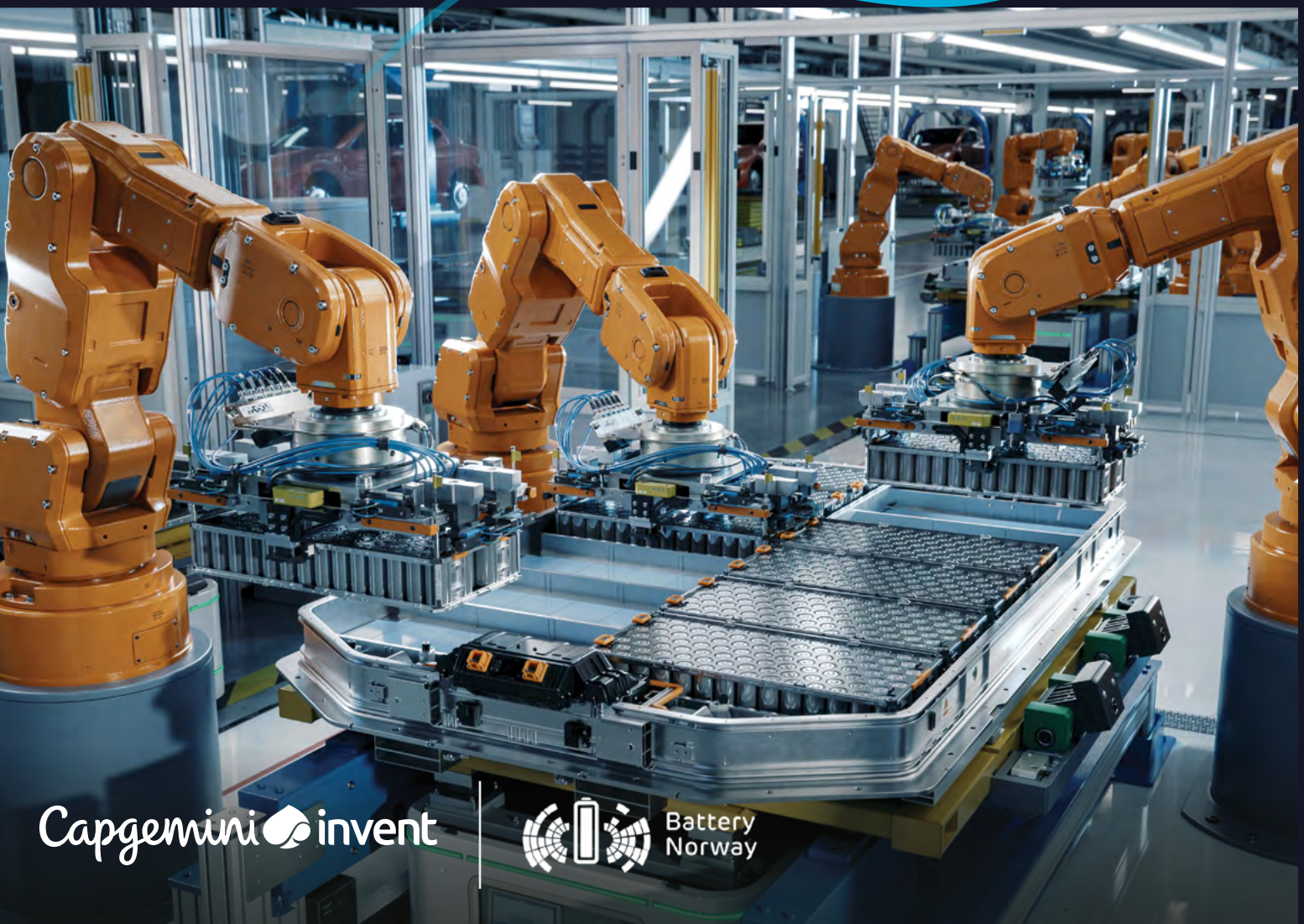
Norway's path to *sustainable battery development*

An analysis of the challenges and opportunities facing the Norwegian battery value chain



Capgemini invent | Battery Norway

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Foreword

The transition from fossil fuels to renewable energy is one of the greatest challenges and opportunities of our time. It is an absolute prerequisite for reaching the goals set by the Paris agreement and to limit the effects of climate change. Recent geopolitical escalations have heightened the attention on security of supply chains, leading to nations having to rethink their approaches and sourcing strategies. The battery industry will undoubtedly play an important role in limiting the effects of climate change and strengthening the energy security in Norway and Europe. To illustrate this, estimates show that switching from a traditional ICE car to an electric vehicle can reduce CO2 emissions by 60% in 2030 if the battery is produced in a country with a predominantly renewable energy mix. Hence, Norway has the unique opportunity of supplying Europe with sustainable batteries given its rich mineral deposits, renewable energy, ethical work standards and experience in process industries. However, to realize this opportunity, we need to act now. At Capgemini Invent and Battery Norway, we are fully committed to accelerating the green transition. This report is a result of our combined efforts in accelerating the growth of a sustainable battery industry. It comprises an overview of key challenges and opportunities directed at authorities and industry players to succeed with Norway's ambitions in battery production.

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About this report

This report is the result of a study carried out by Capgemini Invent. The study is based on interviews with a wide range of industry stakeholders and research into existing reports, publications, and news articles. The challenges and opportunities presented in this report should not be seen as the opinion of the stakeholders interviewed.

Capgemini Invent would like to thank the following organizations for their participation in interviews and for sharing their insights.

This study was conducted between March and July 2024, and challenges and recommendations are based on the status at the time of writing.

Executive summary

The transition to renewable energy sources like hydro, solar, and wind is inevitable for a sustainable future, driving the need for advanced energy storage solutions and significant quantities of batteries. According to the International Energy Agency, meeting COP28 targets hinge on a sevenfold increase of batteries by 2030[1]. While global demand for sustainable batteries rises, the industry continues to experience volatility. Companies are struggling to secure more financing, contracts and plans are being canceled, China is oversupplying batteries, and battery cell and raw material prices are dropping. At the same time, Europe aims to develop a more sustainable and independent battery value chain, backed by ambitious goals and regulations.

Norway is well positioned to contribute to this industry, with extensive experience in land and maritime electrification, access to renewable energy and raw materials, deep material and processing competences, and ethical work standards. Localizing battery production in Norway could reduce emissions by more than 60%, compared to a fully imported supply chain[2]. Despite having developed comprehensive national strategies for both raw materials and battery production, full scale battery cell production is yet to commence. To realize its ambitions and foster the development of a battery industry, Norway must act now.

This report aims to highlight the challenges and opportunities for Norway's battery industry based on interviews with more than 15 stakeholders and analysis of existing research. The goal is to present a holistic view of the industry's potential and outline seven key themes that need addressing – policy and regulations, financing, collaboration and partnerships, ESG, competency, battery technology and digitalization. Central to these themes is the need to navigate regulatory and policy hurdles, secure sustainable financing solutions, and enhance domestic expertise.

Firstly, there is a need for streamlined and supportive policies. Regulatory uncertainties and inefficiencies hinder progress in policies, financing, and collaboration. To enhance Norway's attractiveness for investment, processing times for opening mines and industrial facilities must be reduced. Norway should also explore incentives akin to the US Inflation Reduction Act and align with policies like the Critical Raw Materials Act to facilitate seamless trade with the EU, which is anticipated to be Norway's primary market.

Furthermore, the industry is characterized by high capital intensity and operational costs. This, coupled with declining mineral prices, creates barriers for new investments. Establishing strategic partnerships, offtake agreements, and vertical integration along the value chain can help de-risk projects and initiate production. Simultaneously, the government can facilitate industry development and scaling through public active ownership similar to Finland's Finnish Mineral Group.

Finally, there is a need for a skilled workforce and advanced technological expertise within battery technology and digitalization. With its strong existing research environments, Norway has the potential to emerge as the leading research hub in Europe. The raw material deposits in Norway provide a competitive advantage for certain battery components, such as cathodes and anodes. As Norway develops its battery industry, there is an opportunity to build a digitally native industry from the ground up. This includes creating scalable ecosystems that foster transparency and collaboration to fully harness the power of data. There is a global focus on innovating battery technology to make batteries cheaper, more sustainable, and efficient. However, the successful manufacturers will be the ones who can produce in time, at scale and at cost.

Norway has the potential to become a key supplier to the European battery ecosystem by leveraging its competitive advantages. By acting now, Norway can help Europe to achieve its sustainability goals and lead the way to a green future.

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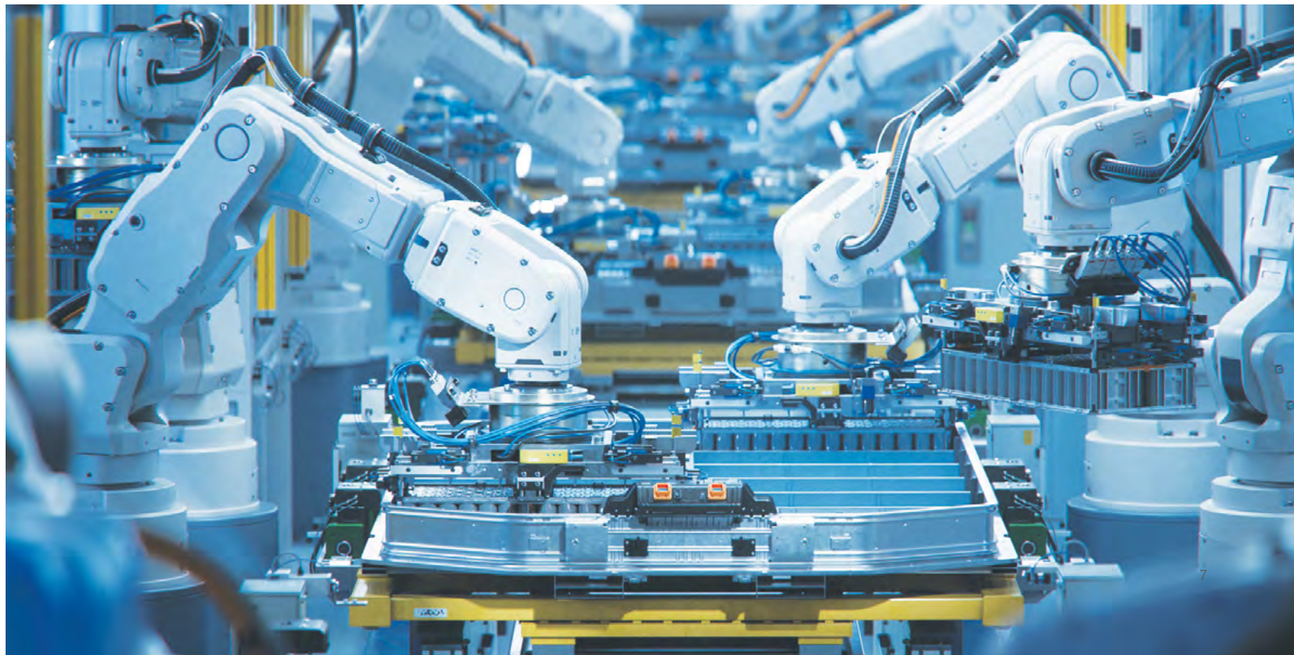
Introduction

Setting the scene

The battery industry faces a twofold challenge: increasing total battery production while reducing its carbon footprint. A sustainable future depends on replacing fossil fuels with renewable energy sources like hydro, solar, and wind. Achieving a successful green transition relies heavily on energy storage solutions and substantial quantities of batteries for both the energy and transportation sectors. According to the International Energy Agency (IEA), the Net Zero Emissions scenario in 2030 sees a 60% reduction in CO2 emissions due to the use of batteries, illustrating the battery's importance in the green transition. While the global demand for sustainable batteries rises, new market entrants struggle as China already manufactures enough batteries to satisfy demand[3]. Meanwhile, Europe aims to lead in the development of greener and more efficient batteries. With established players across the battery value chain, deep material expertise from the process industry, and experience as a leader in both land transport and maritime electrification, Norway is positioned to be an important player in the European battery industry.

This report highlights global trends in the battery industry and examines the status of developments in Norway. Through interviews and analyses of existing material, the report explores the challenges and opportunities for Norway, with a specific focus on seven key themes: policy and regulations, financing, collaboration and partnerships, ESG, competency, battery technology, and digitalization. It further identifies areas where Norway can take a leading role in the industry, and whether the battery industry can become Norway's next industrial success story.



Battery value chain

The battery value chain is generally divided into three parts: upstream, midstream, and downstream. Although there are various ways to further categorize the value chain, a common division encompasses six primary segments: extraction of raw materials, processing and refining, active materials manufacturing, cell manufacturing, assembly of battery packs, and recycling and reuse.

Raw material mining: Exploration of brown and green fields possible for mining and extraction of raw materials, such as lithium, cobalt, copper, and nickel. Raw material processing: Process used to convert impure raw materials to their purest commercial forms.

Active materials: Cathodes and anodes, and electrolytes that facilitate the flow of electricity. Cathode active materials are typically metal oxides such as nickel, manganese, and cobalt, while anode active materials are often graphite, silicone, or both. Other active materials include separators and casings[4].

Cell manufacturing: The process of combining all necessary components into a functioning cell. Coating is typically the first step of manufacturing, followed by several processes involved in electrode manufacturing and cell assembly, resulting in a fully operational battery cell.

Battery pack manufacturing: A mechanical assembly process where cells are arranged in series into battery modules, which are then assembled into battery packs. These packs deliver power at the desired voltage and capacity, and typically include software and temperature regulation systems. For example, an electric vehicle (EV) battery may require 400-800 volts, with each battery cell typically providing four volts[5].

Recycling and reusing: The process of handling used batteries and reusing old battery components for new applications. This involves recovering raw materials and components, such as copper, plastics, aluminum, and black mass, which contain valuable metals like nickel, manganese, cobalt, and lithium[6].

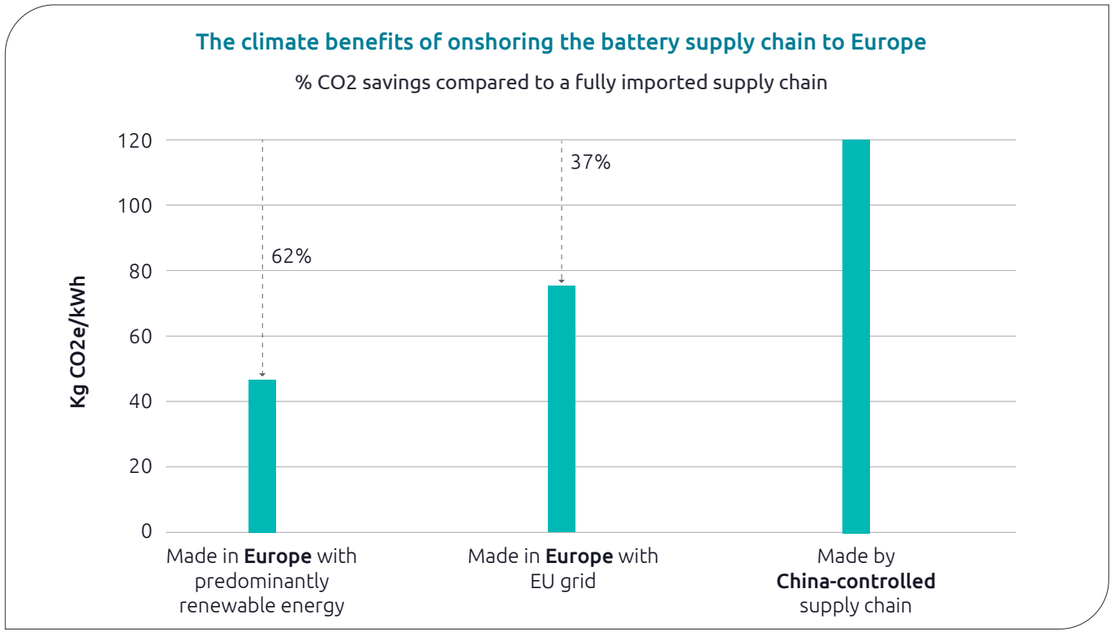
The battery value chain is projected to undergo significant expansion by 2030, requiring unprecedented levels of production and resource extraction. In an analysis from 2019, World Economic Forum stated that mining activities must increase 540x, extracting a volume equivalent to over 300 Great Pyramids of Giza annually. Raw material refining is set to increase 14x, processing a weight comparable to more than 110,000 Boeing 787s each year. The production of active materials will need to grow 15x, sufficient to produce over 800 billion AA type battery cells. Cell production will require approximately 120 additional giga factories, each matching the capacity of today's largest facilities. Furthermore, the recycling sector must expand 15x to handle the end-of-life processing of the equivalent to over 10 billion mobile phone batteries annually[7]. As projections for both battery supply and demand have been significantly increased since 2019, these figures represent the minimum estimates.

Importance of a local supply chain

China currently dominates the entire battery value chain, creating a dependency for the European market on Chinese supply, and posing sustainability challenges[1]. Nearshoring the battery supply chain provides greater control over manufacturing processes and enables Europe to establish and enforce environmental and social standards while ensuring meaningful engagement with local communities. A localized battery value chain would also result in shorter supply chains and reduced transportation related emissions. Additionally, Europe's high share of renewable energy contributes to cleaner production processes[2].

From an emission saving point of view, manufacturing energy intensive battery components in Europe significantly reduces carbon emissions. Producing battery cells locally, as opposed to importing from China, results in a 20-40% reduction in carbon emissions[2]. Local sourcing of nickel can decrease emissions by 85-95% compared to current supplies from Indonesia, and European lithium production can achieve up to a 50% reduction compared to processing Australian ore in China[2]. As shown in Graph 1, localized production based on the EU energy grid can reduce carbon emissions by approximately 37%. This reduction increases to over 60% when using predominantly renewable energy sources. This is projected to save an estimated 133 million tons of CO2 by 2030, equivalent to the annual emissions of countries such as Chile or the Czech Republic in 2022[2]. With Norway's high share of renewable energy, the climate benefits would likely be close to the best case scenario of around 60% emission reduction.

Graph 1. % CO2 saving compared to a fully imported supply chain, Kg CO2/kWh. Source: Transport & Environment, 2024.



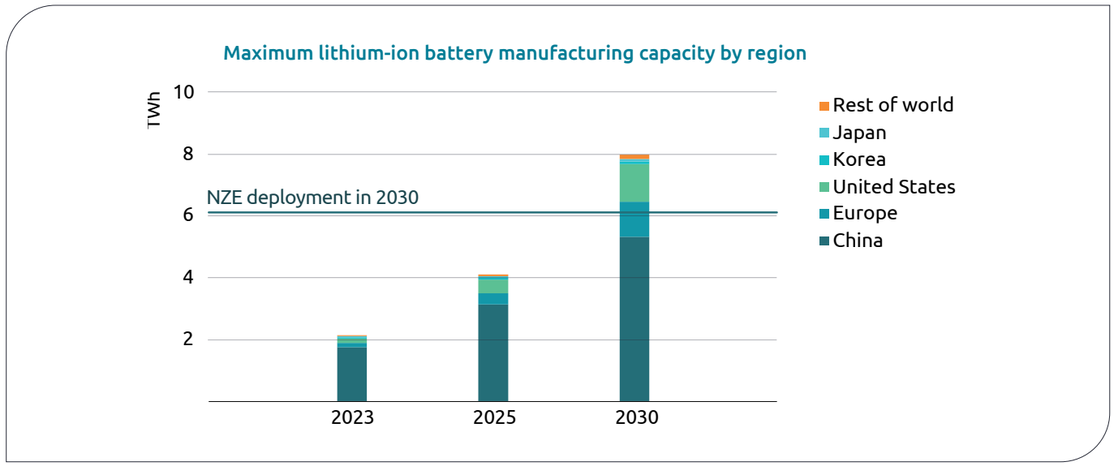
Battery industry status

World – Expected capacity to exceed demand globally

The world is becoming increasingly globalized, and the battery industry is no exception. To understand the challenges and opportunities Norway is facing, it is crucial to comprehend the global battery industry and Norway's position within it. Batteries are a fundamental component of the global energy system and the fastest growing energy technology in the market. From 2018 to 2023, global investment in EV batteries surged remarkably, increasing eightfold[1]. Investments in battery storage saw a fivefold increase, reaching NOK 1,650 billion in 2023, with China, Europe, and the US collectively contributing with more than 90%[1]. As shown in Graph 2, manufacturing capacity is set to quadruple by 2030, reaching approximately 9.4 TWh (assuming 100% utilization), which would be sufficient to fulfill the battery requirements for the NZE Scenario* by 2030. Nearly 80% of this capacity will come from companies certified to serve the EV market [8][1]. This expansion is expected to drive the market for battery packs in EVs and storage applications from NOK 1,330 billion to almost NOK 5,520 billion by 2030[1]. The International Energy Agency's (IEA) analysis indicates that energy storage must increase sixfold by 2030 to meet COP28 goals, a target anticipated to be achieved almost exclusively by batteries.

While battery manufacturing capacity is set to increase, Bloomberg expects the market to head into over supply. Both prices and margins are expected to decrease, making entry to the battery industry difficult[9]. In order to compete, Europe aims to leverage sustainability requirements against cost effective Chinese mass production. New EU regulatory framework for batteries include a Battery Passport initiative, which aims to enforce transparency in the battery industry, and ensure that major players and countries adhere to environmental and ethical standards.

Graph 2. International Energy Agency (2024), Batteries and Secure Energy Transitions, IEA, Paris . Maximum lithiumion (with 85% utilization factor) battery manufacturing capacity by region, 2023, 2025 and 2030.



**According to IEA, The Net Zero Emissions by 2050 Scenario (NZE Scenario) is a normative scenario that shows a pathway for the global energy sector to achieve net zero CO2 emissions by 2050 (10).*

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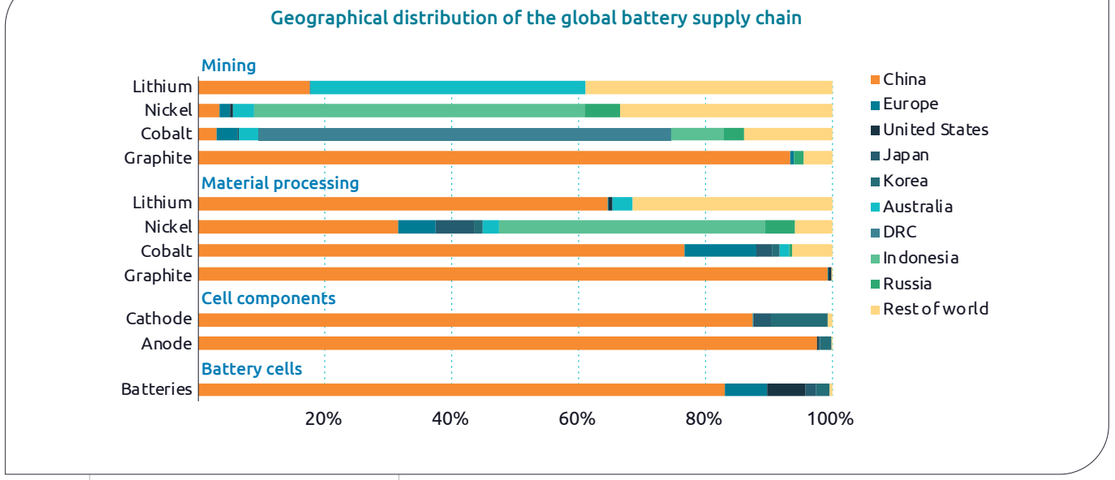
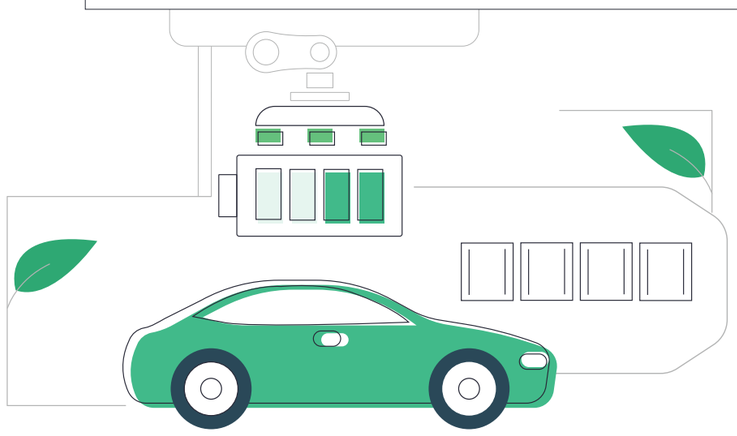
Asia – China dominates the battery industry across the value chain

Asia, with China at the forefront, is dominating the battery industry and leading across the entire value chain, from mining and processing to battery pack manufacturing. China began investing in the battery value chain over a decade ago and has increased its share of global cell production from 75% in 2020 to 83% today[1]. Additionally, China accounts for more than 50% of raw material processing and more than 90% of cathode and anode manufacturing. South Korea and Japan represent 4% of global battery production combined. South Korean companies are key international players in battery manufacturing, with more than 350 GWh of manufacturing capacity outside of its borders [11].

Graph 3. International Energy Agency (2024), Batteries and Secure Energy Transitions, IEA, Paris. Geographical distribution of the global battery supply chain. DRC = Democratic Republic of the Congo. Graphite refining is only refining of natural graphite to spherical graphite. Mining and processing are based on production data. Cathode, anode and batteries are based on manufacturing capacity data.

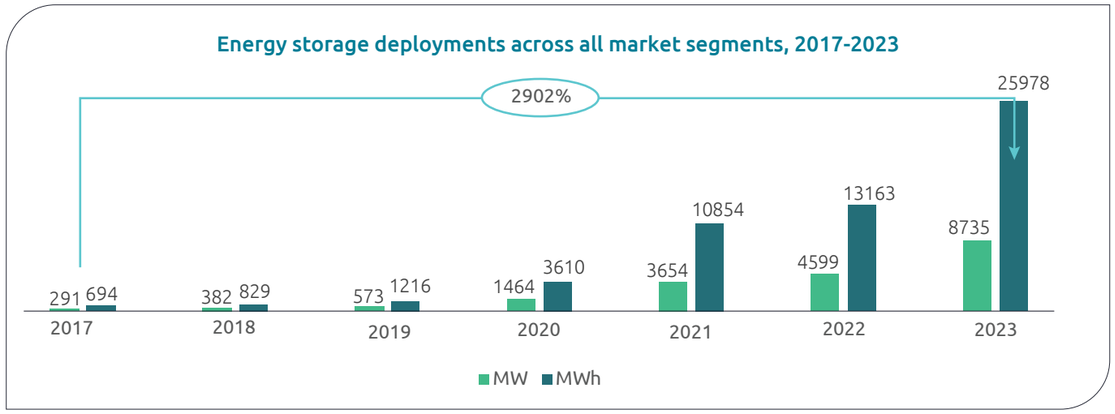




North America – Incentives and natural resources attract battery players

The US is the second-largest battery storage market in the world, with capacity additions roughly doubling year-on-year, reaching over 8 GWh in 2023, as shown in Figure 6. The US is responsible for 10% of global EV production, but only 6% of battery cell manufacturing[1]. The IRA of 2022 has spurred battery companies worldwide to consider the US as a favorable location for their operations, offering more than USD 15 billion of production credits for advanced manufacturing. North America has set ambitious targets to increase its market share of battery production to 15% by 2030 and achieve self-sufficiency domestically[1]. Canada plays a key role in the global battery value chain, ranking as the fifth largest producer of graphite and nickel and the sixth-largest manufacturer of commercial vehicles globally[12]. Access to raw materials, renewable energy, and proximity to the North American automotive market are key reasons why a company like Northvolt have announced plans for a 60 GWh lithium-ion gigafactory in Montreal[13].

Graph 4. Source: Wood Mackenzie (14). US Energy storage deployments across all market segments, 2017-2023.



Europe – Regulatory frameworks are developed to tackle geopolitical risks

Europe contributes to nearly 20% of global EV production, but accounts for only 7% of global battery cell manufacturing, primarily situated in Poland and Hungary[1]. In terms of mining, Europe is the only continent with declining production rates over the past 20 years, producing 5.4% of cobalt, 2% of graphite, and negligible volumes of lithium[15]. Although Europe does not have significant shares in any part of the value chain geographically, many European companies hold substantial shares of production outside Europe. For instance, the European company Glencore owns a third of all cobalt production in the DRC[16]. The EU's CRMA aims to reduce the current high dependence on foreign countries, support a local value chain, and enhance battery sustainability. The European Battery Alliance (EBA) projected that the total European turnover (annual GDP/added value created) in the battery value chain will reach EUR 625 billion in 2030[17], with goals to increase Europe's market share of battery production to 15% by 2030[1]. An initiative by the EBA is the European Battery Academy, which is dedicated to addressing the skills shortage in the battery industry. This program aims to upskill approximately 800,000 workers by 2025[18].

Battery Passport

The Battery Passport is introduced as part of the new EU regulatory framework for batteries. It aspires to report on approx. 100 data points on material prove-nance, chemical make-up, manufacturing history, and sustainability performance, to ensure sustainable bat-tery value chain. However, there are implementation challenges including data silos between suppliers, lack of standards and validity of collected data. The Battery Passport will be required for EV batteries >25 kg, indus-trial batteries >2 kWh and light means of transport batteries [69] [72].

EU's Critical Raw Materials Act (CRMA)

The European Critical Raw Materials Act is a strategic framework by the European Commission to secure and sustain the supply of critical raw materials (CRM) and reduce EU's dependency on single country suppliers. The following benchmarks have been established for 2030:

- >10% of the EU's annual consumption for extraction
- >40% of the EU's annual consumption for processing
- >25% of the EU's annual consumption for recycling
- =/< 65% of the EU's annual consumption from a single third country (33).

US' Inflation Reduction Act (IRA)

The IRA of 2022 is a legislation aimed at combating climate change and driving economic growth. Since its enactment, over $115 billion in clean energy manufac-turing investments have been announced. The IRA provides substantial tax incentives, including up to a 30% credit for renewable energy projects, with addi-tional bonuses, such as a 10% credit for projects in low-income and fossil fuel-dependent communities [73].

Important Projects of Common European Interest (IPCEI)

IPCEI is an EU tool providing state aid to address market failures and fund major innovation and infrastructure projects within the EEA. It aims to develop new products, services, and processes that would not be realized with-out support, fostering sustainable growth, employment, and global competitiveness. Projects must include cut-ting-edge innovation. Innovation Norway coordinates IPCEI efforts in Norway [70].

Norway – Closing in on supplying sustainable and ethical batteries to Europe

Norway has published comprehensive national strategies for both raw materials and battery production. The battery strategy outlines ten actions for sustainable industrialization, covering everything from mineral extraction to battery recycling[17]. Through soft funding mechanisms managed by Innovation Norway and IPCEI, NOK 1 billion has been granted battery companies Vianode, Morrow, Cenate, and Beyonder[19].

Several Norwegian companies are advancing their projects, with some closing in on production. The lithiumi-on battery manufacturer Morrow, plan to begin mass production in Q3 of 2024 in their gigafactory in Arendal[20]. Beyonder, another lithium-ion pouch cell manufacturer, has developed the next generation of eco-friendly and energy-efficient batteries and are set to scale production through Asian giga scale factories[21]. Elinor Batteries has in 2024 produced its first battery cells in collaboration with SINTEF[22]. Freyr Battery operates its Customer Qualification Plant in Mo i Rana, focusing on product development and refinement. In the meantime, Freyr pursues their Giga America project in Georgia[23].

There are also developments and initiatives in other parts of the Norwegian value chain. The graphite anode manufacturer Vianode has been operating an industrial pilot plant in Kristiansand since April 2021 and is set to achieve industrial production at their facility at Herøya Industripark[24]. Hydrovolt, an EV battery recycler, has been operating one of Europe's largest EV recycling plants in Fredrikstad since May 2022. The joint venture between Hydro and Northvolt has also signed an agreement on the delivery of black mass to Fortum's battery material recycling plant in Finland[25]. Norway's early adoption of electric transportation positions it as a pioneer in collecting, reusing, and recycling large quantities of used car and ferry batteries, giving advantages to actors like Hydrovolt. By the end of 2023, Norway had around 700,000 electric cars, one of the highest per capita globally[26]. As of April 2024, Norway operated 92 electric ferries, with Norwegian companies leading in electric boat development for the global market[27].

While the examples above outline numerous plans and projects, full-scale battery production has yet to commence. A Norwegian battery value chain with four full-scale gigafactories (Beyonder, Elinor, Freyr and Morrow) could indirectly employ up to 30,000 people[28]. This would also create significant opportunities for adjacent businesses throughout the value chain. According to an NHO analysis the battery industry revenue could reach at least NOK 90 billion by 2030 and NOK 180 billion by 2050[17].

Norwegian Renewable Energy

Norway has the highest share of renewable energy in electricity production in Europe, and the lowest emis-sions from the power sector. In 2023, Norway pro-duced 170TWh of renewable power. In comparison, annual electricity consumption varies between 130 and 140 TWh. Demand is expected to increase due to electrification of transport and industry (SSB & NVE, 2024).

Raw Materials in Norway

The Norwegian Geology Survey (NGU) valued known metal deposits in Norway at NOK 3,696 billion in De-cember 2021, using prices from London Metal Ex-change. An additional NOK +8,000 billion could be realized should Fensfeltet prove more resourceful. Around 4,600 metal deposits are registered in Norway, but only 247 of these have known tonnage. In other words, there could be a lot of unrealized potential in the Norwegian soil (NGU, 2022).

Challenges and opportunities

While there are many positive developments and efforts, the battery industry is facing a volatility and uncertainty. This report has identified seven themes where both challenges and opportunities will arise for the Norwegian the battery industry.

1 **Policy and regulations**
Regulatory changes and targeted incentives are opportunities to streamline bureaucracy and catch up with mature markets.

2 **Financing**
Securing robust financial support is essential to advance a capital-intensive battery industry.

3 **Collaboration and partnerships**
Partnerships are essential to de-risk projects and create a well-functioning domestic value chain.

4 **ESG**
Onshoring the battery value chain is an important measure towards meeting future industry standards and ESG goals.

5 **Competency**
The Norwegian battery industry could employ tens of thousands, but upskilling and international expertise are needed to bridge the gap.

6 **Battery technology**
Norway must address the dual challenges of performance and sustainability to capitalize on technology opportunities.

7 **Digitalization**
Digitalization is key to scaling up and optimizing Norway's battery manufacturing processes.

Policy and regulations

Regulatory changes and targeted incentives are opportunities to streamline bureaucracy and catch up with mature markets

Challenges

The Norwegian and European battery industries are lagging years behind market-dominating players like China in terms of industry development. The Norwegian government must level the playing field between imports and local production. Strict EU environmental regulations make it difficult to compete with countries with less regulations, as they can offer lower prices. Other countries offer attractive conditions for battery manufacturing. As we have seen, battery players establish themselves in the US due to the beneficial IRA. The US also has stricter tariffs on Chinese EVs and battery cells and components than the EU, even with EU's recent increase in tariffs on Chinese EVs[29] [30]. This makes the European market a stronger target for Chinese exports, increasing the level of competitiveness for European and Norwegian battery companies.

Norway is known for its comprehensive bureaucratic processes, presenting hurdles for companies seeking to establish themselves. Mine lead times in Norway can amount to 20 years[31], about seven years longer than in the US[32], and about 17 years longer than the EU's CRMA demand of only 27 months for so called strategic projects[33]. Some countries even offer tenders for ready-to-mine sites, while in Norway, the developer largely bears the risk. Interviewees have voiced concern about long processing times, delaying investments and initiation of production.

The Norwegian battery players are impacted by global trends, with geopolitical tension, fluctuating prices, and challenging macroeconomic conditions. They ultimately play in an international market and must adhere to international policies and regulations. As the EU will be the main market for Norwegian exports, Norwegian companies must deal with regulations such as the CRMA and continue to adapt to new regulations. For instance, there are discussions about a potential EU ban on many per- and polyfluoroalkyl substances, known as PFAS (forever substances)[34]. Swift changes in policies like this are expected to arise in the next years, especially within sustainability, posing continuous challenges for Norwegian players.

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Opportunities

The IRA has shown great success in attracting both investors and companies to the US through favorable incentives[34]. If the Norwegian government wants to facilitate for a competitive business environment, similar subsidies should be considered. Additionally, Norway must ensure that the trade regulations and customs policies for raw materials and battery components facilitate for seamless and efficient trade with other sustainable countries.

The positive side of Norway's bureaucratic processes is that the country remains relatively stable in terms of political governance, business conditions, and conflict levels, which are attractive factors for developing a new industry. With both battery and raw materials strategies, and a 2024 state budget that commits NOK 1 billion in soft funding to battery projects, the Norwegian government has shown willingness to commit to developing a Norwegian battery industry. Furthermore, the EU's objective to reduce the processing time presents an opportunity for Norway to follow suit and expedite its regulatory procedures and improve its competitive stance in the mining sector. To facilitate faster permitting processes, Norway can consider utilizing existing industrial areas for upstream and midstream battery companies, as these are easier to permit than undeveloped natural zones.

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Financing

Securing robust financial support is essential to advance the capital-intensive battery industry

Challenges

The battery value chain, from mining and refining of raw materials to large gigafactories and recycling facilities, is a capital-intensive industry. There are several factors that drive the capital intensity of the industry, such as complexity, material scarcity, and degree of technological and process specialization, particularly in the up and midstream segments. High CAPEX investments are needed at all stages. While subsidies and tax relief can mitigate investment risks, the delay between initial investments and recurring revenues hinders timely industry development. CAPEX and OPEX for battery cell production are some of the highest in Europe compared to other industries, mainly due to the high energy and labor costs. According to T&E, roughly EUR 215 billion in CAPEX and EUR 61 billion in annual OPEX are needed to reach the stated plans for battery cell manufacturing, cathode facilities, and lithium refining in Europe. If Europe is to match the support given through the US's IRA, it would amount to about EUR 2,6 billion in annual OPEX support[2].

Early stage battery companies in Norway emphasize the need for financial support beyond initial start-up stages, particularly given today's challenging capital market. The NOK 1 billion in soft funding provided by the Norwegian government seems inadequate and has mainly helped already established players. Based on the interviews, early stage companies signal that they are missing financial support, hindering them from even entering the market.

Attracting private equity has proven itself difficult, as the industry has characteristics unattractive for investors. Global announced production capacity is expected to far exceed demand, posing risks of underutilization and market consolidation[34]. Europe has a similar situation with announced capacity exceeding local demand[34]. These market conditions also influence prices for raw materials and batteries. Raw materials have seen large price fluctuations, with lithium spot prices plummeting by 75% and other key materials such as nickel, cobalt, manganese, and graphite seeing declines of 30-45% in 2023. This was mainly due to supply exceeding demand in this period and a correction after record high prices in 2022[35]. On the other hand, battery prices saw a dip of 14% in 2023, according to Bloomberg (9). Additionally, big cash flows from battery players are not expected to be seen until later. This, combined with the industry's need to comply with ever changing regulatory requirements, leaves investors skeptical. The skepticism towards investing in Norwegian battery companies is further enhanced with the trend of companies needing new rounds of financing without creating revenue.

Opportunities

Norway has several options to accelerate the battery industry through financing, including equity and active ownership, debt financing like convertible risk loans, and soft funding. Recently, the Norwegian government has opted for the latter, offering grants through Innovation Norway and the IPCEI.

The Norwegian government can consider equity financing, a strategy that has proven successful in comparable countries. Finland's Finnish Mineral Group (FMG), a state owned company, invests in downstream and midstream mineral and battery companies through long term active ownership. Adopting a similar approach can facilitate the expansion of battery companies along the value chain and support the development of a Norwegian battery industry. Like FMG, the returns from investments can be reinvested in other battery companies, akin to the early state-owned oil companies. This can ensure positive returns while fostering industry growth.

While long term OPEX subsidies may not be a viable solution, as several interviewees have noted the importance of proving a viable business case, there is recognition of the struggle of market entry costs. Some suggest that the most realistic option for the Norwegian government is to provide convertible risk loans or CAPEX support. Public entities like Eksfin have extensive experience providing loans to businesses in emerging exporting industries. This support helps companies in the early and scale-up phases while ensuring they remain accountable and incentivized towards cost discipline. An example within Norway is Hydrovolt, which has secured financing of NOK 63 million through DNB and Eksfin[36]. Morrow has backing from the state-owned Siva for their gigafactory in Arendal[37].

Even with notable public investments and loans, Norwegian companies will need to go the capital market for sufficient equity. Both sustainability and recycling requirements are expected to evolve. Norwegian battery players can position themselves for long-term success by utilizing Norway's clean energy mix in production and leveraging the mature recycling environment. Investors will also find companies with off-take agreements and secured sales volumes more attractive. Looping back to policy changes, an answer to the US IRA from Norway is expected to draw investments and attention from foreign the capital market. The most interesting business cases and top projects will likely secure funding, making it essential for companies to strive for self sufficiency to ensure the industry's success.

Collaboration and partnerships

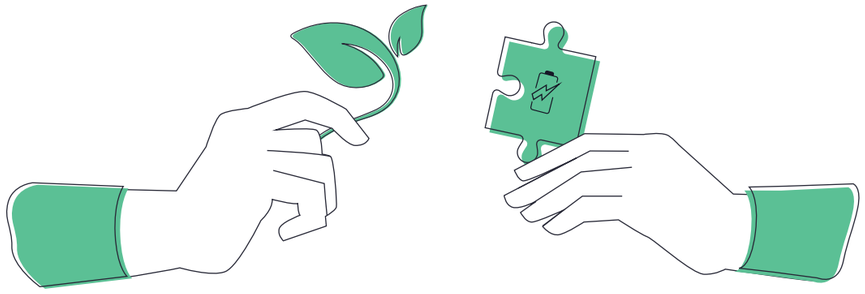
Partnerships are essential to de-risk projects and create a well functioning domestic value chain.

Challenges

Battery production is a complex process, and no Norwegian or European company operates across all parts of the value chain. Due to the industry's high interdependence and risk of overcapacity, battery companies are increasingly integrating along the value chain to enhance supply-chain resilience. However, this trend also introduces challenges such as over-reliance and intensified competition.

Exclusively relying on a single partner poses significant operational and financial risks. Overdependency makes you vulnerable if your partner faces financial instability, operational setbacks, or strategic misalignments. This is exemplified by BMW recently cancelling a USD 2 billion contract with Northvolt due to delivery delays and excessive scrap production by the Swedish company[38]. Additionally, off-take agreements can limit manufacturers and suppliers from capitalizing on spot-market opportunities, especially when demand exceeds supply in the upstream segment of the battery value chain.

The Norwegian battery industry is still in its early stages with a limited market size. Even though there are existing strategic partnerships, such as the one between Morrow, Nordic Batteries and Eldrift[39], immaturity and market size can make it challenging to find domestic partners. While seeking international partners is an op-tion, smaller and new entrants face limited negotiation power due to the trend of major players securing partnerships. This, coupled with the high specialization and technical complexity of batteries (evidenced by the wide range of battery chemistries) that requires matchmaking between suppliers and manufacturers, illustrates difficulty in obtaining strategic partnerships.



Norway's path to
sustainable battery development

Opportunities

Partnerships and collaboration are opportunities for securing financing and de-risking projects. This involves formal partnerships, such as offtake agreements and joint ventures, used to strengthen vertical integration, enhance supply chain resilience, and drive technological innovation. There already players in the value chain vertically integrating operations through formal joint ventures (e.g., EV battery recycling company Hydrovolt being a joint venture between Hydro and Northvolt), majority/minority participation stakes (e.g., Morrow Batteries being supported by an industrial network of companies like Siemens, ABB, and Å Energi), and long term partnerships in the form of offtake agreements (upstream mining company Kuniko's offtake agreement with automaker Stellantis). Several interviewees have stressed the importance of securing strategic partners before investing billions in production, as this can ensure access to materials and secured sales.

Norway's high concentration of EVs offers a unique opportunity to strengthen circular business models by incorporating battery recycling directly into manufacturing processes. This approach can reduce the industry's environmental footprint by minimizing the need for new materials. Norway is already home to Hydro-volt, one of the largest EV recyclers in Europe[40]. Hydrovolt's collaboration with Fortum Battery Recycling on black mass offtakes illustrates an opportunity for Norwegian battery players to utilize recycled materials from EV batteries in their production. With upcoming requirements for minimum recycled content, recycling companies like Hydrovolt will become increasingly attractive partners for battery manufacturers.

The Nordic and Norwegian battery ecosystems were highlighted by multiple interviewees as an arena for collaboration. Domestically, Norway has the national industrial collaboration platform Battery Norway, founded by Vianode, Beyonder, Morrow Batteries, Freyr, Nikkelverket and Batteriretur. The platform coordinates development and scaling efforts across the industry, supports the development of relevant competencies and infrastructure, and explores synergies within the Norwegian and Nordic battery ecosystems. Battery Norway will closely follow the EU's battery strategy and advise the Norwegian authorities[41]. The Nordic region aims to become Europe's most sustainable battery ecosystem by 2026 through the Nordic Battery Collaboration. Launched in April 2021 by Norway, Sweden, and Finland, the initiative focuses on boosting sustainable production, innovation, and global trade, while attracting foreign investments and partnerships (42). As the Norwegian battery industry is in its early stages, leveraging existing ecosystems is crucial to find strategic partners, share knowledge and explore synergies within the Nordic area.

ESG

Onshoring the battery value chain is an important measure towards meeting future industry standards and ESG goals.

Challenges

The sustainable and responsible supply of CRMs to the battery industry relies on interconnected practices including managing greenhouse gas emissions, water consumption, waste generation, safe and fair labor practices, and land use. While IEA highlights positive developments in several areas[16], research has identified negative trends, such as increased waste generation per unit of mineral produced. A 2019 analysis estimated that by 2030, CO2 emissions from the global battery value chain could reach approximately 182 Mt CO2E, which is almost four times Norway's current emissions. The primary contributors are the manufacturing of active materials, other components, and cell production[7].

The rapid scaling of the battery industry presents further strain on social, environmental, and integrity challenges, driven by raw material scarcity, immature ESG practices, and lack of refining capacity in Europe. By 2030, lithium is forecasted to grow by a factor of six, cobalt by two, class 1 nickel by a factor of 24 and manganese by 1.2[16]. With mining and processing operations concentrated in only a handful of countries (e.g., 50% of global cobalt reserves in the DRC and 99% of lithium reserves in Chile, Argentina, Australia and China), dependency on singular economies will increase[16]. The countries that currently dominate the mining industry are often characterized with geopolitical, ethical, and environmental risks. In Europe, the 2022 CRMA aims to mitigate these risks by setting targets for local extraction and processing of raw materials, reducing dependency on any single country to below 65%[33]. However, the act has been flagged as optimistic by several actors, and some interviewees highlighted how the regulations lack support to foster local production. Europe's goal to increase battery cell production from 7% to 15% by 2030[1] reveals mismatch between localization of raw material processing and cell production. With limited processing capacity in Europe, and China dominating refining for nearly all minerals, there is a risk of insufficient sustainable refining capacity.

Battery companies rely on the support and cooperation of small communities to establish their facilities. However, gaining this support can be challenging as these communities often bear the brunt of the negative impacts of production, such as waste generation, disruption of local wildlife, and higher electricity costs. The onshore wind industry has faced similar challenges, with numerous projects being canceled due to public opposition[43].

Europe aims to house the most sustainability producers, but according to Battery Monitor 2023[34], China is implementing stricter emission and wastewater regulations. This raises a concern of whether European regulations will benefit local production or not. China's CATL has announced plans to reach carbon neutrality in its core operations by 2025, and across the entire value chain by 2035[44]. Sustainable battery production is supposed to be Norwegian actors' unique selling point, but if production seizes to begin, this competitive advantage might disappear.

Opportunities

Norway has a competitive edge with the highest share of renewable energy in electricity production in Europe[45]. The electricity mix is a critical factor for GHG emissions as the largest part of CO2 emissions in production of lithium-ion batteries comes from electricity usage for formation, drying processes, and the utilization of clean rooms[34]. The energy affordability and low carbon footprint are levers that attracted players such as Morrow to Norway and can be used to take a leading stance in sustainable battery production.

Given the increased demand for batteries, there will be a need for more sustainable CRMs. The Nordic supply potential for CRMs has been highlighted in multiple geological surveys as promising, but with large variations[46]. Norway has identified approximately 4,600 metal deposits, with only 247 of these having known tonnage. This disparity highlights an opportunity for expanding mining operations. Everything is in place for Norway to pursue sustainable mining, with strict environmental requirements and regulations, and a history as a former mining nation[47]. There are already companies exploring this opportunity, such as Kuniko set on becoming a zero-carbon footprint mining company.

In addition to increased local CRM production, efforts are needed to increase refining capacity, where current capacity remains modest. As of today, Australia produces almost 45% of the world's lithium[1], and virtually all of it is sold to China[48] for processing. There is an opportunity in increasing the processing capacity in proximity to Norwegian gigafactories to reduce emissions and dependency on Chinese refineries. According to T&E, lithium processed in Europe generates only one third of the emissions compared to lithium processed in China, even when the ore is imported from Australia[2]. An example of setting up local refineries is Tesla, who in May of 2023 broke ground for its in house lithium refinery in Texas[49].

The Norwegian battery industry can serve European OEMs with high quality and low impact batteries. In Europe, new EV registrations reached nearly 3.2 million in 2023, up almost 20% from 2022. In the EU, EV sales were 2.4 million with similar growth[50], illustrating a business opportunity in a growing market. Despite the resources and energy needed to produce EV batteries, the emission benefits of EVs compared to internal combustion engine (ICE) cars are significant when you take the whole life cycle into account. Depending on the energy mix of the region in focus, the CO2 advantage over the life cycle of an EV in the base case 2030 ranges from 19% to 60% versus an ICE vehicle during the first life of the battery[7]. As OEMs seek to minimize their overall environmental impact, batteries produced in Norway will likely be in high demand.

Competency

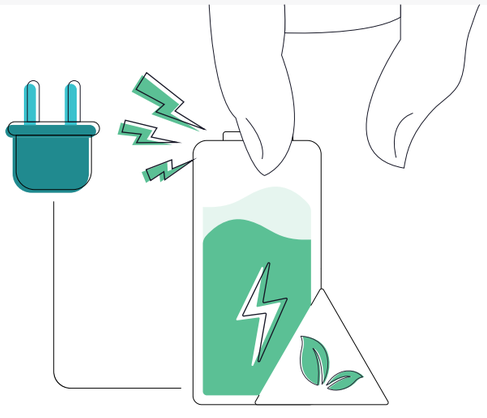
The Norwegian battery industry could employ tens of thousands, but upskilling and international expertise are needed to bridge the gap.

Challenges

The battery industry will require a highly competent workforce. For a 32 GWh battery cell factory, estimates indicate a need for 150 PhD holders, 300 master's degree holders, 600 bachelor's degree holders, 1,500 skilled workers, and 300 individuals with formal vocational qualifications[51]. Norway must acquire or educate thousands of qualified individuals to pursue its ambitious plans.

In the short term, Norwegian battery companies must look internationally to meet their capacity needs, both in terms of quantity and competency. Interviewees stated that Sweden has already been emptied of relevant expertise, especially due to the ramp up of EV battery manufacturing in central Europe. Most of the global expertise resides outside of Europe, particularly in China, Korea and Japan[1]. Norway must compete with bigger battery nations to attract this expertise. Additionally, interviewees report difficulty attracting talent to Norway due to lower salaries compared to the US.

Beyond short term international recruitment, Norway needs to train and reskill its existing workforce. In 2022, there was a notable gap in the number of applicants to engineering programs and available places, indicating that many qualified applicants did not receive admission offers[52]. The EU has identified the need to train and reskill approximately 800,000 employees by 2025 to meet the growth in electrification through battery technologies[17].



Opportunities

Access to a competent workforce is crucial for developing a battery industry. Norway's strengths include expertise in materials technology, metallurgy, electrochemistry, and high-tech industrial processes. The Norwegian industry is also known for collaboration between technical industrial sectors and academia, flat structures, and the use of automation[17]. These strengths are highly transferable to the battery industry, as demonstrated by several companies interviewed who have hired directly from the power, electricity, and process industries. Vianode exemplifies the utilization of existing expertise, originating from Elkem, a world leader in advanced materials with 100 years of experience in carbon solutions[24]. As of 2021, more than 200,000 Norwegians were employed in the oil and gas industry[53], representing a valuable talent pool for the battery industry. IEA forecasts a peak in oil demand by 2030, indicating a mid to long term decline in oil usage[54]. This transition presents an opportunity for Norway's battery industry to attract, hire, and upskill experienced workers from the oil and gas industry.

As experienced in the oil and gas industry, developing a Norwegian battery industry will require leveraging foreign expertise and experience[17]. A success story in Norway is Morrow, which is set to operate the country's first gigafactory. Morrow's diverse workforce includes over 30 nationalities, reflecting a global talent pool. At the University of Agder's Campus Grimstad (UiA), Morrow has established the Morrow Research Centre, comprising a team of 70 highly skilled researchers from more than 20 nationalities[55]. Given the globalization of the industry, Norwegian companies should seek to attract international expertise and use this to train the local workforce. There are multiple ways to attract said expertise, such as compensation, the Norwegian work-life balance, high quality of living, etc.

Beyond seeking international help, Norway needs to build domestic expertise. There will be a need to upskill and re-educate a significant number of people in disciplines critical for the battery value chain. Job availability and the industry's role in the green transition are likely to be key considerations for young people choosing their careers[17]. While educational opportunities in the field exist, there is a need to market these pathways and career prospects to attract young talent. The Battery Coast initiative, hosted by UiA, integrates interdisciplinary battery development and research from academia and industry across the value chain[56]. By establishing an application oriented battery engineering program in collaboration with industry players, Norway will make the opportunities more attractive.

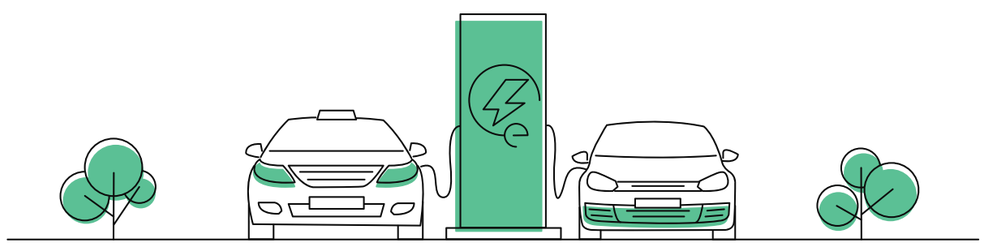
Battery technology

Norway must address the dual challenges of performance and sustainability to capitalize on technology opportunities.

Challenges

R&D in the battery industry is progressing rapidly, aiming to create the best, cheapest, and most sustainable batteries. IEA projects that advancements in battery chemistries and manufacturing will reduce global average lithium-ion battery costs by 40% from 2023 to 2030[1]. The challenge is two-fold: enhancing battery performance and expanding manufacturing capacity while increasing the level of sustainability. Continuous innovation in battery chemistries complicates large scale production, as it is difficult to predict what technologies will dominate in the future. This implies risks for long term investments and strategic planning. An example is the search for PFAS-free batteries. If developed, a global shift in battery production is expected to rapidly emerge[34]. Stakeholders must navigate this uncertainty, balancing the need to stay at the edge of innovation with the risk of investing in obsolete technologies.

Mature battery markets are significantly ahead in technological development. China holds over 5,486 patents related to post lithium-ion batteries, accounting for more than 50% of global patents[57]. Chinese companies are set to begin mass production of sodium-ion batteries, which are expected to cost 60-70% less than lithium-ion batteries. In comparison, Japan holds 1,192 patents, and the US 719[57]. Technological advantage is likely to persist for an extended period as catching up is expensive. China is also ahead in full-scale production. During up-scaling, production lines can have scrap rates of over 30%, while established lines can have as little as 5%. Because of this, Asian factories are currently outperforming European and American competition, who are still in early stages of scaling[34]. Despite some Norwegian companies claiming their technology is world class, they struggle with scaling due to the lack of capital.



Opportunities

The market for manufacturing battery cells and production is still dominated by Asian players excelling in cost leadership. However, there are high quality technologies emerging in Europe, and Norway can play a pivotal role in advancing battery technology with strong R&D environments. Given Norway's rich deposits of raw materials such as cobalt, copper, natural graphite, and nickel, investing in certain parts of the battery production process, such as cathode and anode material production, could be highly beneficial[58].

Currently, the industry leading battery technologies for EVs and energy storage are nickel manganese cobalt (NMC) and lithium iron phosphate (LFP) batteries[59]. Competing on these known chemistries can prove difficult when facing well established producers with existing mass production. However, there are opportunities for competing on next generation batteries. An example of Norwegian companies already pursuing this is Morrow Batteries, set on commercializing Lithium Nickel Manganese Oxide (LNMO) batteries within the next year. If this is a success, it would put Norway at the forefront of this technology. With LNMO, a never-before-commercialized cathode material, Morrow can eliminate the need for cobalt and reduce the required nickel content by up to 60% compared to state-of-the-art NMC[60]. Norwegian companies can compete by focusing on new and more sustainable technologies rather than relying on existing mass produced solutions.

Multiple interviewees have highlighted Norway's opportunity to become an R&D hub for future battery technology. An example of existing initiatives is the FME Battery Center, which has been granted a total of NOK 160 million through the Norwegian Research Council. Hosted by NTNU, the FME Battery Center focuses on technological advancements across all key areas of the battery industry, from battery materials and cell production to battery packs and recycling. The project involves numerous research and industry partners and will educate 65 master's students, 22 Ph.D. students, and 1 postdoctoral researcher[61]. Continued investments in the FME Battery Center can help enhance Norway's position in battery technology. In Asia, most of the innovation is carried out by large companies, while use of SMEs and universities is more common in the US and Europe. This highlights the opportunities for joint R&D projects such as the FME Battery Center, where 51 partners are gathered.

Digitalization

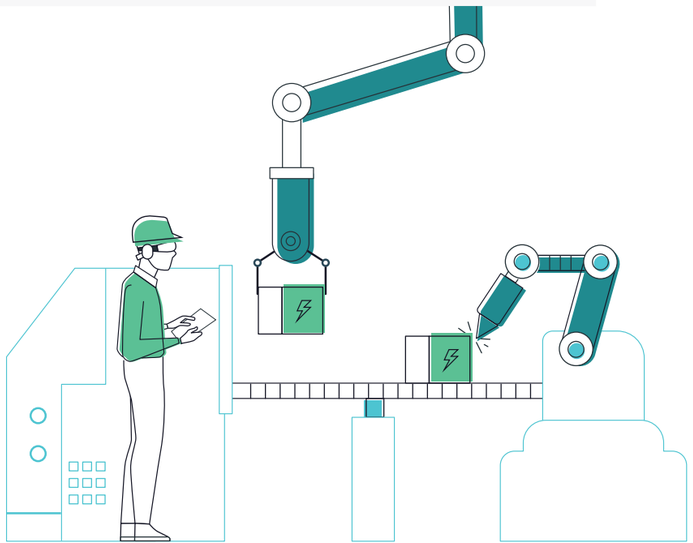
Digitalization is key to scaling up and optimizing Norway's battery manufacturing processes.

Challenges

There are increasing calls for next-generation batteries that are high-quality, customized, safe, more affordable, energy-dense, and available in varied batches with short delivery times. According to Battery 30+, the EU's common research initiative in battery R&D, meeting these demands through optimization alone will be challenging, if not impossible[62]. To address this, the battery industry must embrace digitalization.

Failure to adopt Industry 4.0 technologies and smart manufacturing methods can lead to reduced capacity, resource loss, and diminished global competitiveness. Norway's battery strategy highlights a lack of experience in large-scale digital production, attributed to a historical focus on offshore and maritime sectors[63]. As competition increases and margins are pushed, not implementing digitalization in manufacturing processes will become increasingly harmful. To fully leverage 4.0 technologies, it is essential to utilize high-quality, accurate, and timely data. The challenge lies in managing voluminous and heterogeneous data, underscoring the need for standardized tools to ensure effective data integration and interoperability. With varying hardware, software, and file formats across manufacturers both data gathering and sharing can be challenging.

To fully utilize the power of data, an open and transparent environment is essential. However, interviewees have raised concerns regarding the sharing and potential re-selling of important data to third parties. Additionally, the risks of data outage and cyber security issues increase when a large part of the industry is connected and depend on each other.



Norway's path to
sustainable battery development

Opportunities

As Norway begins developing its battery value chain, there is a unique opportunity to build a natively digitalized industry from the ground up. By embedding digital processes at the core, companies can create digital ecosystems designed for scalability and seamless data sharing. A common framework is crucial for streamlining data processing and improving the reliability and flexibility of data insights. Data will be the cornerstone of this future, but to fully leverage its potential we must address and overcome concerns regarding data security and sharing.

As highlighted in Norway's battery strategy, several Norwegian companies are at the forefront of efficient resource use, automated solutions and digital technologies. The extent of automation used in production depends on different process interfaces and the human intervention needed. Asian battery manufacturers have a higher level of automation and consequently superior technology performance than European and US manufacturers. Norway must utilize existing expertise in automated production lines as a competitive advantage in the race to speed up battery production.

There is a clear opportunity for Norwegian battery companies to utilize artificial intelligence (AI) to optimize battery production. AI and especially machine learning (ML) can decrease development timelines while increasing innovation. AI has already been used in cutting R&D times [64] and ML has been used to speed up screening time for potential new chemical combinations[65]. Generative AI can design novel materials, through models trained on existing battery materials[66]. An example is Chinese company CATL who achieved 100% defect detection in seal pin welding using AI-driven quality inspection with high precision 3D cameras and edge computing[67]. To stay competitive, Norwegian companies must utilize AI to both increase accuracy and improve cost and time effectiveness in their productions and research.

Summary and conclusion

The battery industry is critical to Europe's green transition, with Norway positioned to play a significant role. Norway's renewable energy resources and industrial expertise and competence provide a solid foundation for the industry, but several hurdles must be addressed to capitalize on these advantages. This study identified seven core themes with cohering challenges and opportunities: policy and regulations, financing, collaboration and partnerships, ESG, competency, battery technology and digitalization. Moreover, it is apparent that these challenges are closely interlinked and connected. Based on these, there are four key takeaways that the industry and authorities should consider.

- As the battery industry faces volatility and turbulent capital markets, the government should level the playing field for Norwegian battery companies through developing financial incentives and streamlining bureaucratic processes.
- Norway should take advantage of being in the early stages of industry development to build a natively digitalized industry from the ground up, utilizing existing ecosystems and taking a collaborative approach for sharing data and knowledge.
- Norway has a unique opportunity to serve Europe with high quality, sustainable and ethically produced batteries, but we must act fast as other countries are building renewable energy capacity and improving their battery performance.
- Although Norwegian companies are at the forefront of next generation battery technologies, the successful battery manufacturers will not be the ones with the newest and most complex battery chemistries, but rather those who can produce large quantities in time, at scale and at cost.

It has become clear that the development of the Norwegian battery industry will require massive effort from both the government and the battery players across the value chain, especially when considering the increasingly volatile market it is operating in. Norway has a role to play in securing European access to sustainable raw materials and batteries and enabling the green transition, and the industry should work together to ensure we accelerate the development.

Acknowledgements

We extend our gratitude to all the interview participants who contributed their valuable time, insights, and perspectives to this study, forming the foundation of the report and its findings. For any inquiries regarding the content of this report, please contact the authors.

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