norwegian marine mineral industry (defined by active exploration and with production licensing in place). A project represents operations over 14-15 years extracting around 30 million tons of minerals from marine deposits.

*Number of projects initiated 30 years after assumed start of marine minerals industry
Source: Rystad Energy research and analysis

# Marine minerals could support a billion dollar service industry in Norway

**Annual Norwegian marine minerals spending split by scenario***




*Includes both capital and operational expenditures
Source: Rystad Energy research and analysis

Marine minerals extraction will need a broad service industry. Current development concepts are based on utilization of competence and technology from the oil and gas sector.

Norway's leading position as a service provider in offshore oil and gas serves as an excellent foundation for a successful marine minerals industry.

The level of marine minerals activity is dependent on both the amount and the commercial value of resource accumulations. The four scenarios color possible futures. The NPD mapping of the marine minerals in Norway will help to understand needs and opportunities for a potential new Norwegian offshore industry.

Costs associated with marine minerals activity will be revenue for a supporting service industry.

# Marine minerals industry will make use of all existing Norwegian oil and gas competence

| NORWEGIAN COMPETENCE | | | | COMMODITY INDUSTRY RELEVANCE | | | | COMMENT |
|---|---|---|---|---|---|---|---|---|
| **Norwegian geographical cluster** | **Field of industry competence** | **2019 Norwegian employment** *[# employees]* | **Examples of relevant players*** | **Oil and gas** | **Bottom fixed wind** | **Offshore floating wind** | **Marine minerals** | **Competence relevance in a potential marine minerals industry** |
| Eastern Norway | **Seismic** | 2,500 | TGS, emgs, roxar, allton, PGS, magseis fairfield | ●●● | ○○○ | ○○○ | ●●● | High frequency seismic surveys used for detecting minerals in seabed formations. E.g. by use of seismic vessels, AUVs and electromagnetic (EM) methods |
| | **Geology** | | | ●●● | ●○○ | ●○○ | ●●● | Initial and life cycle geological studies and analysis of formations. Studying mineral resource potential and mapping of field characteristics |
| | **Engineering** | 9,500 | moss maritime, Dr. Techn. Olav Olsen, Global Maritime | ●●● | ●○○ | ●●○ | ●●○ | Design and engineering of marine minerals extraction concept, incl. the mining production vessel and e.g. the solution for potential low carbon energy sourcing |
| | **Subsea** | 16,500 | AkerSolutions, TechnipFMC, subsea 7 | ●●● | ●○○ | ●○○ | ●●○ | Delivering the vertical transportation system (risers), subsea pump and mining tool for ore cutting collection |
| West coast | **Marine operations** | 9,000 | DeepOcean, DOF, Østensjø Rederi, Solstad Offshore | ●●● | ●●○ | ●●● | ●●● | Transportation of de-watered mineral masses on wet bulk shuttle tankers. Also in need of various support vessels and potentially personnel transfer |
| | **EPC- and shipyards** | 15,000 | aibel, Vard, Kværner, Kleven, Ulstein | ●●● | ●○○ | ●●○ | ●●● | Construction, hook-up and commissioning of mining production vessel (e.g. topside modules) and subsea components. Various scope on wet bulk tankers |
| | **Drilling** | 10,000 | Transocean, Seadrill | ●●● | ○○○ | ○○○ | ●○○ | Deep water (1000-3000 m depths) shallow drilling down to ca. 100 meters below seabed. Coiled tubing methods already used for marine mineral purposes |
| South coast | **Drilling rig- and topside equipment** | 22,000 | Schlumberger, ABB, mhwirth, NOV, Wärtsilä | ●●● | ●○○ | ●○○ | ●●○ | Engineering and fitting of drilling rigs and the mining production vessel. Pumps, water treatment, loading/discharge systems etc. |
| Country wide | **Automation and digital technologies** | 26,000 | Sekal, Cognite, Eelume, Kongsberg | ●●● | ●○○ | ●○○ | ●●● | Automation needed for remote operations and subsea ROVs. Digital technologies through the value chain, e.g. for exploration, operations monitoring, logistics |
| | **Other, incl. maintenance services** | | DNV-GL, Axess, IKM, Jotun | ●●● | ●●● | ●●● | ●●● | Various operational services and maintenance activities. For example classification, IMR operations and manning |

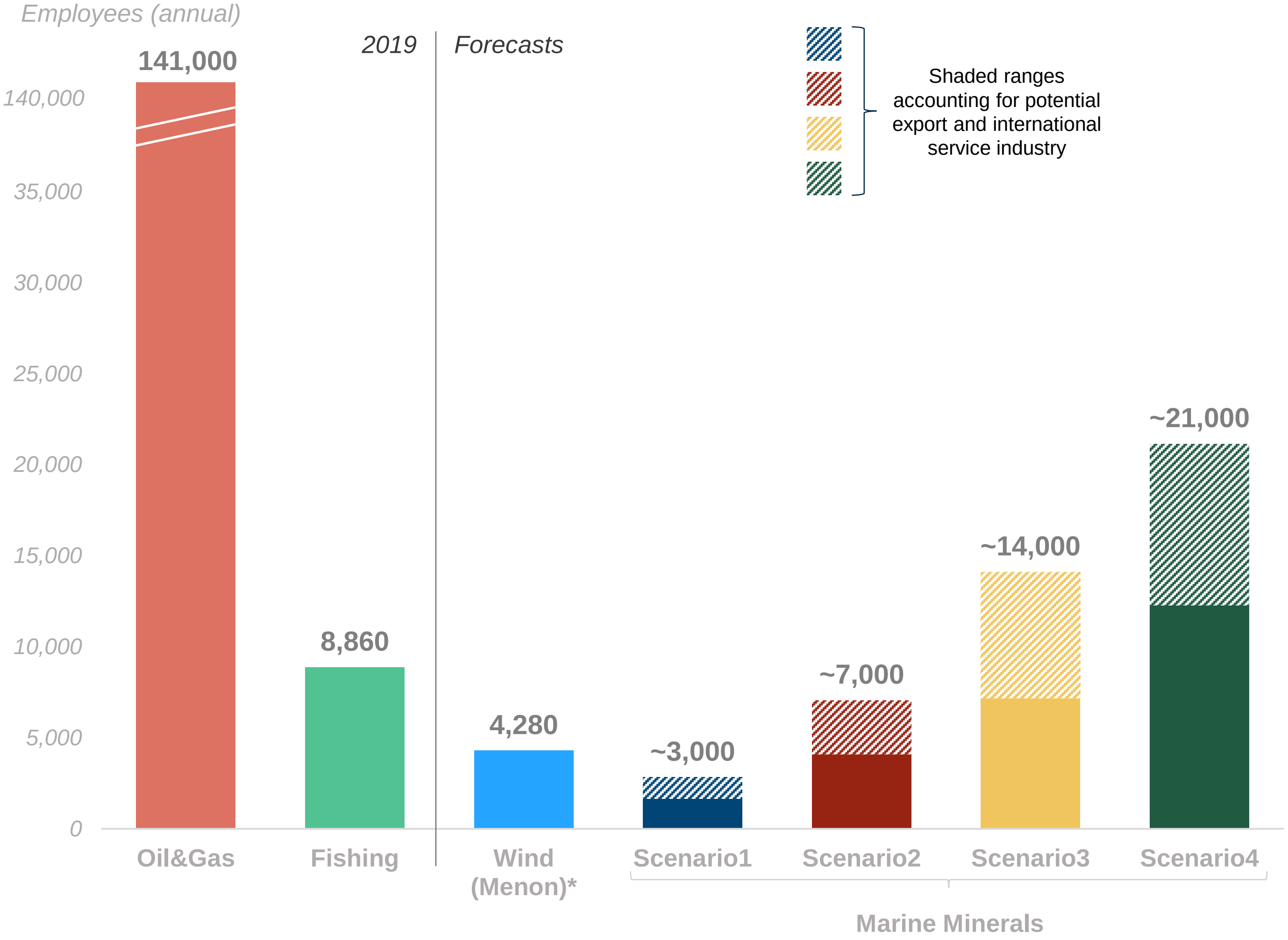
*Many of the listed oil field service companies perform work within several fields of competence, logos placed based on their main activities

Source: Rystad Energy research and analysis; Brønnøysundregistrene; Statistics Norway; Norwegian Petroleum

○○○ *Relevance degree - from high (3 filled) to low (1 filled)*

# Employment effects from marine minerals expected to surpass offshore wind high-case

## Norwegian employment effects (including service industry)




The graph on the left-hand side illustrates current and forecasted Norwegian employment in various industries. Three out of four scenarios for a marine minerals industry depict significantly larger employment effects than a Menon high-employment case for offshore wind, and two with more employment than the current fishing industry.

The marine minerals solid (not shaded) base estimates are based on assumed direct industry employment plus a service industry with an equal ratio as within the oil and gas industry.

The full figures (incl. shaded) are derived by scaling the ratio of employment and spending in the oil and gas industry with the estimated annual spending on mineral mining.

Given these assumptions, the employment potential from exports in the mineral mining industry is assumed to have a similar ratio as to what oil and gas currently holds. However, significant upside to the export potential is likely present if Norway can rapidly develop a successful industry and also provide most of the service industry.

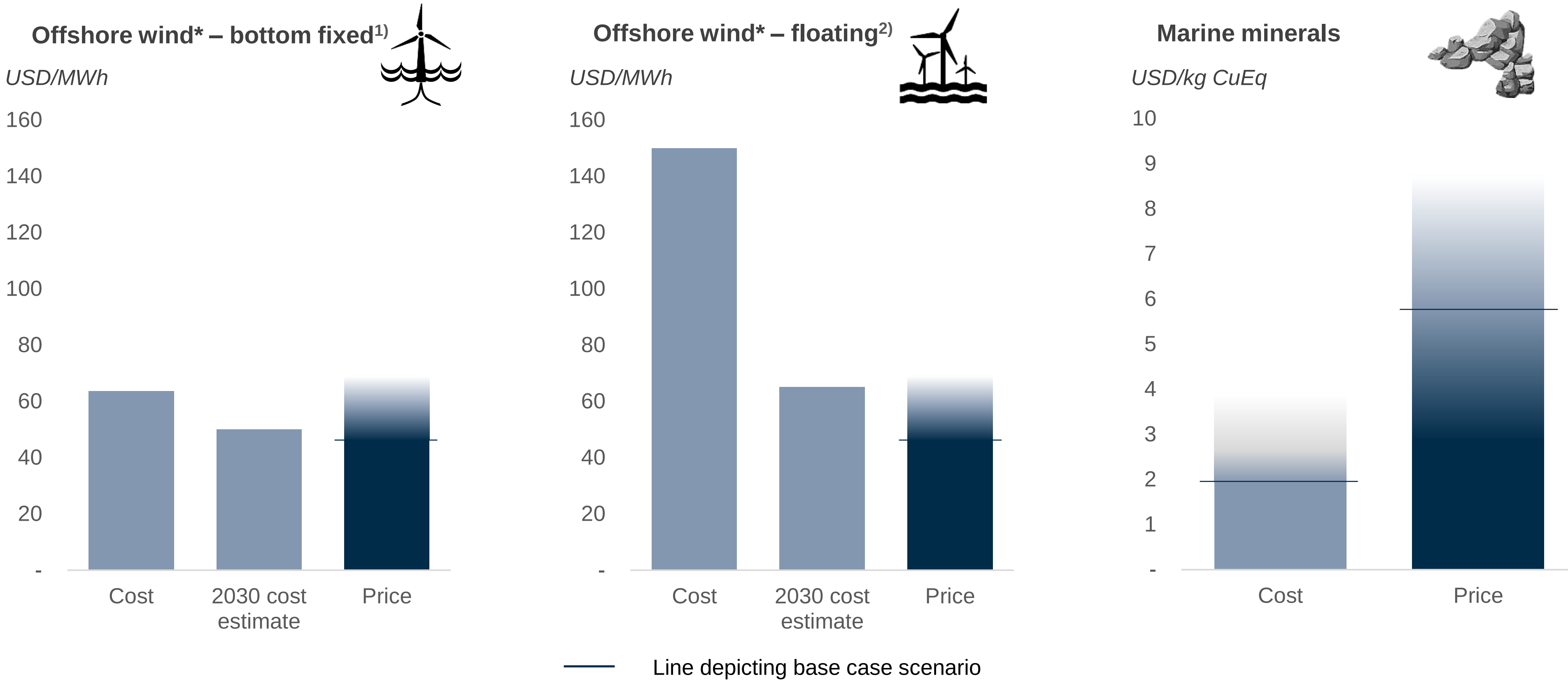
*Menon Economics 2019 report on floating offshore wind – 4,280 represents the high case
Source: Rystad Energy research and analysis; Brønnøysundregistrene; Statistics Norway; Norwegian Directorate of Fisheries; Menon Economics

# Marine minerals – in the money with current production concept

## Current cost versus price for offshore wind and mineral mining alternatives

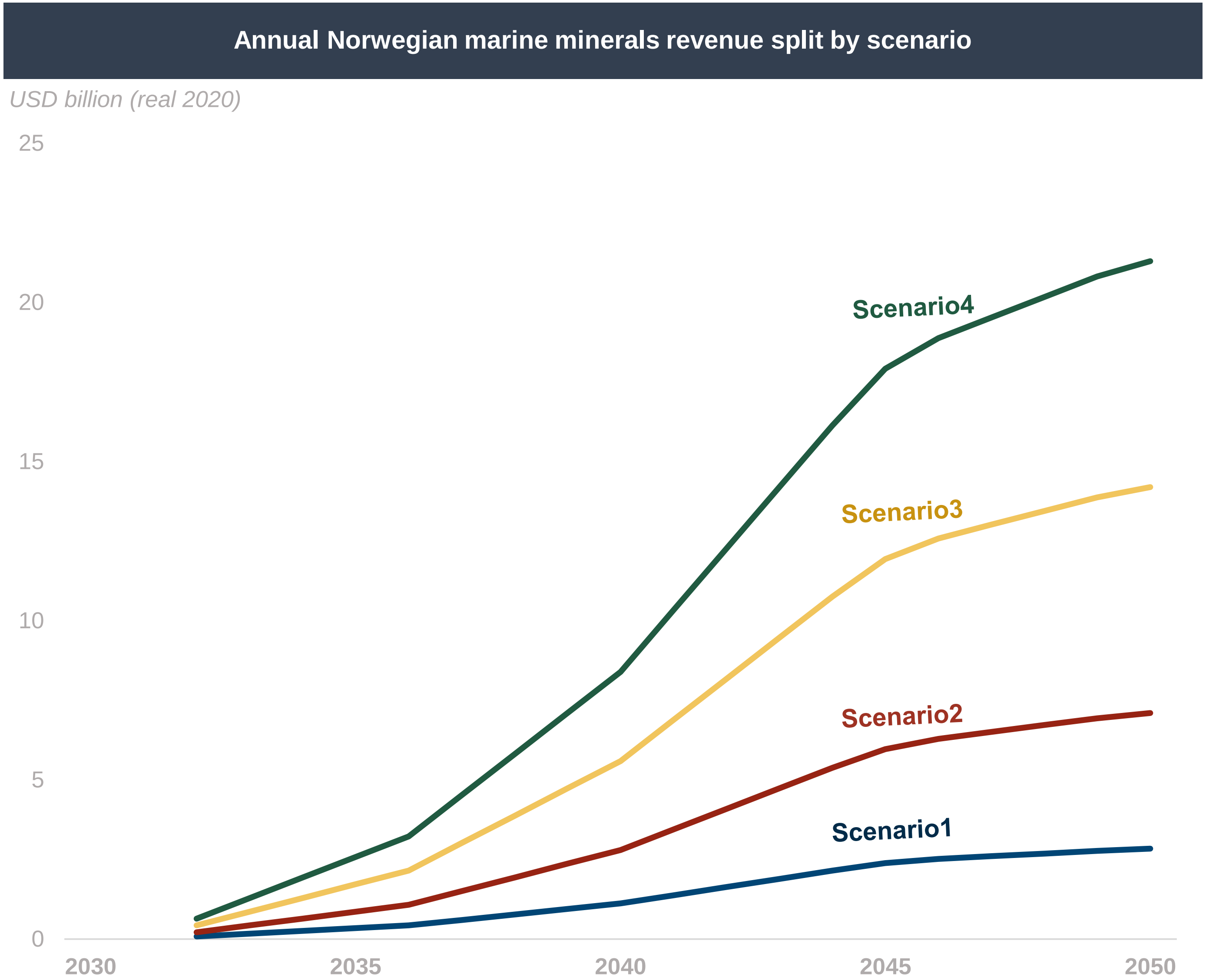
The current stand-alone profitability of offshore industry alternatives to oil and gas depicts still substantial costs for offshore wind power, especially for floating facilities. Hence, the offshore wind industry will require substantial subsidies going forward until prices gradually come down as the technology and industry matures.

At the far right below, the case for current marine mineral estimates is quite different. Supported by the mature competence and technology from the oil and gas industry, marine minerals could become a significant income source for Norway with its current production concept.




* Price calculated as average of selected largest European markets in 2019 including upside range to capture variations. 1) Cost calculated as average of multiple projects in 2019. 2) Aker Offshore Wind rough estimates 2020. Source: Rystad Energy research and analysis; Aker Offshore Wind

# Marine minerals with annual revenue potential up to USD 20 billion




Source: Rystad Energy research and analysis

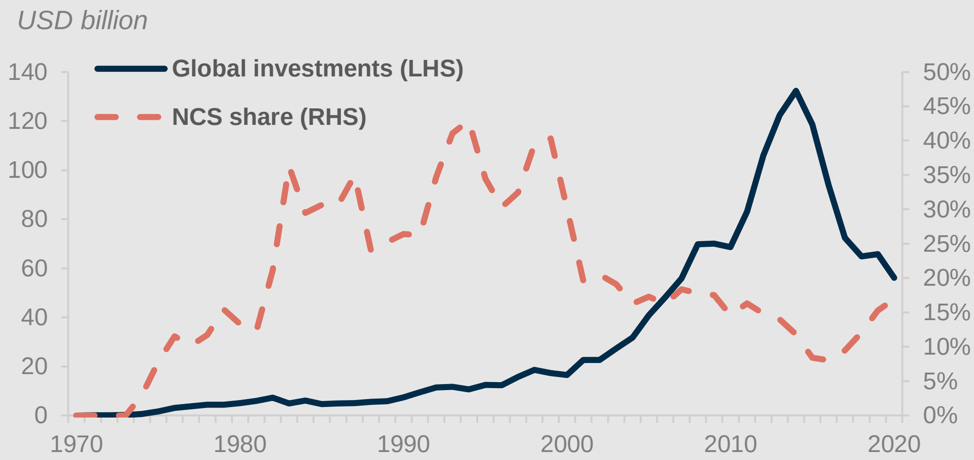
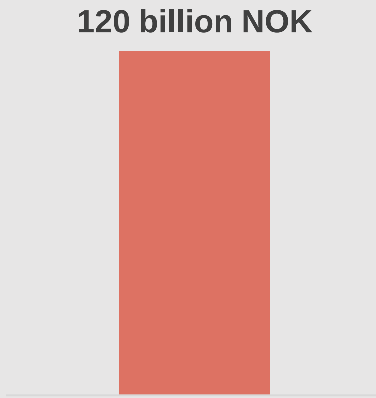
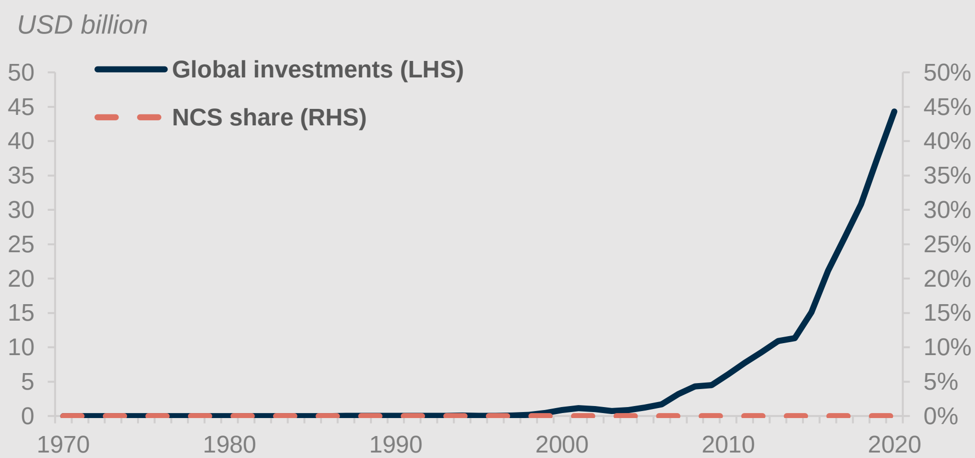
A Norwegian marine minerals industry could enable vast value creation potential. Given the assumptions outlined in this report such an industry has the potential for annual revenue of up to around USD 20 billion towards 2050.

In comparison the revenue from the oil and gas sector peaked at around USD 120 billion in 2008 and 2012 with oil prices above 100 USD/bbl. 2019 oil and gas revenue was around USD 61 billion from the NCS.

Marine minerals revenue will generate value in terms of; costs as revenue for a service industry, tax to the Norwegian society, and profits to the companies involved in production of the minerals.

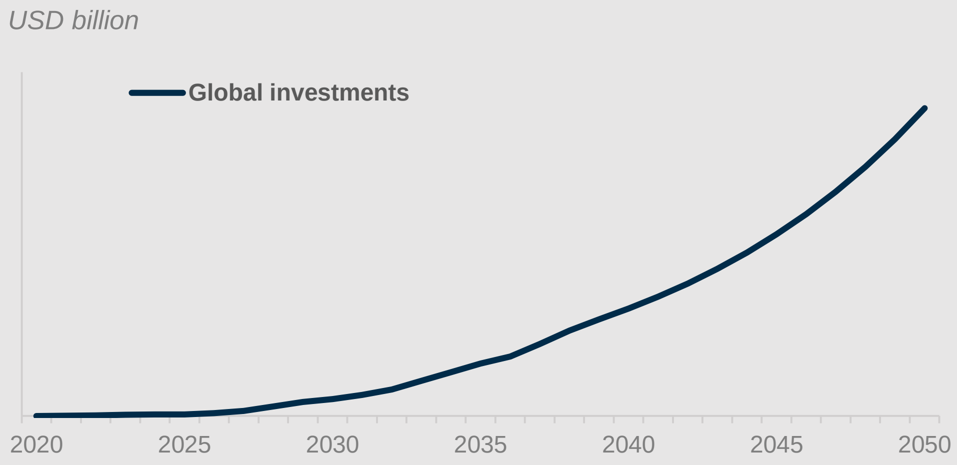
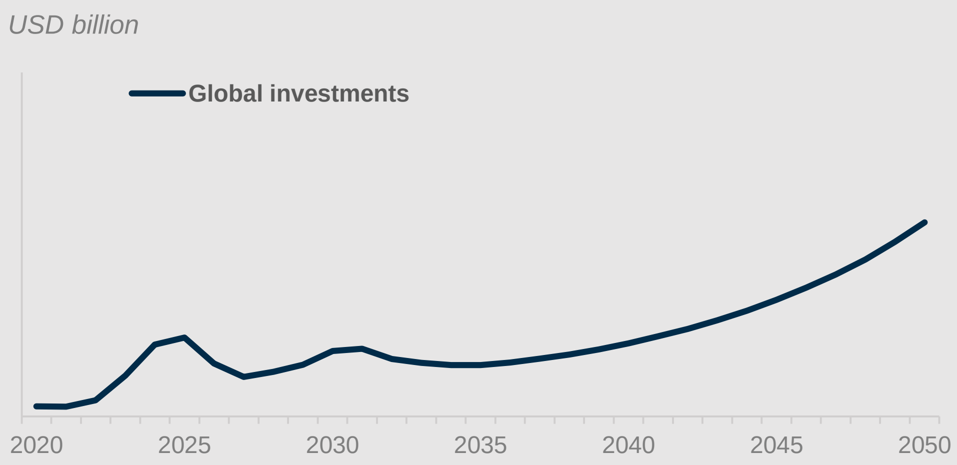
# Content

# In order to develop a competitive service industry being an early adopter is key

| Sector | Global investments and NCS share | Norwegian 2019 export* |
|---|---|---|
| **Oil & Gas Deepwater**  |   |   |
| **Offshore wind (bottom fixed)**  |   |   |

*Norwegian service industry international revenue
Source: Rystad Energy research and analysis; Rystad Energy Offshore Wind

# Marine minerals and floating offshore wind could be successes like deepwater oil and gas

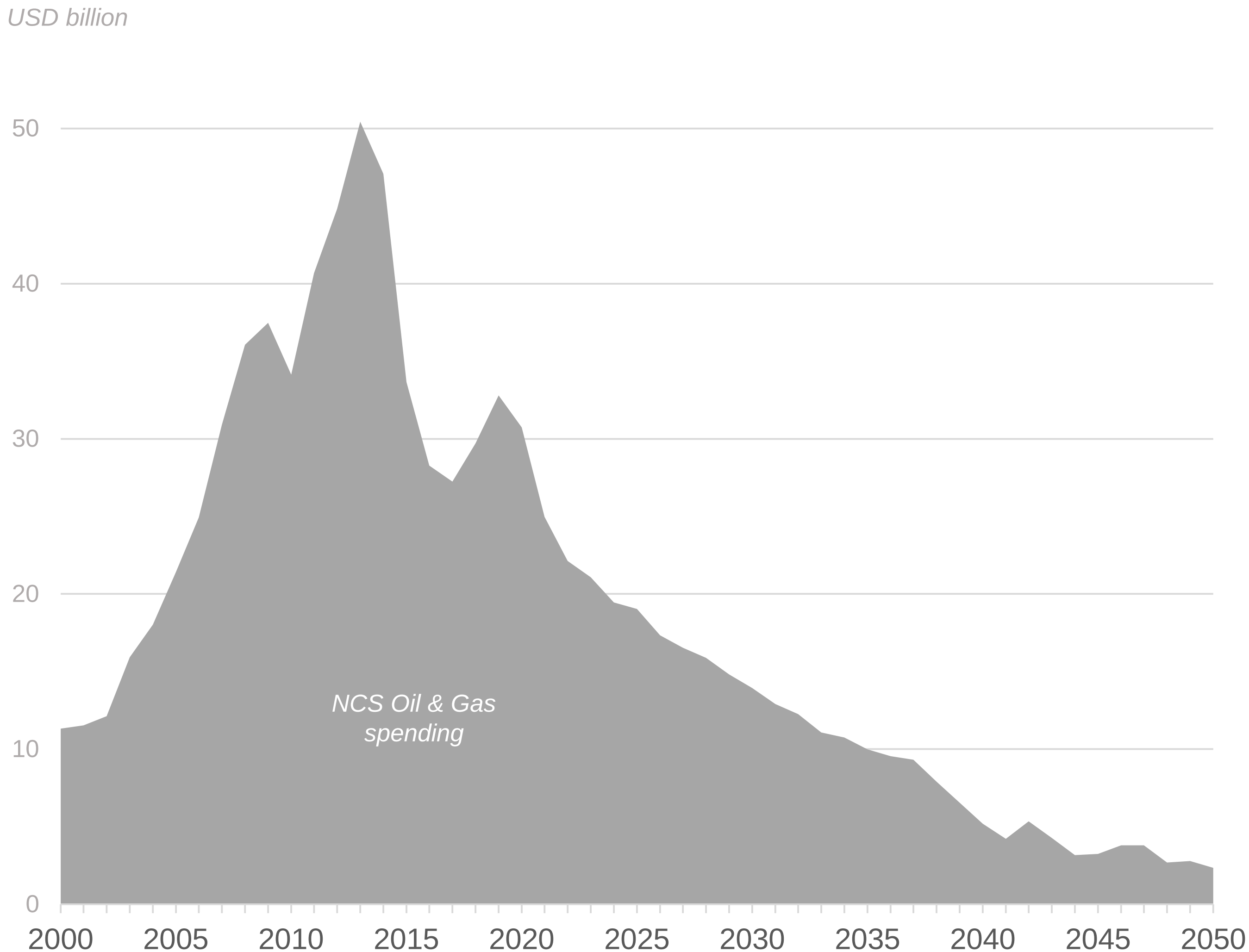
| Sector | Global investments | Norwegian future export* |
|---|---|---|
| **Marine minerals** |  | ? |
| **Floating offshore wind** |  | ? |



*Norwegian service industry international revenue
Source: Rystad Energy research and analysis; Rystad Energy Offshore Wind

# Norwegian oil and gas spending is set to decline

**Norwegian oil and gas spending from sanctioned fields***




Oil and gas activity is in decline on the Norwegian Continental Shelf. The graph shows spending from sanctioned fields (producing and under development). Spending is assumed to be a fair metric for activity level as it will cover ripple effects on the service industry.

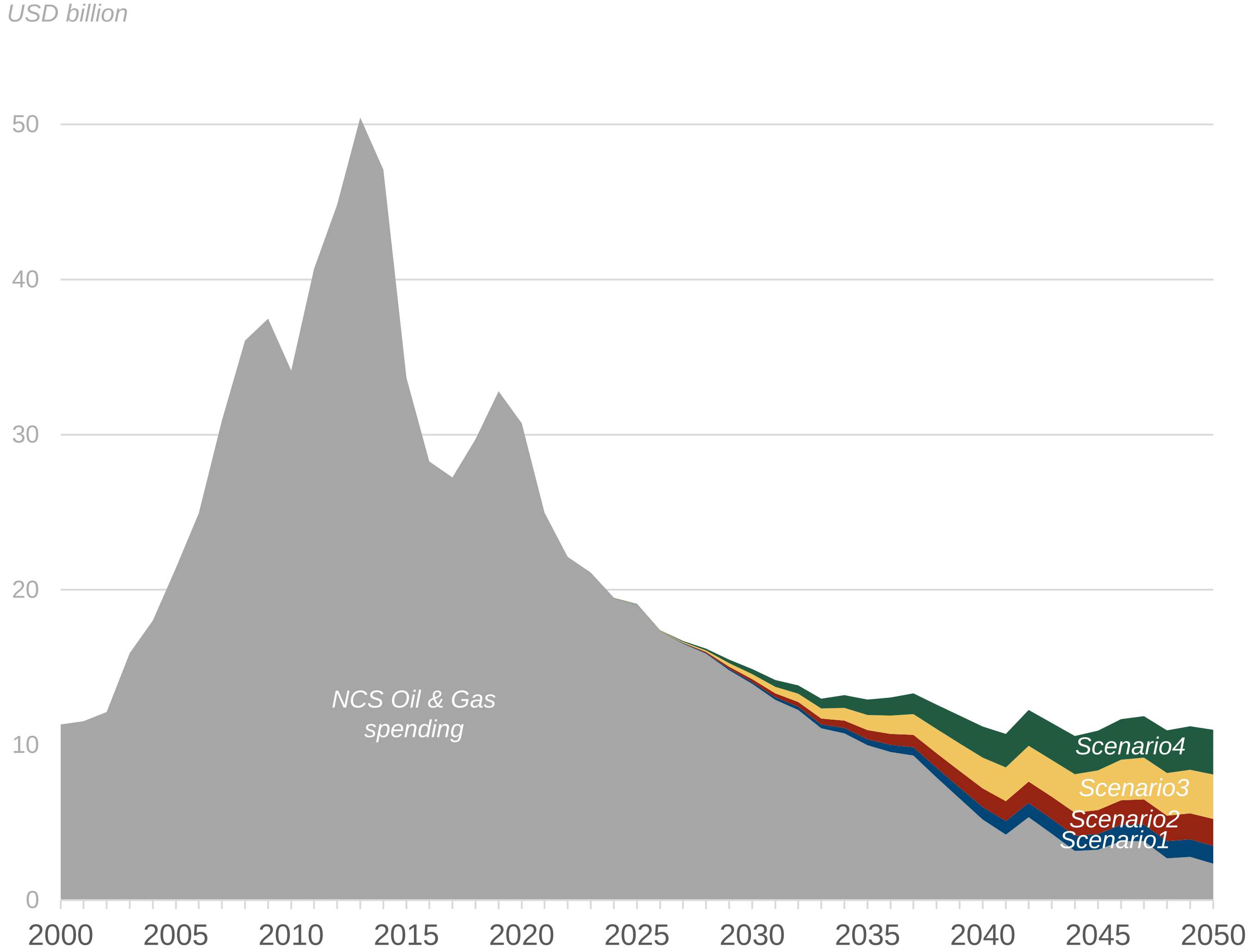
Spending peaked in 2012 at around USD 50 billion and experienced a steep drop following the oil price downturn in 2014.

New fields coming onstream, like major Johan Sverdrup, triggered a new local peak in 2019. Even with ongoing large developments like Johan Castberg and Johan Sverdrup phase 2 further decline is expected. In addition, a limited portfolio of discoveries not yet sanctioned is not expected to be able to offset further decline to spending and activity levels.

*Includes both capital and operational expenditures, in addition to historical exploration costs and assumed future exploration costs
Source: Rystad Energy research and analysis; Rystad Energy UCube

# Marine minerals could contribute to a continued vibrant Norwegian industry

**Norwegian oil and gas spending from sanctioned fields* and marine minerals spending**




Due to inevitable decline in oil and gas activity on the NCS new industries will have to develop if Norway wants a future vibrant industry.

Marine minerals seem to be one new industry that could help fill the expected growing gap being created by declining oil and gas activity.

However, in order to transfer the competence from oil and gas to marine minerals it will be key to not straddle the fence and miss out on knowledge and infrastructure as the oil and gas activity declines.

*Includes both capital and operational expenditures, in addition to historical exploration costs and assumed future exploration costs
Source: Rystad Energy research and analysis; Rystad Energy UCube

# Content





RYSTAD ENERGY

# IEA climate change scenarios

| SCENARIO ACRONYM | SOURCE | SCENARIO DESCRIPTION |
|---|---|---|
| **RTS** | Reference technology scenario from the IEA ETP (2017) report | Assumes all countries will implement their Nationally Determined Contributions (NDCs), as proscribed under the Paris Agreement, resulting in an average temperature increase of **2.7°C by 2100** |
| **2DS** | 2-degree scenario from the IEA ETP (2017) report | Scenario with at least a 50% chance of limiting the average global temperature increase to **2°C by 2100** |
| **B2DS** *(Most ambitious IEA scenario)* | Beyond 2-degree scenario from the IEA ETP (2017) report | Scenario with a 50% chance of limiting average future temperature increases to **1.75°C by 2100** |

Source: Rystad Energy research and analysis; International Energy Agency (IEA); World Bank

# Production unit capacities and operational efficiency set the production rate

## Technical economical model input assumptions

**Production rate**
×
**Enrichment factor**
×
**Mineral/metal prices**
×
**Discount to prices**
–
**Capital expenditure**
–
**Operational costs**
–
**Abandonment costs and/or Re-use of equipment**

| Production unit | Capacities from Design Basis V 0.2. | Daily production potential | Operational efficiency |
|---|---|---|---|
| *Subsea Mining Tool* | Ore excavation volume: 100m3/hr<br>Corresponding mass: 330t/hr | 2400 m3<br>7920 tons | 85%<br>=> 6732 tons/d |
| *Vertical Transportation System* | Particle max size: Max 50mm<br>Solids content in ore slurry: 12%<br>Ore slurry density (SG) 1.28 kg/dm3<br>Pumping system flowrate: 850 m3/hr | 2448 m3<br>8078 tons | 95%<br>=> 6395 tons/d<br>(6732*0.95) |
| *Mining Production Vessel* | De-watering 850 m3/hr<br>Liquid content in ore slurry after de-watering: 10% | No limit as water capacity is assumed to be as pumping system flow rate | 90%<br>=> 5754 tons/d<br>(6395*0.90) |

The effective production rate will be a function of production units' capacities and their operational performance.

**Current assumptions result in around 5.8 thousand tons per day**
*(operational efficiency at 73%)*

Source: Rystad Energy research and analysis; Loke Marine Minerals Design Basis V0.2

# Enrichment of copper, cobalt and zinc based on NPD and Loke inputs

Technical economical model input assumptions

Production rate

×

**Enrichment factor**

×

Mineral/metal prices

×

Discount to prices

−

Capital expenditure

−

Operational costs

−

Abandonment costs and/or Re-use of equipment

| Metal | Lower range | Upper range | Base case model assumption |
|---|---|---|---|
| Copper *(Cu)* | 3% | 14% | 4% |
| Cobalt *(Co)* | 0.2% | 1% | 0.5% |
| Zinc *(Zn)* | 0.5% | 3% | 1% |

Upper limits based on NPD chemical analyses of sulfides from 2019.
Ranges based on discussion with Loke Marine Minerals.

Source: Rystad Energy research and analysis; Norwegian Petroleum Directorate (NPD); Loke Marine Minerals

# Unit prices for refined metals – large variations between metals and over time

**Technical economical model input assumptions**

- **Production rate**
- ×
- **Enrichment factor**
- ×
- **Mineral/metal prices**
- ×
- **Discount to prices**
- –
- **Capital expenditure**
- –
- **Operational costs**
- –
- **Abandonment costs and/or Re-use of equipment**

| Metal | Average 2020 unit price* (refined) *[USD/mt]* | Metal price development 2016-2020YTD |
|---|---|---|
| **Copper** *(Cu)* | **5,840** |  |
| **Cobalt** *(Co)* | **31,500** |  |
| **Zinc** *(Zn)* | **2,150** |  |

The technical economical model will assume the average 2020 year-to-date* metal prices flat going forward, but note that large variations in metal prices are observed over time (see last four years' price development per metal above)

*Average metal unit prices from January to and including September 2020
Source: Rystad Energy research and analysis; World Bank; United States Geological Survey (USGS)

# Prices vary with metals' refining complexity and associated cost

Technical economical model input assumptions

Production rate

×

Enrichment factor

×

Mineral/metal prices

×

**Discount to prices**

–

Capital expenditure

–

Operational costs

–

Abandonment costs and/or Re-use of equipment

| Metal | Price discount ore to refined metal | Discount rationale |
|---|---|---|
| **Copper** *(Cu)* | **~80%** | Copper ore price similar to refined copper price. Refining processes relatively simple and low-cost |
| **Cobalt** *(Co)* | **~30%** | Cobalt refining associated with highly engineered processing methods, large investments and high-tech equipment |
| **Zinc** *(Zn)* | **~55%** | Complecity and costs associated with refining of Zinc somewhere in between Copper and Cobalt. |

Ore to pure metal-discounts for the same metal vary from mine to mine and geographically based on mineral quality (metal concentration). But variations in discount per metal type are more evident as refining processes demand different levels of engineering, investments and resources.

Like for other commodities several miner-smelter contract forms exist, e.g. spot vs. long-term. For the latter, the risk usually falls on the miner as contracts are linked to prices at delivery date. In some cases however, smelter and miner have been observed to share the price fluctuation risk.

Source: Rystad Energy research and analysis

# Estimates for investments in the specific production units

Technical economical model input assumptions

Production rate

×

Enrichment factor

×

Mineral/metal prices

×

Discount to prices

–

**Capital expenditure**

–

Operational costs

–

Abandonment costs and/or Re-use of equipment

| Production unit | System/comment | Rough estimates of cost: | Base case model assumption |
|---|---|---|---|
| Mining Production Vessel | Production vessel (DP)<br>Launch and Recovery<br>Riser handling<br>De-Watering<br>Storage<br>Offshore loading/export | Hull/LQ Conversion:<br>85-120 million USD<br>Hull/LQ Newbuild:<br>100–300 million USD<br>Topside equipment:<br>100-200 million USD | Hull/LQ Newbuild:<br>200 million USD<br>Topside equipment:<br>150 million USD |
| Vertical Transportation System | Subsea Pumping<br>Vertical Riser | ~100-200 million USD | 150 million USD |
| Subsea Mining Tool | Need two subsea mining tools per project | ~50-100 million USD per unit | 150 million USD for two units |
| Power generation | Could be capex:<br>Wind power<br>Thermal power<br>or opex with:<br>Diesel turbines | Currently assumed OPEX | |
| Contingency | | 20% | 130 |
| ***Total CAPEX*** | | ***~ 460 – 1080 million USD*** | ***780 million USD*** |

Source: Rystad Energy research and analysis

# Power costs assumed to drive OPEX for mineral mining

Technical economical model input assumptions

- **Production rate**
- ×
- **Enrichment factor**
- ×
- **Mineral/metal prices**
- ×
- **Discount to prices**
- –
- **Capital expenditure**
- –
- **Operational costs**
- –
- **Abandonment costs and/or Re-use of equipment**

| Element | Key assumption | Estimated annual cost: |
|---|---|---|
| Power consumption | 22 MW avg. (max capacity 30MW)<br>Diesel generator 190 g/kwh ~ 100 tons per day | 45 million USD |
| Bulk shuttle tanker | Capacity: 40,000 tons<br>Days per loading 6<br>(1 day load/discharge, 1.5 days voyage)<br>Charter rate: 57,5 kUSD/d<br>Harbor fee: 100 kUSD/d | 13 million USD |
| Offshore and onshore manning | 50 POB (2 shifts – 3:3 rotation)<br>10 onshore<br>= 110<br>3 million NOK/employee | 37 million USD |
| Logistics (manning/supplies) | Helicopter for personnel<br>and supply ship twice a week | 10 million USD |
| Maintenance | 10% yearly of CAPEX related to subsea mining vessel, vertical transportation system and topside equipment | 45 million USD |
| ***Annual OPEX cost*** | | ***150 million USD*** |

Source: Rystad Energy research and analysis

# Diesel cost for 22 MW is estimated to around 45 million USD

Technical economical model input assumptions

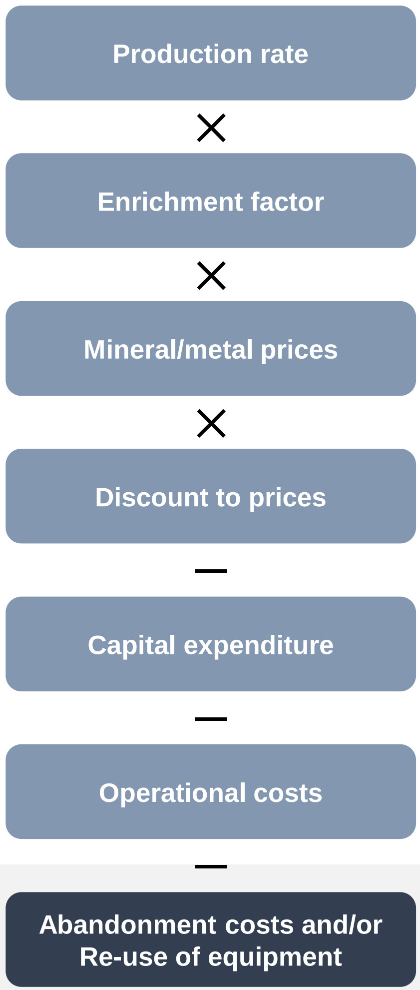
- **Production rate**
- ×
- **Enrichment factor**
- ×
- **Mineral/metal prices**
- ×
- **Discount to prices**
- –
- **Capital expenditure**
- –
- **Operational costs**
- –
- **Abandonment costs and/or Re-use of equipment**

| *Power consumption assumptions:* | | | |
|---|---|---|---|
| | 22 | MW | Power need |
| * | 24 | hours | |
| * | 365 | days | |
| = | 192,720,000 | kWh per year | Yearly power consumption |
| * | 3.6 | MJ/kWh | Conversion rate |
| = | 693,792,000 | MJ per year | Yearly power consumption |
| | 38.6 | MJ/l | Diesel energy content |
| | 39.8 % | % | Diesel energy efficiency |
| / | 15.35900709 | MJ/l | Diesel efficiency to power |
| = | 45,171,670 | liters | Diesel consumption |
| | 7.55 | NOK/l | Diesel cost per liter (excluding mva and road tax) |
| | 1.45 | NOK/l | Co2 tax per liter diesel |
| * | 9 | NOK/l | Diesel cost per liter |
| = | 406.5 | Million NOK | Diesel cost per year |
| /9 = | **45.2** | Million USD | Diesel cost per year |
| | | | |
| | 0.23 | USD/kWh | |
| | 2.11 | NOK/kWh | |
| | | | |
| | 1238 | Diesel: liter per ton | |
| | **100** | Diesel consumption per day (tons) | |

Source: Rystad Energy research and analysis

# Any significant abandonment costs or potential to re-use equipment?

Technical economical model input assumptions




Assumed to be **end-of project value** of around **USD 75 million** for the production units.

**Abandonment costs** are estimated at around **USD 100 million**. There is expected to be limited footprint caused by operations.

Source: Rystad Energy research and analysis