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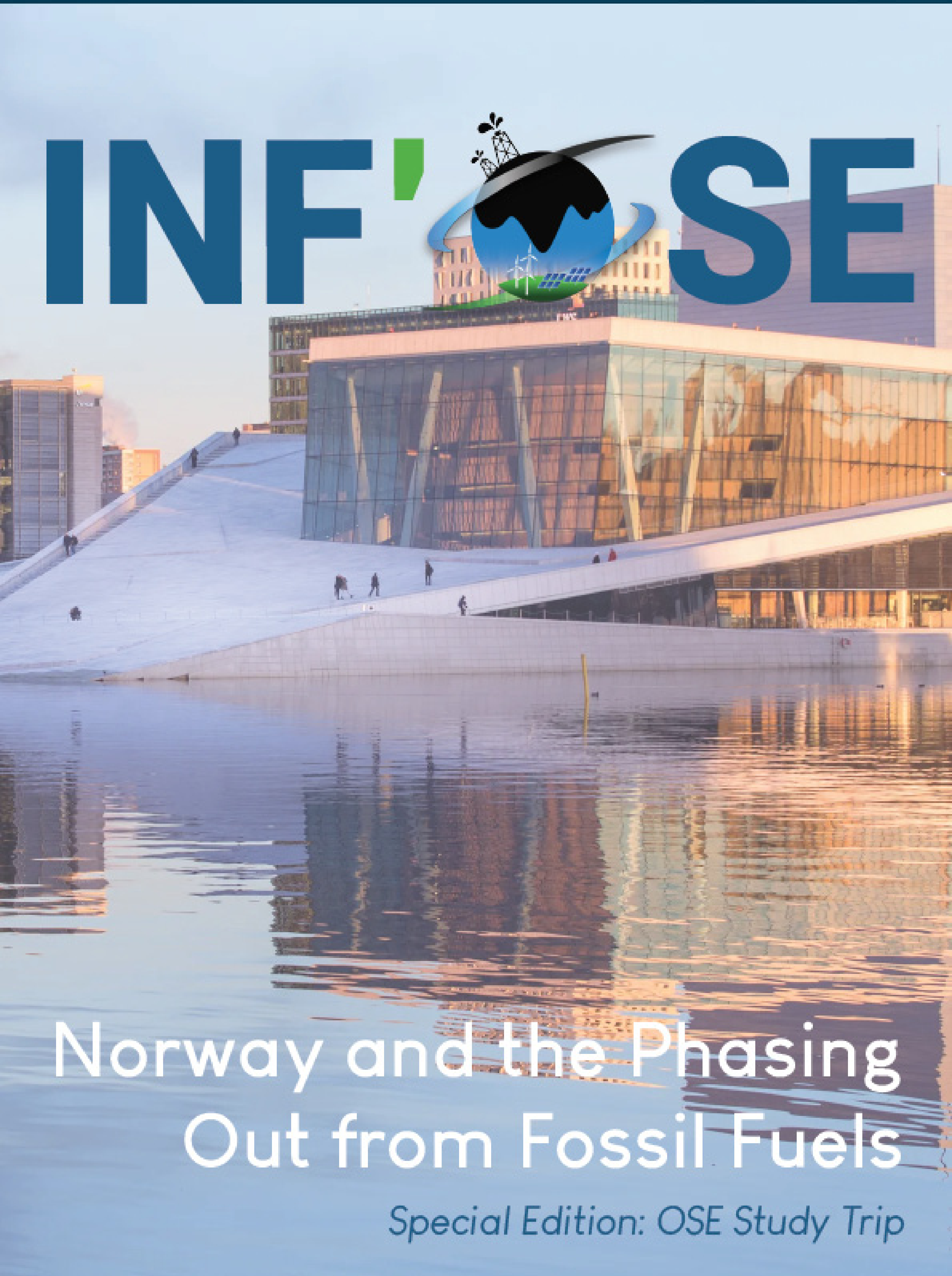
INF'OSE

Norway and the Phasing Out from Fossil Fuels

Special Edition: OSE Study Trip



Dear Reader,

The urgency of moving away from fossil fuels has been clearly demonstrated. At a time when COP 28 is calling on countries to “transition away” from fossil fuels, and when agreements are multiplying to get Western countries off coal by the end of the decade, the need to move towards an energy transition is generally recognized. But the effort required depends on the role currently played by fossil fuels in the economies of different countries. Hence the importance of our study topic this year: the impact of energy transition on fossil fuel-producing countries.

Norway is an exception in this respect. Being a first-rate oil and gas producer, it nevertheless benefits from a largely decarbonized energy mix thanks to its substantial hydraulic resources, and has managed to overcome the natural resources “curse” thanks to the early creation of a sovereign wealth fund to manage revenues from the oil and gas industry. Norway’s fossil fuel production and consumption trajectories are therefore relatively atypical. As such, it represents a particularly interesting case study for deepening our understanding of possible diversification and decarbonization strategies. Hence the decision to organize our annual class trip to the Oslo area.

In this issue, we invite you to discover the various people we had the pleasure to meet. We give an overview of the sites and infrastructures we visited, as well as a brief outline of the two lectures we had the honor of presenting at the Institute for Energy Technology (IFE) and which will be covered in greater detail in our book on the impact of the energy transition on fossil fuel-producing countries, due to be to be published in 2024.

Finally, we’d like to close this editorial by thanking everyone who made this trip possible. Thank you to all the partners and manufacturers who opened their doors to us, allowing us to discover their businesses and the exciting challenges they face. Thank you to Hydrovolt, Hafslund Oslo Celsio, Brevik cementery and Eramet for allowing us to visit exceptional infrastructures at the cutting edge of innovation: these are images we’ll keep in our minds for a long time to come. Thanks to Norges Bank, Norad, Norsk Hydro and NordPool for their stimulating presentations and rich discussions, which enabled us to discover the many facets of Norway’s energy transition. Thank you to IFE for the fruitful exchanges that resulted from the presentations by the Energy Systems Analysis Department teams, and the valuable insights and questions that followed our own presentations. Thanks to the French Embassy in Norway, and in particular to the Ambassador, Florence Robine, for making herself available to share her enlightened perception of Norwegian energy issues and Franco-Norwegian relations on energy transition.

Last but not least, we’d like to thank Gilles Guerassimoff, Director of the OSE Specialized Master’s program, Nadia Maïzi, Director of the Centre de Mathématiques Appliquées, and Alice Spasaro, Administrative Manager, for making this trip such a success.

Now, let us guide you through the many aspects of Norway’s energy transition, which we briefly glimpsed during our five-day visit around Oslo.

Enjoy your reading!

Emilie Normand

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OSE OPTIMISATION DES SYSTÈMES ÉNERGÉTIQUES

CMA Centre de Mathématiques Appliquées

Reading time : 5 min

As an energy-rich country, Norway has a unique position with respect to the energy transition. On the one hand, abundant affordable hydropower enabled the development of energy-intensive industries and a high level of electrification of homes and businesses. On the other hand, as a major oil and gas producer and exporter, Norway needs to support the evolution of its energy sector to achieve energy transition and meet its ambitious greenhouse gas (GHG) emissions reduction targets [1].

A largely decarbonated energy mix

Norway has an almost entirely renewables-based electricity system with renewable sources accounting for 99% of power generation in 2022 (151.21 TWh). Furthermore, its extensive hydropower resources covered 88% of electricity generation in 2022 (Figure 1) [2]. Indeed, hydropower is at the core of Norway's power and industry sector. Modern Norway emerged thanks to its increasing hydraulic exploitation which began in 1891 with the Hammerfest dam construction. Pioneers such as Sam Eyde or Gunnar Knutsen rapidly included hydropower in industry and policies, paving the way for a government-owned hydropower infrastructure; currently, the Norwegian State owns 90% of total hydropower capacity through Statkraft [3].

Norway is the main hydropower producer in Europe and the 6th largest producer globally [3]. About 1,769 hydropower facilities produce between 136 and 138 TWh per year – covering approximately 90% of Norwegian total power demand. However, by relying that much on hydropower, Norway is highly impacted by hydric seasonal variations which could become more important in the coming years [4].

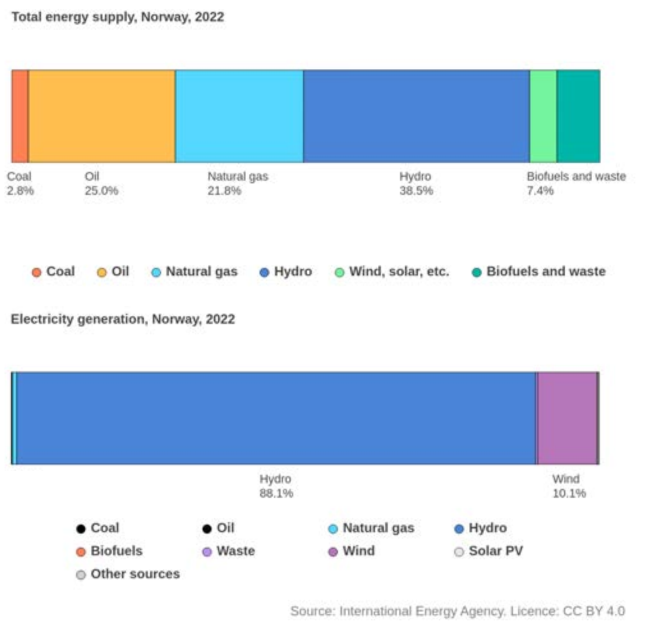


Figure 1. Norway's energy (top) and electricity (bottom) mix in 2022 (TWh) (source: IEA).

Additionally, the share of wind in Norway's electricity system dramatically increased in the last decade – from 705 MW in 2012 to 5,073 MW in 2023 [5]. It accounted for 10.4% of total electricity generation in 2022. Statkraft intends to massively invest in the wind sector development to achieve 2,500 GWh wind power production through modernisation of existing wind farms and greenfield projects, such as Moifjellet project (260 MW), or projects in Rogaland and Finnmark regions, in the North of the country. Such projects will nevertheless have to overcome difficulties such as lack of network development and local opposition to onshore wind projects, especially from the Sami indigenous population.

Regarding solar power, Norway's capacity is still rather limited. In 2023, the existing solar power came from photovoltaïc panels installed on the roofs of households and industrial buildings, and covered only their electric consumption. The country does not yet have any solar installations truly dedicated to large scale electricity production [5].

Norway is historically a net exporter of electricity to neighbouring countries. Moreover, its energy demand is highly electrified: in 2020, electricity covered half of the country's total final consumption – this is the highest share among IEA member countries [1]. However, as more electrification will be needed across sectors to meet Norwegian climate targets, additional renewable generation capacity will be required. The Norwegian government also has ambitions to build offshore wind capacity and supply chains: Norway is currently building the world's largest floating offshore wind farm (Hywind Tampen) with a total installed capacity of 88 MW [6].

An important oil and gas producer and exporter

The first oil and gas deposits were found in the North Sea in 1959. Boosted by the 1973 and 1979 oil crises, Norwegian oil prospection flourished in the 1970s and a significant oil and gas industry quickly developed. Norway was soon able to tap into vast oil fields (Troll, Statfjord, Ekofisl, Oseberg, Snorre...) and to become a major oil and gas producer and a net energy exporter [7]. As of January 2022, Norway had 7.7 billion barrels of proved crude oil reserves – the 18th largest reserves (0.48% of global oil resources) – and 51 trillion cubic feet of proved natural gas reserves. Hence, Norway was the 8th largest oil exporter of oil in 2021, accounting for 4.06% of the global oil trade [8], despite Norwegian oil production's steady decline since 2000 (Figure 2), and the 4th largest exporter of natural gas globally (pipeline and LNG). In 2022, as an aftermath of Russian sanctions following Ukraine's invasion, Norway replaced Russia as the largest supplier to the European natural gas market, exporting 122 billion standard cubic meters [9].

The oil and gas sector is the one generating the most value added, revenues, investments, and export values in Norway. Therefore, it plays a critical role in the Norwegian economy. The country's export revenues from the petroleum industry are estimated to be over NOK 800bn (€68.61bn) in 2021. The Government Pension Fund Global, which is financed by the revenues from oil and gas production, funds public expenditures, provides a financial safety net for both current and future generations, and protects the country's long-term economy from volatility in oil and gas revenues.

The energy transition as a cornerstone of Norwegian energy policy

Norway has set ambitious targets for reducing GHG emissions: the 2017 Climate Change Act set a target of 90-95% emissions reduction compared to 1990 levels by 2050 and the 2021 Climate Action Plan aims at reducing emissions by at least 50% by 2030. The Climate Action Plan's main emphasis is on emissions from sectors not covered by the EU Emissions Trading System (ETS), including transport, buildings, waste, and agriculture.

Indeed, as part of its agreement on the European Economic Area, Norway participates in the European Union (EU)'s internal energy market. Notably, it participates in the EU ETS, the Effort Sharing Regulation (ESR) for non-ETS emissions, and in the land use, land-use change and forestry regulation (LULUCF). The polluter-pays principle is a cornerstone of Norwegian policy which was one of the first countries in the world to introduce a carbon tax in 1991 covering the combustion of fossil fuels and the petroleum sector. Today, approximately 85% of domestic GHG emissions are either covered by the EU ETS or subject to a CO_2 tax or both. The national CO_2 tax is currently around €83 per tonne of CO_2

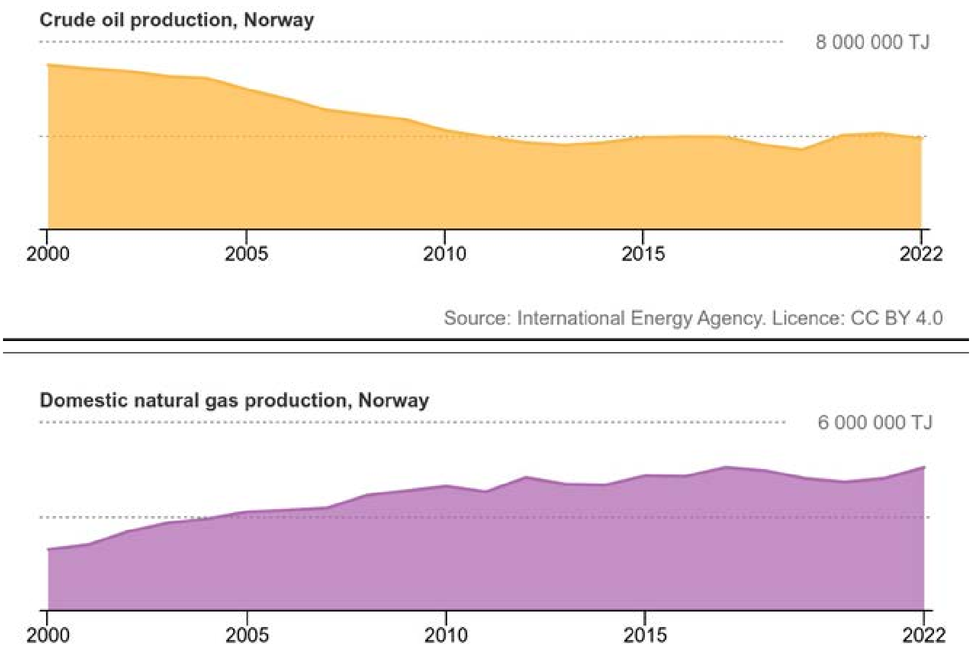


Figure 2. Norwegian oil (top) and gas (bottom) production evolution between 2000 and 2022 (source: IEA).

equivalent [1].

Energy efficiency also has an important role to play: the government has set a target to lower the overall energy intensity of the economy by 30% in 2030 compared to 2015. In the buildings sector, which accounts for 34% of Norway's total final consumption (TFC), Norway has a target to reduce energy use in existing buildings by 10 TWh by 2030 relative to 2015 levels [1]. In the transport sector (21% of TFC), Norway is pursuing an ambitious policy on EVs: fossil fuel cars are subject to a high registration tax on purchase and to a CO_2 tax and road use tax on gasoline and diesel while zero emissions vehicles are heavily subsidised. This is why Norway has the highest share of electric vehicles both in car stock and car sales – the EV share of passenger vehicles sales reached 82.4% in 2023 [10].

Finally, Norway has a strong policy on energy technology and innovation. Innovation in Norway's energy sector is spearheaded by Enova, an entity owned by the Ministry of Climate and Environment. It supports new industries development such as hydrogen, offshore wind and a future-oriented oil and gas industry with low emissions from upstream activities. CCS is especially identified as a priority area in which the Langskip ("Longship") project, currently under construction, plays a key role [11]. The project comprises state support to two full-scale capture facilities and one storage facility in the North Sea.

References

[1] IEA, « Norway 2022 Energy Policy Review », IEA, juin 2022. Consulté le: 10 avril 2024. [En ligne]. Disponible sur: https://iea.blob.core.windows.net/assets/de28c6a6-8240-41d9-9082-a5dd65d9f3eb/NORWAY2022.pdf

[2] H. Ritchie, M. Roser, et P. Rosado, « Norway: Energy Country Profile », Our World in Data, mai 2020, Consulté le: 10 avril 2024. [En ligne]. Disponible sur: https://ourworldindata.org/energy/country/norway

[3] Ministry of Petroleum and Energy, « The History of Norwegian Hydropower in 5 Minutes », Government.no. Consulté le: 10 avril 2024. [En ligne]. Disponible sur: https://www.regjeringen.no/en/topics/energy/renewable-energy/the-history-of-norwegian-hydropower-in-5-minutes/id2346106/

[4] Y. Rack, « Climate impact on water supplies puts squeeze on hydropower ». Consulté le: 10 avril 2024. [En ligne]. Disponible sur: https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/climate-impact-on-water-supplies-puts-squeeze-on-hydropower-59293719

[5] « Electricity production », Energifaktanorge. Consulté le: 10 avril 2024. [En ligne]. Disponible sur: https://energifaktanorge.no/en/norsk-energiforsyning/kraftproduksjon/

[6] Equinor, « Hywind Tampen », Equinor. Consulté le: 10 avril 2024. [En ligne]. Disponible sur: https://www.equinor.com/energy/hywind-tampen

[7] Norwegian Petroleum, « Norway's petroleum history », Norwegianpetroleum.no. Consulté le: 10 avril 2024. [En ligne]. Disponible sur: https://www.norskpetroleum.no/en/framework/norways-petroleum-history/

[8] A. Twin, « The World's 10 Biggest Oil Exporters », Investopedia. Consulté le: 10 avril 2024. [En ligne]. Disponible sur: https://www.investopedia.com/articles/company-insights/082316/worlds-top-10-oil-exporters.asp

[9] International Trade Administration, « Norway - Offshore Energy - Oil, Gas and Renewables ». Consulté le: 10 avril 2024. [En ligne]. Disponible sur: https://www.trade.gov/country-commercial-guides/norway-offshore-energy-oil-gas-and-renewables

[10] « Norwegian EV market », Norsk elbilforening. Consulté le: 10 avril 2024. [En ligne]. Disponible sur: https://elbil.no/english/norwegian-ev-market/

[11] « The Longship CCS project in Norway », CCS Norway. Consulté le: 10 avril 2024. [En ligne]. Disponible sur: https://ccsnorway.com/the-project/

Emilie Normand

Institute for Energy Technology (IFE) Visit

Reading time : 5 min

We started the week with a visit on familiar ground, since we met with IFE (Institute for Energy Technology) and its Energy System Analysis department, which has been working with the Centre for Applied Mathematics of Mines Paris - PSL (CMA) for several years.

We arrived under a bright but fresh morning sun in Kjeller, which is located 45 minutes north from Oslo. After a short and unexpected trip to the neighbouring military facilities, where we were greeted by surprised faces as our large group of French students arrived unannounced , we managed to find Mari Lyseid Authen from IFE welcoming us at the entrance of the Institute. All dressed up and slightly anxious about our future presentations, we got to know some of the team members composing the Energy System Analysis department around a warm cup of coffee. The morning was divided into two parts: first, presentations were given by IFE about their ongoing work, then, we gave our two presentations, inspired by some of the work carried out as part of this year's class project.

Mari Lyseid Authen, chief of the department of Energy System Analysis, started the morning by giving us a brief overview of the Institute from its funding until today. IFE is a nonprofit private research centre founded in 1948 by Gunnar Randers under the name of IFA (Institute for Atomic Energy). Gunnar Randers led the creation of the first Norwegian nuclear reactor, named JEEP, which went critical in 1951. Norway became the sixth nation in the world to have an operational nuclear reactor after the US, the UK, France, USSR and Canada. Over the years, public funds devoted to nuclear energy decreased progressively and the Institute shifted towards other industrial research activities. Nowadays, 730 employees are working at IFE, divided among two R&D centres, and work on eight main research topics: hydrogen, energy systems, PV, stationary batteries, CCS (carbon capture and storage), nuclear, resilient cities and transport electrification.

We met with the department of Energy System Analysis. This department started with 2 people and has now grown to 11 researchers and it is still expanding. As a member of the IEA-ETSAP, like the CMA, the Energy System Analysis department develops scenarios and strategies to reduce greenhouse gas emissions, analyses the development of energy carriers and possible future technology choices or energy efficiency solutions. The department developed its own IFE-TIMES model (and others) on a local, national, Nordic, European and global scale. The projects it carries are public and privately funded, thanks for instance to collaborations with Equinor or Statnett (the Norwegian TSO).

After this introduction, Johan Kristian Svenn, head of research, presented some of the research carried out by his department on hydrocarbons extraction. Kristian quipped that it was the first time in over ten years that he had been asked to talk about their research in the oil and gas industry. He alleged that the experience earned by IFE in more than 20 years of nuclear technologies allowed the research on oil and gas extraction to become so successful. A local legend says that Gunnar Randers visited the existing nuclear reactor in the US and managed to measure the size of the facilities by foot length. Based on these measurements, he designed JEEP, the first nuclear reactor in Norway. Its development and maintenance have enabled them to acquire skills in cooling systems and fluid mechanics. In 1979 with the discovery of oil and gas fields in the Northern Sea, the team adapted their engineering skills to the modelling of oil and gas flows. This shift led to the development of IFE's Multiphase Modelling (OLGA), which has been applied to several oil fields and saved around 4 billion USD making it one of the most profitable research projects ever. Today, only 5% of all projects are publicly funded, the remainder is financed by private funds and European projects, as Norway is part of the Horizon Europe research funding program. IFE's research topics are now oriented towards stability and optimization of existing oil and gas activities rather than the growth of this sector.

The second speaker was Kari Aamodt Espegren, main scientist at IFE. Kari is an active member of

[1] IEA-ETSAP is an international initiative to promote the analysis and modeling of energy systems to support energy policy decisions under the umbrella of the International Energy Agency.

the IEA-ETSAP program and is well known by the researchers of the CMA. Some of her publications have also been quoted in our class project. Kari presented some recent works by NTRANS (Norwegian Center for Energy Transition Strategies) to which the Institute contributes. NTRANS aims to build bridges between technologies and social sciences by creating different energy transition pathways quantified by mathematical models. The study presented by Kari describes four scenarios, each defined by some degree of changes compared to the existing sociotechnical state. The first scenario is the "Incremental Innovation" (INC) which represents few discontinuities and less challenges for society. This scenario is called incremental because it is led by incremental improvements in energy efficiency and a modest growth of renewable energies. The second scenario is the "Technical Change" (TECH) which introduces new fundamental technologies with a minor socio-institutional adaptation. The third scenario "Social Change" (SOC) focuses on major changes on a socio-institutional level with less modifications on subsystems technologies. The fourth and last scenario is the "Radical Transformation" (RAD), which represents major changes at a technological and socio-institutional level.

The results show a growth in electricity consumption in all of four scenarios, illustrating the role of electricity as the main energy vector of the future. The TECH scenario sees as well natural gas as the main source for hydrogen production. In the same way, bioenergy demand rises in every scenario, with a larger growth in the INC scenario, backing up the transition toward greener fuels. As for GHG emissions, all four scenarios lead to a decrease in emissions thanks to a greater use of renewable energies and – in some cases – to the use of CCS. The RAD scenario shows the greatest decrease in all measured values reflecting its more radical approach to energy transition.

After Kari Espegren, Mari Lyseid Authen presented IFE's work on the electrification of the Norwegian continental shelf. She showed us the results of a study made by IFE with NCS2030, which is the Center for Sustainable Utilization of Energy Resources on the Norwegian Shelf of the University of Stavanger. The study considered the electrification of 17 oil and gas fields by developing submarine connections, lowering the use of gas on the offshore platforms and developing offshore wind turbines. The results show that electrification from the continent can play a key role in reducing the use of gas from 2030 onwards. The study insists on the role of carbon taxation as a main lever to foster the energy transition. The analysis of NCS2030 highlights the necessity of long-term energy planification, decision-making improvements and advances in energy and infrastructure scenarios.

Finally, the last talk from our hosts was delivered by Pernille Seljom and Kristina Hasskjold. They presented us an analysis of Norway's strategy to integrate offshore wind turbines into the national electricity mix to reach their decarbonation targets. They explained to us that government incentives aim to develop 30 GW of total wind turbine capacity by 2040, which would imply a positive economic fallout and great emissions mitigation. The IFE-TIMES energy model describes how offshore wind can influence demand and investments in renewable energies according to various prices and demand scenarios. This last talk emphasised the great significance of offshore wind in Norway's energy transition while acknowledging economic and technological uncertainties linked to its large-scale development.

After IFE's final presentation, we were able to gather around a coffee, talk about each other's project and to prepare ourselves mentally for our forthcoming talks.

Around 11am, the first OSE students group started to illustrate some aspects of our class research project. The theme of this first presentation was "Lowering demand and adjusting supply are key to the transition away from fossil fuels". The presentation explored the contrasted long-term fossil fuel consumption scenarios between the IEA and OPEC and illustrated the difference between the point of views of the two major institutions, as well as the bias that we can have as Europeans -an OECD focused vision- which put aside a large part of the world. The theme of peak oil consumption is a symptom of these contradictory issues, being projected before 2030 by the IEA and after 2040 by OPEC. Following various questions, Nils Morten Huseby, Director of IFE, underlined the difficulties of modelling crises in prospective studies, crises which are the most likely to profoundly modify consumption habits. As a modeller, it is essential to take a step back from the results obtained, which can become obsolete in extreme cases.

The second OSE students group tried to estimate the energy diversification potential of fossil fuel producing countries. First, we presented a classification of forty producer countries based on twenty criteria (macroeconomics, energy mix, availability of renewable resources and vulnerability to climate change). In particular, the evolution between 1970 and 2020 of each producing country with regard to its economic resilience and dependence on fossil fuels was shown. We selected four groups by clustering method and chose to study one country from each group for the remainder of the study. Norway was, for obvious reasons, the representative of rich, diversified countries. We chose the United Arab Emirates among the highly dependent but diversified countries, Brazil being among those less dependent on fossil fuels and developing countries, and finally Egypt as one of the quite dependent but less diversified countries. We presented the methodology used to assess the potential for economic diversification of countries through new energy vectors. To do this, we established an aggregate indicator based on data on access to capital, availability of renewable resources, resilience to climate change and potential for substitution of fossil rents by new energy carriers (low-carbon hydrogen and biofuels). Our results showed that Norway has significant rent-substitution potential, more so than Emirates, Brazil and Egypt. During the question and answer session, it was pointed out that our estimate of access to Norwegian capital was probably overestimated, as it was based in part on Norway's non-allocable national sovereign wealth fund.

This last presentation rounded off a rich morning and led us to a nice buffet to exchange ideas with our hosts. We talked about our respective cultures, brown cheese, the superiority of Norwegian waffles to Belgian ones (they were very good indeed), but also about our respective projects, forthcoming visits and possible future partnerships. We were able to say goodbye to our hosts, enriched with knowledge and good humour, ready to brave the cold again to return to Oslo and visit the Norwegian bank.

Joseph Denieul & Imane Rahali

Norges Bank Visit

Norges Bank

Reading time : 2 min

On Monday afternoon, we were welcomed at the Norges Bank by Ms Anna Jahr Svalheim, Advisor Active Ownership, Mr. Vegard Torsnes, Lead Investment Stewardship Manager, and Mr. Ståle Laegreid, Portfolio Manager. They introduced us to the Norwegian sovereign wealth fund created in 1990 and managed by the Central Bank of Norway. Norges Bank Investment Management, the 2nd largest sovereign wealth fund in the world, aims to ensure the long-term management of revenues from Norway's oil and gas resources, so that this wealth might benefit present and future generations.

In 1969, one of the world's largest offshore oil deposits was discovered off the coast of Norway. Suddenly, Norway recorded huge revenues, and the country's economy grew spectacularly. It was decided early on that oil and gas revenues should be used carefully to avoid imbalances in the economy. In 1990, the Norwegian parliament passed a law to this end, creating what is today known as the Government Pension Fund Global. Each year, the Norwegian government can only spend a small portion of the fund (the equivalent of the fund's real return, estimated at around 3% a year), which nevertheless represents almost 20% of the government budget.

Revenues from oil and gas production are transferred to the fund, but these deposits represent nowadays only one of the several sources of the fund's value. Today, more than half of the fund's value is composed of investments in equities, bonds, real estate and renewable energy infrastructure.

The fund holds nearly 1.5% of all listed company shares worldwide, mainly based in the USA and Europe. With 71% in equities and 27% in bonds, the fund aims to develop its investments in private equity, particularly in renewable infrastructures, which currently account for only 0.1% of the portfolio. The fund is also showing a new and growing interest in artificial intelligence.

Drawing on their years of experience in this field, Mr. Vegard and Mr. Ståle Laegreid emphasized the importance of managing capital responsibly concerning climate change. To this end, the bank relies on three main pillars: financial targets, commitment and transparency.

As a long-term investor in around 9,000 companies in 70 countries, the fund takes environmental and social issues into account and publishes clear expectations for portfolio companies, as well as a climate action plan outlining the next steps to sup-

port and incentivize companies in their portfolio to be aligned with net zero emissions by 2050. The fund is committed in fostering the dialogue on ESG compliance, as well as in actively participating in board meetings. With 68% of the companies in their portfolio having set a target for zero net emissions by 2050, it is very important for the fund to ensure that companies are aligned with climate ambitions. The fund's strategy is to not divest from companies active in the Oil & Gas business, but managers may decide to sell companies that do not meet their climate commitments.

Once again, we would like to thank Ms Anna Jahr Svalheim, Mr Vegard Torsnes and Mr Ståle Laegreid for their welcome, their presentation and the inspiring discussions.

Amira Attar, Kihima Charles Ouattara & Clara Paturel

Norwegian Agency for Development Cooperation (Norad) Visit

Norad

Reading time : 4 min

On Tuesday morning, we walked towards the west of Oslo to visit Norad, the Norwegian Agency for Development Cooperation. Their offices are located in the historical buildings of NorskHydro, relatively close to the Norwegian Royal Palace. We were welcomed there by Petter Nore and Henrik Lunden.

Petter Nore is an emeritus professor at the Nord University of Norway. He worked previously in Washington for the World Bank and was once vice-president of NorskHydro and president of NorskHydro Russia. Nowadays, he advises Norad as a senior consultant and knows very well its project and history. Henrik Lunden works as a senior advisor within Norad's Department for Climate and Environment.

Petter started by explaining that the agency's funding is fixed by a decree at 1% of the Norwegian GDP, which is one of the highest rates in all OECD countries. With this budget, Norad now handles around 4 billion USD per year with just 270 employees. Since the funding of the institute, the annual budget rose steadily following the country's GDP, while the number of employees stayed the same, implying that their working process has evolved throughout the years. Nowadays, a large part of the annual budget is transferred to international financial institutions such as the World Bank.

After this brief introduction, Petter and Henrik chose to present the agency through two main case studies which are representative of the work Norad has been carrying since its creation in 1968. Petter presented us the Oil for Development project and Henrik some projects of the Department for climate and environment.

The Oil for Development department (OfD) was funded in 2005 to share Norway's skills in petroleum resources management. Petter tried to make us more aware of the process at stake with the oil and gas industry. He quoted the famous sentence of the former Venezuelan's minister of energy in the 70s: "Oil is the shit of the devil". Being the most lucrative industry ever, its operation implies many risks of disputes, outside interferences or corruption among producing countries. Showing us a graph of Norway's annual expenditures with its crude oil revenues, he explained to us that Norway managed to decorrelate these two quantities. Using the same type of graphs for other producing countries, we could see the annual public expenditures increasing and decreasing as a function of oil and gas incomes. With such a volatility in public expenditures, it is normal to imagine the perpetuation of a political instability. In this regard, Norway is one of the countries which have managed to handle its oil industry best.

Thanks to its intelligent use of revenues, the Nordic country got quite early requests from other countries to help them handling their earnings. It's in this context that the Oil for Development program was created in 2005, thanks to the skills of many former employees of the Norwegian oil and gas industry who were hired by Norad. Since its funding, the OfD department has helped more than a dozen countries, such as Benin, Colombia, Sudan, South Sudan, Ghana, Iraq, Lebanon, Uganda or Mozambique.

Petter insisted on the fact that the program always required transparency from beneficiaries' institutions and that the agency never dictated to the countries how to use their money. Norad only served as a support or advisor to the exploitation of national resources through programs on environment conservation, installation security and fiscal resources management. In this regard, the agency has never been a way to develop a form of Norwegian imperialism. In 2021, because of a political decision, it was decided to shut down the OfD program to focus on the new Energy for Development program, despite latent needs in many producing countries.

The Energy for Development department, which was presented to us by Henrik Lunden, was founded in 2023 with the aim of transforming Norwegian activities and skills from the oil and gas sector towards renewable energies. One of the main objectives of the program is to strengthen the competences and capacity of institutions in cooperating

countries to develop renewable energies over the long term. With this in mind, the program aims to improve SDGs (Sustainable Development Goals) 7, which regards access to clean, affordable energy, and 13, which regards climate action, through SDG 16, which focuses on peace, justice and reliable institutions.

Today, the program has been launched in three phases with Malawi, Nepal, Mozambique, Nigeria, Tanzania and Somalia. Henrik gave us a presentation on the program in Nepal, Norad's partner country for over 60 years, which aims to restructure the national electricity sector and plan new low-carbon production capacities, including hydroelectric dams.

Once the presentations were over, we were able to ask questions.

Firstly, we asked about the countries where Norad's help had been most successful. Vietnam was Petter's first answer. In 1985 already, Asian countries were asking for support from Norway to handle their natural resources. After 20 years of fruitful collaboration, Vietnam decided to stop the partnership as it has mastered the whole value chain. Ghana and Uganda have also been quoted as countries where Norad's support has allowed to build a quite healthy oil and gas industry. Finally, Norad helped the smaller Timor-Leste to create a sovereign wealth fund whose worth in terms of GDP rate is higher than Norway's own sovereign fund.

Regarding Norad's project on the Nepalese electricity market, someone asked whether the project had been carried out in partnership with NordPool and in general if local studies were made in collaboration with Norwegian actors. Henrik answered that Norad usually tries to involve local actors to help them increase their skills as much as possible. Thus, in this Nepalese project, the local transport system operator has been mainly responsible for the studies.

A question was asked about the differences between Norad and the World Bank. Petter's answer (as mentioned before, he worked in Washington DC for the World Bank) might provoke a smile to the World Bank's sympathisers, as he suggested Norad's approach is a bit "humbler". In his opinion, the Norwegian organisation tries to focus on local needs and to avoid huge premade projects. However, he underlined that, thanks to its skills and public utility, a large part of Norad budget is in fact allocated to the World Bank.

Thanks to the many fascinating interventions we received over the year, we have been educated about the geopolitical aspects of water usage. Therefore, we then asked Henrik about the implication of Norad in the Nepalese water dam project he talked about and its possible geopolitical impacts with Nepal's neighbours. For Henrik, these are obviously very important considerations to deal with during the project execution, but Norad is not directly involved in this kind of discussions. Their support is more technical and involved in the downstream process.

A final question was asked about any mistakes Norad might have made over the years. For Henrik, it's especially in the water-related projects, whether abroad or in Norway, that nature has not been given sufficient consideration. Petter also mentioned the lack of consideration sometimes for indigenous peoples' rights in the building of new projects. This negligence can then be the root of many social, environmental and economic issues. He insisted on the necessity to involve more local populations into the decision process of every project.

After these fruitful exchanges, we went back to the hall of the building, whose architecture is inspired by riverbanks as a symbol of Norsk-Hydro who built the facilities. We took a group picture, expressed our deep gratitude and went back filled with new knowledge on Norway.

Joseph Denieul

Norsk Hydro Visit

Hydro

Reading time : 3 min

We then headed towards Norsk Hydro's head office in Vækerø, a few kilometres west of Oslo. We were also supposed to visit the Vemork hydroelectric dam. However, because of the current geopolitical context caused by the conflict between Russia and Ukraine, security measures around "sensitive" sites have been stepped up and access to these facilities restricted. Our visit therefore took place exclusively at Norsk Hydro's head office, where we attended an extended presentation of the company and its various activities.

In 1902, a Norwegian by the name of Samuel Eyde bought a waterfall in the Rjukan region with the intention of building a hydroelectric power station. In 1903, with the help of the scientist Birkeland, Samuel Eyde discovered how nitrogen could be used to produce chemical fertilisers. The electrical energy generated by the dam was then used to power an electric arc furnace devoted to the production of fertilisers.

In 1905, Samuel Eyde founded Norsk Hydro. At the same time, the company launched the construction of other hydroelectric power stations, such as Svelgfoss (Europe's largest power station at the time) and Vemork (the world's largest hydroelectric power station at the time). Other dams were subsequently built in the towns of Rjukan and Tinn. In 1934, the company established the first commercial heavy-water electrolysis plant at Vemork, which later became the epicentre of the famous "heavy-water battle" of World War 2. Post-war technological developments shifted fertiliser production towards oil consumption. Hydropower, on the other hand, enabled the production of many metals, first magnesium and then aluminium. Today, Norsk Hydro's focus is on the aluminium value chain, *i.e.* low-carbon aluminium production, refining and recycling. All these activities are grouped together under the umbrella of "Hydro aluminium", which is one of the sub-entities of the Norsk Hydro company.

Norsk Hydro is present on 5 continents and in over 40 countries, and employs 35,000 people, 4,000 of them in Norway. Part of the company's business is carried out through various subsidiaries, notably in France, with Technal in Toulouse for extrusion, Wicona France in Lyon and Hydro Aluminum Extrusion in Albi. The company's success is based on two main factors: historically developed know-how and the comparative advantage offered by the country's hydraulic potential. Norway is the leading producer of hydropower in Europe and 6th in the world. Hydro's extensive portfolio of hydropower assets, including the Frøystul, Såheim, Moflåt, Mæl, Svelgfoss and Vemork dams, accounts for a third of the country's hydropower production.

Thanks to the know-how developed over more than 100 years, Hydro aluminium is now able to produce low-carbon aluminium with a carbon content of less than 4 $kgCO_2eq/kg$ of aluminium produced (4 times less than the world average), for use in various sectors such as the automotive, construction, electronics, and industrial sectors, as well as in the development of renewable energy technologies. Hydro aluminium masters the entire aluminium value chain, from extraction to production, extrusion and recycling. This ownership of the complete value-chain enables the company to minimise its impact on climate, nature, and society by reducing its carbon footprint.

To produce low-carbon aluminium, Norsk Hydro has also developed a second entity within the company, called "Hydro Energy", with the aim of specialising in the production of energy from renewable sources to power its aluminium production facilities. This entity includes the "Hydro Rein" subsidiary, which oversees the entire renewable energy production activity. Today, 100% of Norsk Hydro's Norwegian production facilities are powered by renewable energy. Worldwide, 70% of Norsk Hydro's alumi-

nium production use renewable energy. Although energy production is only a small part of its business, Norsk Hydro is nevertheless Norway's third-largest energy producer, with a total output of 13.7 TWh. Hydro energy operates 40 renewable energy plants, including 17 hydroelectric dams (for a total production of 9 TWh) and numerous onshore wind and photovoltaic power plants.

Hydro also helps industry to fight climate change by offering renewable energy solutions to industrial customers. Hydro Rein (the entity developing this activity) currently has a portfolio of 26 projects under development and aims to reach a capacity of 3 GW in operation by 2026.

More generally, Hydro's main ambition is to make its value chain more sustainable by acting on all its business segments. One of the company's major challenges is to secure a competitive, renewable energy supply to produce high-quality, low-carbon aluminium. To this end, Hydro also has a large portfolio of renewable energy purchase agreements (PPAs) in place in Norway and Sweden. This portfolio includes an extensive list of hydroelectric and wind power contracts. All Norsk Hydro's PPA contracts have been added to Hydro's hydroelectric portfolio in Norway.

Omar Perez-Alvarez & Lucas Richard

Meeting with the French Institute and the Economic Service of the French Embassy in Norway

AMBASSADE DE FRANCE EN NORVÈGE
Liberté
Égalité
Fraternité

Reading time : 4 min

For the last visit of the day, we met with the services of the Embassy of France in Norway at the premises of the French Institute.

The mission of the embassy is to represent the French government in front of the Norwegian authorities and to promote the development of bilateral relations. As such, it informs the French government of Norwegian current affairs and it also promotes French activities at the economic, cultural and scientific level. The Embassy is divided into several departments, all under the supervision of the Ambassador Florence Robine: The Chancellery, which coordinates all the services of the Embassy and ensures the monitoring of diplomatic relations, the Consulate, the Information and Press Service, the Defence Mission, as well as the French institute and the Economic Service. During the visit we had the pleasure to meet these last two.

We were first received by Mr. Frédéric Bessat, Scientific and University Attaché at the French Institute, who introduced the missions of the Institute and told us about the cooperation between France and Norway on cultural and scientific topics. In 2010, the cooperation services of embassies and cultural centres merged to create the global network of French Institutes. This network is led by the Ministry of Europe and Foreign Affairs and aims to facilitate the construction of projects and partnerships. The French Institute in Norway is primarily responsible for the development of a network of partnerships in the cultural, artistic, linguistic, scientific and academic fields. It facilitates the Franco-Norwegian cooperation, disseminating the French vision on major social themes and promoting the learning and practice of the French language.

Even If the creation of new French Institutes is gradually slowing down worldwide – notably because of the desire not to multiply the channels of partnerships – the French Institute in Norway remains a dynamic structure that builds strong bilateral cooperation. This involves the development of cooperation programmes, the award of scholarships and the organisation of various events and mobility programmes – for example, the French Institute recently obtained the funding of a mobility programme for researchers by the Norwegian Research Council. Several themes are particularly targeted, including the Arctic, biotechnologies, security and cybersecurity issues. However, the cooperation is marked by a strong asymmetry: while Norway strongly attracts French peoples, especially because of its positive image and advantageous living conditions, Norwegians are not very inclined to move to France, often worried about degrading their quality of life and about less competitive salaries.

Mr Bessat stressed the fact that for Norway attracting foreign talent plays a key role in building the post-oil era. The reduction of greenhouse gases, the energy transition and the possible technological innovations, are therefore major axes of the Franco-Norwegian cooperation in the academic and scientific field (CCS being one of the main topics).

Mr. Frédéric Choblet, the head of the Economic Service of the Embassy, then took over to detail the Norwegian economic framework and the main characteristics of Franco-Norwegian economic relations. The Economic Service, which depends upon the Ministry of Economy, has in fact the mission to monitor the economic and financial situation of the country, as well as to foster economic cooperation. Mr. Choblet shared with us the key features.

Norway was the fourth richest country in the world in 2023 with a gross national product per capita of USD 101,800 – by comparison, France's GNP per capita was USD 45,000. It also benefits from a very high HDI and a very low unemployment rate, that is a real problem for recruitment. The Norwegian economy is mainly reliant on the tertiary sector (55.3%), but the secondary sector retains an important role as well (41.7%), because of the Oil & Gas industry. The Norwegian economy is a "rent economy". It has largely benefited from the war in Ukraine: 2023 was a record year for investments in the oil and gas industry. Norway has a solid fiscal position: mandatory withdrawals account for almost half of GDP, nearly 65% of GDP is redistributed – hence its qualification as a welfare state. Norway is indebted up to 36.3% of its GDP.

Obviously, the fossil fuel industry is a major factor in the Norwegian economy. It is significant to note that the price of the Norwegian krone follows roughly the variations in crude oil. The Norwegian government directly receives a significant share of oil revenues through taxes paid by operators and dividends paid as a result of its shareholder status in companies like Equinor. Another part of oil revenue is directly redirected to the sovereign wealth fund, held by the Ministry of Finance, which represents an important source of financing for the energy transition. Norway is at the forefront in the reconversion of the fossil fuel industry know-how into offshore wind and CCS technologies.

The agricultural sector plays a unique role in the country's economy. Accounting for only 3% of the economy, agriculture is nevertheless considered a very important activity. Farmers are recognized as essential players for the local territory, contributing to the safeguard of certain areas and the maintenance of public heritage. The preservation of local agriculture is set as a priority and is one of the main barriers for an engagement of Norway in the European Union (EU). Food prices are on average higher because of the strong political choice to support national agriculture instead of facilitating imports.

Globally, Norway has a very favourable financial balance sheet: its trade balance is positive thanks to its exports of oil and fisheries resources, its services balance is equilibrated and its financial balance is positive thanks to foreign investment revenues. It is largely in surplus in terms of bilateral relations with France, which imports mainly hydrocarbons (€4.7bn), metallurgical and metal products (€495m) and agri-food products (€308m). Norway is France's leading gas supplier. Main export items from France to Norway are mechanical, electronic and computer equipment (€554 million), transport equipment (€327 million) and agri-food products (€321 million). France invests heavily in Norway, more than Norway invests in France. TotalEnergies is the leading investor in Norway, but other companies such as Saint Gobain, Nexens, Eiffage, Capgemini or BNP Paribas are also relevant investors. In France, Norwegian companies account for about 4,500 jobs through Norsk Hydro (energy company), Elkem (silicon producer), Yara (fertilizer producer) or MOWI (salmon farms).

We warmly thank Mr. Bessat and Mr. Choblet for their availability and their valuable lessons about the Franco-Norwegian cooperation.

Emilie Normand & Gabriele Triscari

Hydrovolt Visit

hydrovolt

Reading time : 4 min

Hydrovolt is a large battery recycling plant for electric vehicles. It was commissioned in Norway and has been operational since May 2022, following a collaboration between Norsk Hydro (50%), a leading aluminium and energy company, and Northvolt (50%), a European supplier of battery cells and systems. Located in the town of Fredrikstad, the plant is designed to manage end-of-life electric vehicles batteries and stationary electricity storage batteries. These batteries have the status of waste, not products, and so cannot be sold for a second life. Hydrovolt's business model is the sale of black mass for separation in hydrometallurgy, mainly to Northvolt and Fortum, and the sale of recycled aluminium, mainly to Hydro. Copper fractions also constitute revenues for the company.

To collect batteries, Hydrovolt signs contracts with car manufacturers, and otherwise participates in recall campaigns, or even works through pack suppliers. The plant tries to buy as few batteries as possible for recycling.

The plant mainly recycles NMC (Nickel - Manganese - Cobalt) and NCA (Nickel - Cobalt - Aluminum) batteries, but also LFP (Lithium - Iron - Phosphate) batteries. The latter are becoming increasingly popular as Tesla floods the Norwegian market with electric vehicles, and the company makes extensive use of them. The plant also recycles solid batteries, where the electrolyte is solid rather than liquid, and stationary batteries, mainly sodium.

Now let's explain the battery recycling process.

The first steps of the Discharging & Dismantling (D&D) part of the plant are still under study, particularly with the objective of developing Northvolt and Hydro's activities in this sector.

First, the batteries are discharged. The electricity recovered from the packs is used to power the plant and fed into the local grid. The plant therefore aims to consume almost all its own energy from the residual electricity within the batteries. This operation is closely monitored, using thermal imaging cameras, as the risk of ignition is high. The batteries that are most damaged present safety risks (explosions, ignition, etc.), and therefore are discharged outdoors, dissipated in the form of thermal energy into the atmosphere.

Afterwards, the battery packs are dismantled. The electronics, cables, plastics, glycol cooling systems and battery modules are separated. The glycol in the battery is also directly separated and recycled. These modules have previously been discharged, but a last residual voltage remains, so the modules are short-circuited to achieve zero voltage. This is necessary for further safety reasons, in order to shred the modules. These operations, carried out manually for the moment, are planned to be automated in the future. The process is still not automated because packs are not necessarily assembled in the same way. The most common assembly is a cell to module to pack assembly, but Tesla and other car manufacturers is opting for cell to pack assemblies, and intends to do cell to chassis assemblies. On average, it takes 30 to 50 minutes to dismantle a battery pack.

Once discharged and dismantled, the battery modules are taken to the crushing and sorting facility, which is fully operational on site today. Before shredding, the modules are dried to remove glues and electrolytes from the cells. The electrolytes are then condensed and stored.

The modules are shredded in a fully automated, closed-loop system. Hydrovolt can recover and isolate around 95% of the materials in a battery, including plastics, copper, aluminium and black mass (a compound containing nickel, manganese, cobalt and lithium). Their aim is to achieve a 100% recovery rate for raw materials.

Part of the black mass is supplied to Northvolt for further recycling to support its target of using 50% recycled material in battery production by 2030. The transformation of the black mass into battery-grade material requires hydrometallurgical treatment. By 2025, Hydrovolt should be producing more than 2,000 tons of black mass a year. The cost of a ton of black mass varies from €1,500 to €2,500, depending on nickel and cobalt prices [1], [2].

Aluminium can be recycled with just 5% of the initial energy required to produce primary aluminium, making it a perfect material for a circular economy. The recovered primary aluminium will be delivered to Hydro for reuse in aluminium products.

Its processing capacity is around 12,000 tons of battery packs a year (25,000 electric vehicle batteries), enough to recycle the entire Norwegian end-of-life battery market. The plant's current charge rate is 50%.

Recycling batteries, especially electric car batteries, presents three major challenges:

- The first challenge is quality. Grinding and separating the black mass requires a degree of homogeneity in the choice of batteries. For the moment, known processes do not allow NMC and LFP batteries to be mixed in the crushing process to achieve satisfying quality.
- The second issue is logistics. The logistics of batteries transport and recycled materials redistribution account for 40% of total costs. If we look at unit costs and the profit per unit of battery recycled, logistics account for more like 80% of costs. Therefore, the need for the expertise of companies like Veolia, Suez and Paprec to transport batteries and distribute the materials obtained is critical to the development of the EV recycling sector.
- Finally, a third major challenge lies in the economic model for recycling EV batteries. It is wrongly presented as highly profitable, but recyclers lack volume because it is a fledgling market. What's more, car manufacturers and battery producers expect to be paid for obtaining batteries at the end of their life. They can also expect premiums for selling recycled materials on the market. Currently, the selling price of black mass depends on the cost of nickel and cobalt, and the content of these materials in the black mass.

References

[1] « Northvolt – Hydrovolt, Europe's Largest Electric Vehicle Battery Recycling Plant Begins Operations – Batteries News ». Consulté le: 9 avril 2024. [En ligne]. Disponible sur: https://batteriesnews.com/northvolt-hydrovolt-europe-largest-electric-vehicle-battery-recycling-plant-operations/

[2] « Europe's largest electric vehicle battery recycling plant begins operations ». Consulté le: 9 avril 2024. [En ligne]. Disponible sur: https://www.hydrovolt.com/en/news/europes-largest-electric-vehicle-battery-recycling-plant-begins-operations

[3] « Home | Hydrovolt ». Consulté le: 9 avril 2024. [En ligne]. Disponible sur: https://www.hydrovolt.com/en

Lucien Coussieu & Benjamin Schatz

Hafslund Oslo Celsio Visit

Reading time : 4 min

On the morning of March 21, we visited the waste-to-energy plant of Hafslund Oslo Clesio located in Klemetsrud and were welcomed by Dr. ing. Øyvind Nilsen, thermal energy advisor, and Anders Norling, the site operations director, and Truls Jemtland, CCS communications manager.

Hafslund Celsio is a leader in circular energy in Norway, offering a diverse range of services including waste incineration (400,000 tonnes/year) and district heating (2.3 TWh by 2030). They also plan to become the leading provider of district cooling (150 GWh by 2035) and are pioneering carbon capture and storage on waste incinerators. Additionally, they are Oslo's largest electricity producer, generating 150 GWh in 2023.

Hafslund Oslo Celsio's plant in Klemetsrud is Norway's major waste incineration plant, operating since 1985 with a capacity of 350,000 tonnes/year, and has expanded its energy production to 1 TWh in 2022 – including 140 GWh of electricity and 835 GWh of district heating. In 2023, their energy mix mainly includes heat rejection (50.7%), electricity (19.5%), and wastewater heat pumps (9.8%), with various other sources such as wastewater, wood, wood pellets, biodiesel, fossil oil, liquefied natural gas (LNG) and energy recovery from 360,000 tonnes of waste per year. These advances are backed by a substantial investment of 10 billion in new electricity generation infrastructure. Additionally, heat pumps have been installed to use heat from Oslo's wastewater, providing up to 130 GWh/year of district heating. This is in conjunction with their data center, which has a hot water thermal storage capacity of 8500 m3, which operates with a cooling demand of 3 to 4 MW, maintained between 15 and 10 °C, using heat pumps provided by Celsio. These pumps recover dissipated heat to provide 5 to 6 MW of useful heat, operating 4000 to 4500 hours per year, which makes it possible to recover 13 GWh/year and provide 22 GWh/year of useful heat at high temperature.

The team also communicated about their new projects, the first was regarding CCS (carbon capture and storage) aims to reduce high-temperature heat from the steam system to the 40 MW district heating network, which will be converted into low-temperature heat by heat pumps. In addition, the data centre, located east of Oslo, plans to recover heat at low temperatures with heat pumps to supply the district heating network, recovering 100 GWh/year and supplying 150 GWh/year to the network, and the project in Filipstad, which transforms the port area into a new residential and commercial space, is achieved by using seawater and heat pumps for heating and air conditioning, with a cooling demand of 15 GWh/year and heating demand of 25 GWh/year.

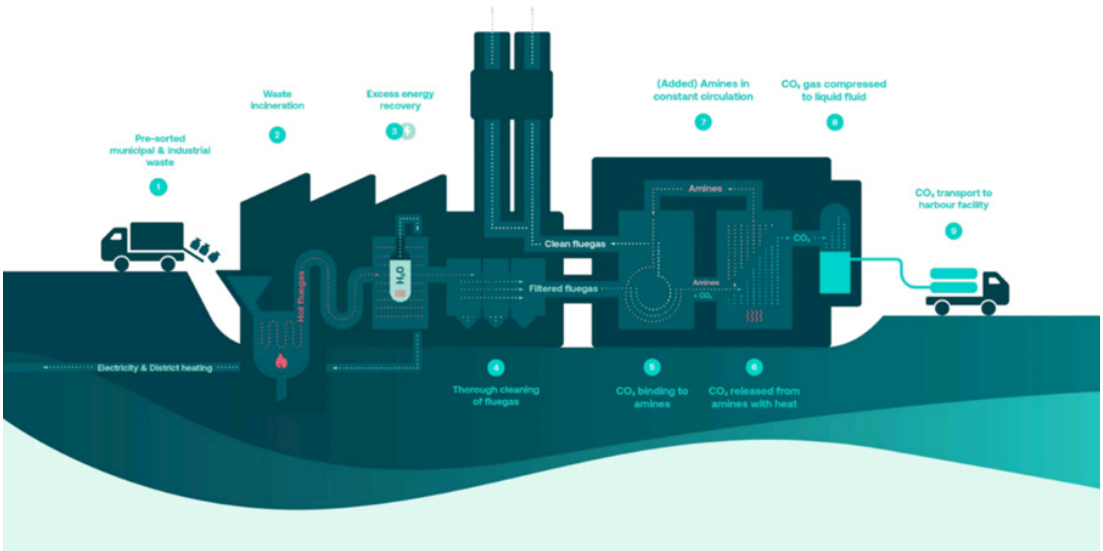


Figure 1. CSS process – Hafslund Olso Celsio

Part of the Longship CCS project stores CO2 permanently beneath the seabed providing a 50% reduction in CO2 emissions for waste to energy. It includes three CO2 capture sites (Celsio, Brevik CCS and Yara Sluiskil) and a reception and storage terminal at the "Northern Lights" site. Among the storage concepts of Northern Lights, there is one that involves high pressure and temperature, where CO2 is injected into a layer of porous sandstone, which is then covered by layers of shale. The CO2 will slowly dissolve in the salt water and, over time, turn into minerals.

The flue gas undergoes a rigorous filtration process to remove pollutants and fine particles, leaving behind almost solely CO2 and water vapour. CO2 is captured through the selective action of amines, which are chemical compounds designed to bind with CO2. Subsequently, the CO2 is detached from the amines through a heating process, thereby allowing the recovery of the amines for future uses and releasing the CO2 which can then be stored or used. Finally, this CO2 is compressed to transform it into a liquid, thus simplifying its transport to geological storage sites or to other industrial sectors that can exploit it. The process used is illustrated in the figure 1 (provided by Hafslund Celsio).

Globally, the main objectives and new revenue avenues consist of the sale of carbon reduction certificates (CDR) generated by bioenergy with carbon capture and storage (BECCS), and the increase of access tariffs for carbon-neutral waste management services. There is also revenue potential in issuing Net Zero Plastic certificates, promoting the reduction of the carbon footprint in plastic production.

Furthermore, the development of a CO2 port terminal could become a key infrastructure for carbon logistics, while the commercial development of carbon capture and storage (CCS) solutions promises new markets and partnerships.

At the same time, the dimension of avoided costs is important, thanks to the early application of the Emissions Trading System (ETS), which will include energy recovery from waste by 2028/2031, and the impact of Norwegian CO2 tax, which could reach NOK 2000 (approximately 170€) by 2030.

Nousseiba Bouabellou & Zakarya Rais

NordPool Visit

Reading time : 3 min

The Nord Pool presentation began with Jwalith Desu, *Strategy Business Developper*, introducing us to Nord Pool, which manages Europe's largest electricity market. Prior to 1991, Nord Pool was present in Norway. Between 1991 and 2000, the Nordic electricity market deregulated, with the creation of Nord Pool ASA in 1996, which became an independent company owned by Swedish and Norwegian network operators. Finland, Western Denmark and Eastern Denmark then joined Nord Pool ASA. Since 2000, Nord Pool has been expanding in Europe, and currently operates in the Nordic and Baltic regions, the UK, and across Central and Western Europe, covering Austria, Belgium, France, Germany, the Netherlands and Luxembourg.

NordPool offers Single Day Ahead of electricity (SDAC) and Intraday trading. Mr. Desu gave us an overview of SDAC, which aims to create a European day-ahead electricity market that transcends national borders and increases overall trading efficiency by promoting effective competition, increasing liquidity and enabling more efficient use of generation resources across Europe. The intraday market operates continuously, with daily trading taking place 24 hours a day up to one hour before delivery, and sometimes even up to delivery time, depending on the country. Prices are determined on a first-come, first-served basis, where the best offers are processed first, with buyers offering the highest price and sellers the lowest. The volume traded through Nord Pool in 2022 amounts to 1,077 TWh, distributed over the SDAC market for 1,039 TWh and intraday for 38 TWh.

Mr. Desu also spoke about the Euphemia algorithm, which has been developed to solve the European market coupling problem for SDAC. Euphemia combines energy supply and demand for all periods of a single day, taking into account market and network constraints. Euphemia's main objective is to maximize "social welfare", *i.e.* the total market value of the next day's auction expressed as a function of consumer surplus, supplier surplus and congestion rent including interconnection tariffs if present. Euphemia provides market clearing prices, matching volumes and the net position of each auction zone, as well as the flow across interconnections. It also returns the selection of block, complex, merit and PUN orders to be executed. For blocks that can be reduced, the selection status will indicate the percentage accepted for each block. Finally, Mr.Desu explained how the different market places in Europe cooperate in order to perform the optimal market coupling using Euphemia. Indeed, it is often misunderstood that if a market participant chooses a marketplace for trading, it will indeed be seen by Euphemia, just as if he had chosen another marketplace. In order to do so, all marketplaces alternatively run Euphemia, collecting all orders from the different marketplaces. Indeed, Euphemia, as a non convex algorithm, provides results that can vary from a run to another. This organization provides an additional guarantee that no marketplace will use it at its advantage.

Then, Vladimir Temelkovski, *Service Manager*, former Service Owner at Intraday Trading, introduced us to intraday trading. Firstly, he delineated the reasons behind the intraday market, which complements the SPOT market and futures markets, allowing market participants to adjust their positions in real-time. Producers can thus value their production by considering the latest technical and meteorological contingencies. This latter aspect is pivotal to the development of the intraday market, which remains secondary to the SPOT market in terms of traded volumes. The significant growth of renewable energies in Europe will require the development of markets and products closer to real-time delivery to refine production forecasts. Moreover, demand-side actors also benefit from increased trading volumes to minimize deviations from their actual consumption or balancing perimeter. Additionally, these real-time adjacent markets foster the deployment of new flexibility mechanisms.

Secondly, Mr. Temelkovski elaborated on the establishment of the European platform XBID. NordPool, along with EPEX Spot and other European electricity exchanges, strives for the coupling of European markets, ultimately aimed at enhancing overall social welfare at the European level. Several European exchanges (EPEX SPOT, NordPool, GME, OMIE) and 11 countries' transmission system operators united to create the "Cross-Border Intraday initiative". The initiative materialized initially in 2018 with the launch of the XBID platform, enabling intraday trading among Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Latvia, Lithuania, Norway, the Netherlands, Portugal, Spain, and Sweden. A second wave in 2019 extended the trading platform to include Poland, the Czech Republic, Slovenia, Croatia, Romania, and Bulgaria. Following this historical overview, we observed how an operator could interact with this platform live, under the expert guidance of Mr. Temelkovski.

Finally, the visit wrapped up with a tour of the intraday trading supervision office, overseen by Isidora Micic, *Senior Power Market Expert* at NordPool. Despite limited access due to confidentiality, Ms. Micic shared insights into market supervision, a demanding profession requiring constant monitoring of all relevant indicators for an advanced understanding of market dynamics. Notably, a large screen in the supervision room displays a map of European winds, a useful indicator for predicting imminent variations in the intraday market.

We warmly thank all NordPool team for their hospitality and for sharing their insights into electricity markets.

Riff Fakhry & Kamil Takhi

Reception at the French Embassy

AMBASSADE
DE FRANCE
EN NORVÈGE
Liberté
Égalité
Fraternité

Reading time : 2 min

We had the unique opportunity to end this day of visits with a reception at the French Embassy in Oslo, an historical and charming mansion over the Oslo Fjord, which is the hotspot of the Franco-Norwegian friendship. In this exceptional location, we were received by Madam Ambassador, Florence Robine, who honoured us with her presence. We spent the evening discussing Norway and its relations with France and other various topics, all very inspiring, such as: the role of science in diplomacy, the different perceptions of energy transition in different countries, the life and challenges of being an ambassador.

As required by tradition, Ambassador Florence Robine welcomed us with an opening speech, which had the role of science in the challenge toward energy transition as one of its key topics.

As a Doctor in epistemology and history of exact sciences and a former associate professor of physics and rectress, Ambassador Florence Robine particularly stressed the responsibility of scientists in raising awareness and educating on major contemporary issues. On top of that, she also highlighted the need for a close connection between science and diplomacy in order to properly deal with these important issues.

In response to the opening speech of the Ambassador, Nadia Maïzi, director of the Center for Applied Mathematics (CMA) of Mines Paris – PSL and lead author at the IPCC, reminded that the topic of our dissertation and field trip (i.e. the impact of fossil fuels phase-out on producing countries) was consistent with the decision taken at COP28 to “transition away from fossil fuels in energy systems”. In this regard, she stated that learning from the historical connection between Norway and fossil fuels and from their new diversification strategies was a great opportunity to discover the combination between the deployment of policies and new technologies.

After the speeches, the Ambassador held an informal Q&A session which was the occasion to give us an overview of her missions and commitments as the French Ambassador in Norway. We will not transcribe here the details of all the questions and answers, that were very rich. The topics covered included but were not limited to: the various aspects of the job of ambassador, the challenges of climate change related to the arctic region, the previous experience of the Ambassador in Bulgaria and the differences with Norway, the importance for diplomats to have a scientific culture, and the role of women in science and diplomacy both in France and Norway. We left the French Embassy in Oslo with a profound sense of gratitude for this unique opportunity and a determination to rise to the challenges highlighted by the Ambassador. Before leaving, we were also given a reading tip to further develop our knowledge on epistemology: *The Structure of Scientific Revolutions* by Thomas Kuhn.

We deeply thank Ambassador Florence Robin for the invitation and her willingness to discuss with us: it was an inspiring evening, filled with insightful and meaningful conversations. We also would like to thank the team of the French Embassy that made this evening possible, in particular Mr. Bessat, Mr. Choblet and Mr. Falsanisi.

EMILIE NORMAND & GABRIELE TRISCARI

Visit of the Brevik Cement Plant, first cement plant in the world to be equipped with a CCS system

Heidelberg Materials

Reading time : 4 min

For the last day of visit in Norway, we took a 2-hour drive toward the south of Oslo, to reach Brevik, a peaceful town nestled on a beautiful Fjord Coast. In this idyllic framework, there is a cement plant owned by the Heidelberg Materials group that produces 1.5 million tons/year of cement. However, this one is not like any other plant, because it is going to be the first one in the world equipped with Carbon Capture equipment (CC), with a capture rate of about 400 ktons of CO_2 per year. There, Ingrid Vik Jondahl and Petter Thyholdt, Senior Engineers at the plant, received us and showed us around the CCS construction site.

Who is Heidelberg Materials?

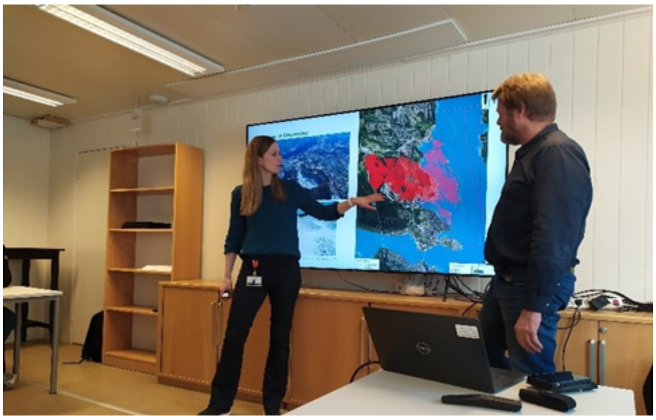
Heidelberg Materials is a German company, one of the biggest raw construction materials in the world. Heidelberg Materials is the second cement producer in the world after Holcim and owns 3,000 locations on all five continents, with two cement plants located in Norway (Brevik & Kjopsvik). The group has strong ambitions for its Net-Zero emissions target and plans to reduce its carbon scopes 1 and 2 by 47% by 2030, in comparison with 1990 levels. These targets are even higher for the plants located in Norway, where the carbon pricing is expected to rise faster compared to continental Europe. It is then essential for the company to implement new methods of decarbonation to stay competitive.

The cement industry

During the presentation, Ingrid Vik Jondahl reminded us that "concrete is the foundation of our society". This construction material is vital to us as it allows fast and convenient large-scale construction. However, the cement industry accounts today for 5%-7% of global greenhouse gas emissions. It is also considered a hard-to-abate industry as 2/3 of CO_2 emissions comes from the industrial process itself ($CaCO_3 \rightarrow CaO + CO_2$) with only 1/3 coming from the fossil fuel and raw materials use. To reduce this last third, the industry is working on alternative fuels (household waste mainly) and alternative materials (fly ash, volcanic pozzolan).

There are several materials used to make cement, including limestone (CaO), representing 90% of them. Other ingredients aim at giving some specific physical properties to cement and are Eramet Slag, Serox (Al_2O_3), "cobberslag" (FeO_3) and quartz (SiO_2). Most of the materials come from mines in Norway but some of them are imported from other countries like Turkey. The historical open cast-mine located nearby is no longer operational. The limestone is therefore carried from a large Norwegian mine (with a significant part under the sea) and from another open cast-mine in Norway that is famous for its limestone quality and availability of reserve.

The cement making process requires the use of row mills to crush the materials and furnaces for the calcination. The crusher and grinders are electrical and, as Norway's electrical mix is 88% from hydropower and at 10% from wind, their use is already decarbonized. To continue, the furnaces are powered at 80% with alternative fuels (in 2022), but fossil fuel is still needed for its start-up and for the control. About 70% of the alternative fuels used are composed of household and hazardous wastes, a part of which is imported from Ireland. The rest is made at 30% from biomass. Coal is the main fossil fuel used to power the furnaces, but work is currently underway to reduce its share in favour of al-



ternative fuels like biodiesel. But what can be done to capture the remaining emissions?

The Carbon Capture project

As for Hasflund Oslo Celsio waste to energy plant, Brevik plant Carbon Capture is part of The Longship CCS project. The Carbon Capture project at Brevik is well underway and should be operational by 2025. Everything started in 2005 with a full-scale desk study, followed by a series of pre-engineering and feasibility studies from 2011 to 2021, when the construction began. This CCS project has been developed thanks to a collaboration between Norcem, its motherhouse HeidelbergCement, and Aker Solutions. The last one is the company in charge of the development of the CCS technology and is involved in all phases of the Norwegian government's Longship project.

The construction site combines many challenges including: managing the operations in a restricted space and adding huge industrial process equipment in an existing installation.

The CCS technology used for the project is an **Amine-based post-combustion capture (PCC)** which is well-proven and commercially available, as it has been used in the petroleum sector since 1996 and in the coal-fired power industry since 2014. In the cement industry, it has shown great results during a small-scale trial at the Brevik plant. The capture process uses an amine solvent to scrub CO_2 from the flue gas. The flue gas is first fed into an absorption column, where the amine solvent selectively removes the CO_2. The CO_2-rich solvent is then fed into a desorber column, where it is heated to release the CO_2, which is then captured before being sent to a storage site. This regeneration process is highly energy intensive but can benefit from heat recovery of the calcination process. Finally, the regenerated amine solvent is cooled down and returned to the absorption column.

As soon as the system is operational and ramped up, it will be able to capture nearly 400ktons of CO_2 per year, which represents roughly 50% of the cement plant emissions today.

At the end of the presentation, we went to the platform to see and discuss the process equipment already in place. It has been a great opportunity to fully understand the immensity of the project and the resources to be deployed.

Guillaume Desermeaux & Nicolas Mourard

Eramet's Porsgrunn Plant Visit

Reading time : 3 min

During the last day, we visited the Eramet plant in Porsgrunn. This industrial site, steeped in history and innovation, offered a fascinating insight into the production of manganese, and many of us marveled at the process by which this molten metal is produced.

Founded in 1913 on the island of Roligheten, the original factory, named Porsgrund Elektrometallurgiske Aktieselskab (PEA), has gradually grown to become a world leader in its field. Integrated into the Herøya industrial zone, it now coexists with numerous historical companies.

Over the decades, PEA has undergone several metamorphoses, passing under the Elkem umbrella before joining the Eramet group. These transformations not only reflected the evolution of the industry, but also enabled the plant to remain at the cutting edge of technology and production.

Today, it produces a wide range of standard silicomanganese and refined ferromanganese, based on manganese ore extracted from the Eramet Group's mines in Gabon, South Africa and Colombia. In 2023, the company produced 7.4 Mt of manganese ore and holds 25% of the world's reserves. It also produced 635 kt of manganese alloys, with six plants located in Gabon, the United States, Norway and France.

Once refined, manganese is exported throughout Europe, but also to Turkey and North America.

In addition, the plant also stands out for its energy consumption and energy recovery initiatives. Although the plant consumes 570 GWh of electricity each year, it recovers almost 200 GWh in thermal energy, and supplies CO gas to Yara's nearby ammonia plant in Herøya.

With a view to the energy transition, Eramet is tackling decarbonization through a strategy targeting both internal emissions (scopes 1 and 2) and external commitment (scope 3). Internal efforts include improving energy efficiency, decarbonizing electricity consumed via solar power plants, and hydrogen to reduce fossil fuels use. Initiatives to capture and reuse CO_2 complete these actions. Notable projects include the Energy Recovery Unit in Norway, which optimizes the use of furnace gases to produce electricity and heat. Eramet aims to have two-thirds of its partners adopt emissions reduction targets aligned with the Paris Agreement by 2025, with 33% already committed by the end of 2022.

Figure 1. SiMn and FeMn manufacturing process

During our visit, we had the chance to learn about the furnaces' electrical configuration in detail from electrical engineer Tommy Fjeld, and other chemical specifications with Dr Matthieu Rivollier. During this presentation, we learned that the Porsgrunn plant boasts two large furnaces, n°10 and n°11, replacing the old n°1 furnace from 1913. They produce respectively 250 and 350 tonnes of manganese per day. With a much higher capacity than previous generations, these modern facilities enable the annual production of almost 170,000 tonnes of manganese alloys, instead of the 6,000 tonnes produced in 1915.

The furnaces are 33MW and 38MW electric arc furnaces. Each consists of 3 electrodes weighing 30 tons a piece, which are energized at 155kA to achieve a heat of 2,000°C.

We then enthusiastically set off to observe the fabulous stages of manganese production, which enabled us to understand the process from ore reception to transformation into alloys.

Before entering the plant's enormous furnaces and the heart of the process, let's take a look at the ore used. Inputs are called «rocks», and they come in two forms: MMA (Manganese Metal Alloy), very rich in manganese with a small ferrous component, designed for the production of ferro-manganese (FeMn), and MMD (Manganese and Silica Mineral Deposit), high in manganese and silica, for the production of sili-manganese (SiMn). Other inputs can be used, such as HM (High-Grade Manganese) for products requiring high manganese quality (e.g. batteries).

The manufacture of ferromanganese and silicomanganese is simplified to a reduction of the manganese oxide contained in the ore and a dilution of the manganese formed in the molten cast iron: this reaction results in the presence of carbon in the alloy. Carburized ferro-manganese includes 7% carbon.

It is then further purified later in the process by oxygenation before having previously separated from the slag thanks to density. Carbon monoxide results once again. Very strict safety measures are applied regarding this toxic gas, each operator thus wears a CO sensor equipped with an alarm. The refined ferromanganese finally contains less than 1.5% carbon.

Once refined, the ferromanganese or silicomanganese is transported back to the end of the line, where it cools before being stored.

The sweep of the baskets carrying the molten manganese and the rich descriptions of the manufacturing process of one of the critical metals by Eramet's engineers was a precious experience for us, and we warmly thank the company and especially the team that welcomed us to the Porsgrunn site.

Dorian Fourniret & Anas Naciri

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