SOCIO-ECONOMIC ANALYSIS

Of a potential restriction and analysis of alternatives of the per- and polyfluoroalkyl substances (PFAS) used in Lithium-ion battery cells and scalable battery systems

SUBSTANCE: **Per- and polyfluoroalkyl substances (PFAS)**

FROM: **Northvolt**

USE: **In Lithium-ion battery cells and scalable battery systems**

DATE: **05 July 2023**

PREPARED BY:
EPPA SA/NV
Place du Luxembourg 2
1050 Brussels, Belgium

EU transparency register: 31367501249-92

SOCIO-ECONOMIC ANALYSIS

Of the potential restriction and analysis of alternatives of the per- and polyfluoroalkyl substances (PFAS) used in Lithium-ion battery cells and scalable battery systems

PROJECT TITLE:

Socio-economic analysis of the potential restriction and analysis of alternatives of the per- and polyfluoroalkyl substances (PFAS) used in Lithium-ion battery cells and scalable battery systems

VERSION:

05 07 2023

PREPARED FOR:

Northvolt

PERFORMED BY:

EPPA: Jonathan Blanckaert, Rudy Colacicco, Parvoleta Luleva, Meglena Mihova, Karin Steiner.

CITATION:

EPPA, '*Socio-economic analysis of the potential restriction and analysis of alternatives of the per- and polyfluoroalkyl substances (PFAS) used in Lithium-ion battery cells and scalable battery systems*', Report for Northvolt, 07 2023.

DISCLAIMER:

Contents

Abbreviations

Al	Aluminium
BEV	Battery Electric Vehicles
BOM	Bill of Materials
CAGR	Compound Annual Growth Rate
CAM	Cathode Active Materials
CAR	Competent Authority Report
CAs	Competent Authorities
C&S	Crushing and Sorting
CLP	Regulation on Classification, Labelling, Packaging of Chemicals
CVs	Commercial Vehicles
DC-IR	Direct Current Internal Resistance
DRC	Democratic Republic of Congo
EBIT	Earnings Before Interest and Taxes
EC	European Commission
ECHA	European Chemicals Agency
EEA	European Economic Area
EEE	Electrical and Electronic Equipment
EIB	European Investment Bank
[CONF.]	[CONF.]
EPR	Extended Producer Responsibility
EU	European Union
EUR	Euro (currency)
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
FTE	Full-Time Equivalent
GDP	Global Domestic Product
UN GHS	Globally Harmonised System of United Nations for Classification and Labelling of Chemicals
GW	Gross Weight
GWP	Global Warming Potential
HEV	Hybrid Electric Vehicle
HF	Hydrogen Fluoride
[CONF.]	[CONF.]
[CONF.]	[CONF.]
[CONF.]	[CONF.]
IPCEI	Important Projects of Common European Interest
IP	Intellectual property
Li-ion	Lithium-ion
LRTP	Long-Range Transport Potential
[CONF.]	[CONF.]
NMP	N-methyl-2-pyrrolidone
NPV	Net Present Value
OECD	Organization for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
[CONF.]	[CONF.]
PFAS	Per- and Polyfluoroalkyl Substances
PHEV	Plug-in Hybrid Electric Vehicle
PMT	Persistent, Mobile and Toxic
[CONF.]	[CONF.]
PTFE	Polytetrafluoroethylene
[CONF.]	[CONF.]
[CONF.]	[CONF.]
PVDF	Polyvinylidene Fluoride
RAC	Committee for Risk Assessment
REACH	Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals
R&D	Research and Development
SEA	Socio-Economic Analysis
SEAC	Committee for Socio-Economic Analysis
SME	Small and Medium Enterprise
SVHC	Substance of Very High Concern
TRL	Technological Readiness Level
T&E	Transport & Environment
vPvM	Very Persistent and Very Mobile
[CONF.]	[CONF.]
wt%	percentage by weight

1. SUMMARY OF SOCIO-ECONOMIC ANALYSIS

Purpose

On 13 January 2023, the Competent Authorities (CAs) of the Netherlands, Germany, Sweden, Denmark, and Norway submitted a joint proposal to ECHA for a broad restriction under REACH of a group of fluorinated substances (PFAS). Per- and polyfluoroalkyl substances (PFAS) is a group of more than 10,000 synthetic (i.e., man-made) chemicals that are ingredients in various consumer and industrial products.

The use of fluoropolymers, a subgroup of PFAS, is prevalent in the battery industry. While they share a similar chemical structure to other PFAS, fluoropolymers have unique physical and chemical properties that set them apart from other members of the PFAS family, resulting in specific toxicological and environmental characteristics. Combining and grouping all PFAS together ignores the differences in their toxicity profiles. Although fluoropolymers can be classified as PFAS, they possess distinct properties; those that meet the OECD polymer of low concern criteria[1] are by the OECD considered safe for human health and the environment, as they are non-toxic, bio-compatible, non-soluble, and immobile.

This socio-economic analysis (SEA) focuses on the value of specific PFAS used for Lithium-ion (Li-ion) battery cells and scalable battery systems on the European market. It has been performed by EPPA[2] at the request of Northvolt, in view of providing regulators with strong evidence-based findings on the expected social and economic impacts that are expected to occur should these substances be restricted under REACH.

Northvolt, founded in 2016, has the ambition of becoming a leading Western supplier of sustainable, high-quality battery cells and systems in the battery market and is expected to grow 20x between 2022 and 2030, according to Transport & Environment (T&E).[3] The company focuses on sustainability throughout its activities, including recycling, sourcing, and manufacturing, and aims to provide sustainable solutions for various industrial sectors and applications, including for the automotive industry, renewable energy storage, industrial solutions, and aviation. Northvolt has its primary manufacturing base at Northvolt Ett in northern Sweden, as part of an expanding presence in Europe, with activities in Sweden, Poland, Norway, Portugal, and the USA and ongoing political negotiations on a potential establishment in Germany. Its key business facilities include a demonstration and pilot plant, R&D campus, cell manufacturing facilities, a cathode active material production plant, recycling facilities, and an assembly plant for battery modules and energy storage solutions. Many of its facilities run on 100% renewable energy.

[1] OECD, 2006. OECD definition of polymer. OECD Environment, Health and Safety Publications. Available at: https://www.oecd.org/env/ehs/oecddefinitionofpolymer.htm (Accessed in April 2023).

[2] www.eppa.com

[3] Transport & Environment, 2023. How not to lose it all Two-thirds of Europe's battery gigafactories at risk without further action. Available at: https://www.transportenvironment.org/wp-content/uploads/2023/03/2023_03_Battery_risk_How_not_to_lose_it_all_report.pdf (Accessed in May 2023) based on the direct citation: ''*From around 69 GWh of production output in 2022, Europe could reach 293 GWh in 2025, 620 GWh in 2027 and 1,374 GWh in 2030.*''

Methodology

The assessment has been **conducted in accordance with the existing official guidance from ECHA under REACH**,[4] and it is based on information and data gathered through a detailed survey from **Northvolt, a manufacturer and recycler of Lithium-ion battery cells, packs, and scalable battery systems that use PFAS in their manufacturing process**, covering a long-term market share in the range of 10 to 20% of the EEA Lithium-ion battery market.[5]

This SEA gathers technical and economic information to describe in both qualitative and where feasible, in quantitative terms, the (order of magnitude of) socio-economic impacts the Lithium-ion battery industry as well as the EEA supply chains and society are expected to face from the ban of PFAS. In particular, this SEA covers the function of PFAS in Lithium-ion battery cells, packs, and systems as well as the importance of the PFAS at the different stages of the manufacturing and recycling process of Lithium-ion battery cells, packs, and systems. The report also covers the **analysis of alternatives** which shows the lack of availability of technologically suitable and economically viable alternatives, the technical difficulties associated with the substitution of PFAS via alternatives. The SEA also covers the social and economic impacts from the PFAS restriction and the broader impacts to society.

The assessments presented in this report are as close to real data or to perception of future changes as possible to have conservative estimates, always putting the protection of human health and environment first.

Main findings

- **Lithium-ion batteries, as well as Northvolt's manufacturing process, heavily depend on some of the most common PFAS chemicals (fluoropolymers) on the market, in particular PVDF, [CONF.], and PTFE** due to their unique properties, such as thermal and chemical resistance and processibility and electrochemical stability.
    - Polyvinylidene fluoride (PVDF) in cathode slurry manufacturing, which is a critical step of electrode processing;
    - [CONF.] in several applications of the cell such as gaskets, seal gaskets, and seal balls;
    - Polytetrafluoroethylene (PTFE) in many equipment parts within the manufacturing process, such as tubes, pipes, gaskets, and in tank and pipeline linings/coatings.
    - Additional PFAS for specific applications are mentioned in the 'analysis of alternatives' section (3) further down in this document.
- **Fluoropolymers, such as PVDF, [CONF.] and PTFE, are necessary and essential for the manufacture of Lithium-ion batteries today. There are currently no known alternatives which would provide the same properties and which could be deployed in the short/medium term.** It is not technically feasible to switch to a different manufacturing technique within a short period of time, [CONF.].
- **According to the research performed, there is currently no evidence of technically suitable and readily available alternatives which can substitute the relevant PFAS in Lithium-ion battery cells and scalable battery systems, as well as in the manufacturing process**. In particular,

[4] The ECHA Guideline for SEA for the restriction proposals is available at: https://echa.europa.eu/documents/10162/23036412/sea_restrictions_en.pdf/2d7c8e06-b5dd-40fc-b646-3467b5082a9d

[5] Due to the fact that future estimations are referred to, with variable market dynamics, Northvolt is not able to provide an exact estimate within a specific range of 10 to 20%.

there are no viable alternatives to **PVDF** in NMP wet solvent-based cathode electrode manufacturing, which is the current industry standard utilised by Lithium-ion battery producers. In addition, PFAS ([CONF.]) remains indispensable for meeting the safety requirements of the automotive industry. There are also no alternatives for the larger part of the equipment used at Northvolt's facilities that rely on **PTFE**. Other PFAS applications used by Northvolt, detailed below, also do not have viable alternative options. **The development and launch of a new PFAS-free Lithium-ion battery onto the EEA battery market could take approximately [CONF.] years**. However, this timeline does not account for the additional years necessary for chemical producers to identify and develop alternative chemicals used inside the Lithium-ion battery cell and required for the Lithium-ion battery production process. **If chemical producers cannot offer alternatives today, it will take them at least [CONF.] years to develop new chemistry for batteries**, which must subsequently undergo testing and validation to ensure their suitability for use in batteries. In addition, possible development of new or revision of existing standards is required, to make sure that testing of new substances and materials meet the safety requirements based on the new specifications and technology, a common timeline for development of standards is 5 - 10 years. Most of the **alternative battery technologies** are still in development and are not commercially available yet. As discussed above, alternative technologies may also rely on PFAS for their functioning or may not have the required performance standards. **There are therefore also no alternatives available today at scale for Lithium-ion batteries used in the applications of Northvolt's customers**.

- A potential broad restriction without a derogation for batteries would have disproportionate socio-economic implications on the EEA Lithium-ion battery sector. It would also have significant implications for Europe's ability to achieve its net-zero economy goal by 2050 as outlined in the European Green Deal. **Overall, the total impact of a PFAS restriction is monetised as more than [CONF.] EUR for Northvolt,** including [CONF.] EUR of social impacts from unemployment in the EEA and [CONF.] EUR of economic impacts (EBIT loss). **This is a conservative estimate (lower bound), based on the understanding that this is not the sole injury likely to be suffered in the EEA.** Moreover, the total impacts for the whole EEA are unknown. As the expected long-term market share of Northvolt has been estimated in the range of 10 to 20%, no extrapolation to cover the EEA market is made based on such a low percentage.
- Additionally, the proposed restriction on PFAS substances in articles would **effectively prohibit manufacturing and importing Lithium-ion batteries in the EEA until alternatives are found.** This is because the fluoropolymers used are integral components of Lithium-ion batteries, as well as critical elements in the equipment required for battery manufacturing. This would have a significant impact on the industry's electrification, particularly on automotive companies based in the EEA, as they rely on a steady supply of Lithium-ion batteries for electric vehicles (EVs) to shift away from combustible engines.
- **The proposed restriction on PFAS would also have significant detrimental impact on Northvolt's recycling operations**. As recycling is a key pathway towards reducing the environmental impact of batteries, this restriction would have a negative impact on Europe's fulfilment of recycling and environmental goals. Lithium-ion batteries contain many materials that are listed on the existing Critical Raw Materials list, as well as on the EU Critical Raw Materials Act (European Commission proposal). As such, recycling is a preferred means to recover and reuse this material in a circular manner. Battery recycling represents a logical activity, from economic, geopolitical, and environmental perspectives. Sourcing raw materials from battery recycling (in the manner proposed by Northvolt) carries a lower environmental cost, with reduced carbon footprint, compared to sourcing virgin materials. Additionally, sustainability risks associated with mining virgin materials are eliminated, and dependence on the few, dominant nations currently serving the market with virgin materials is alleviated.

- **Lithium-ion battery recycling operations depend on recovering recyclable volumes from markets which operate over long timeframes (most electric vehicle battery lifetimes are between 10-15 years).** Restrictions which would constrain the battery recycling market would therefore carry socio-economic consequences long into the future, whilst also severely limiting Northolt's ability to produce batteries in the most sustainable way.
- A thorough risk assessment (jointly submitted to the authorities with this SEA) has been conducted by Royal HaskoningDHV at the request of Northvolt. **This risk assessment demonstrates that all possible technical means, supported by organisational risk management measures and, where indicated, personal protection equipment, are employed to minimise exposure to workers and emissions to the environment**. The report includes the following:
  - A clear description of the process using PVDF, including the operational conditions and risk management measures under which it is handled and used.
  - A clear description of the collection and disposal of PVDF-containing waste, including the treatment of waste by certified handlers.

  The risk assessment distinguishes between the emission and exposure of (A) PVDF in the manufacturing of Lithium-ion battery cells and (B) PFAS in the recycling process of battery cell material at Revolt. Based on evidence-based considerations, the report concludes that the **risks of the exposure to workers and emissions of PVDF and PFAS in both processes are controlled, [CONF.]. During normal battery usage, there is no PFAS exposure to human health or emissions of PFAS to the environment**.
- From an EEA macroeconomic standpoint, the broad restriction of the relevant fluoropolymers in the EEA will have impacts on innovation and on the overall EEA trade balance. **Non-EEA production facilities will be the only ones able to supply non-EEA markets.** Indeed, they would not be subject to a restriction of PFAS used in the product and in different stages of production. As a result, **the attractiveness of the EEA for investment in innovation and R&D would be jeopardised**. The 'wider economic impacts' section (4.2) provides a discussion on the wider macroeconomic impacts and consequences on EU society at large.

Based on the evidence-based considerations below, the SEA and AoA performed conclude that a broad restriction without a long-term derogation for the use of PFAS in the manufacturing and recycling of Lithium-ion battery cells and scalable battery packs and systems will have disproportionate negative impacts on the European economy and society. The analysis presented below reasonably justifies the request for a time-limited derogation of [CONF.] years for the use of critical fluoropolymers, such as PVDF, [CONF.], and PTFE and other specified PFAS in Lithium-ion battery cell and scalable battery system production, the use of batteries containing PFAS, and the recycling of batteries containing PFAS.

2. AIMS AND SCOPE OF THE SEA

2.1. Purpose, scope, and methodology of SEA under REACH

On 13 January 2023, the Competent Authorities (CAs) of the Netherlands, Germany, Sweden, Denmark, and Norway submitted a joint REACH restriction proposal for a broad group of fluorinated substances to limit the risks to the environment and human health from the manufacture and use of a wide range of PFAS in Annex XVII of the REACH based on persistent/very persistent (P/vP) criteria according to REACH Annex XIII and that are not able to degrade under environmental conditions. All PFAS in scope of this restriction proposal are either persistent themselves or degrade to other persistent PFAS. Additionally, supporting concerns emphasised by ECHA are mobility (M) of compounds, resulting in potential (bio)accumulation and toxicity in animals, as well as long-range transport potential (LRTP), accumulation in plants, and global warming potential (GWP). The opinion-making phase at ECHA takes 12 to 15 months. After this, the proposal, and the opinions of RAC and SEAC are forwarded to the European Commission (EC) for decision-making by the EC with the Member States (the entry into force of a potential restriction is anticipated to take place in 2025 and become effective in 2026/2027).

In the proposed restriction, PFAS (Per- and Polyfluoroalkyl Substances) are defined as any substance containing at least one fully fluorinated methyl (CF3-) or methylene (-CF2-) carbon atom (without any hydrogen, chlorine, bromine, or iodine attached to it). The definition is based on OECD definition of PFAS published in 2021 and covers over 10,000 PFAS, including some fully degradable subgroups. PFAS is divided into two groups, non-polymeric and polymeric. Within the polymeric group the most commonly used fluoropolymers are found, such as PVDF and PTFE. Fluoropolymers possess distinct properties as described in below sections and meet the OECD polymer of low concern (PLC) criteria[6], which are by the OECD considered safe for human health and the environment, as they are non-toxic, biocompatible, non-soluble, and immobile. The PLC criteria have further been examined and assessed by the industry to show that fluoropolymers met the set criteria.[7]

Based on information provided by manufactures of fluoropolymers, more than 50% of the fluoropolymers produced no longer require the use of fluorinated polymerisation aids, which is in line with the restriction proposal. This is due to new techniques that have been developed. The fluoropolymer industry has pointed out that these new techniques lower the emission of PFAS to air and water when manufacturing fluoropolymers, such as PVDF and PTFE.

Great Britain's Health and Safety Executive (HSE), the agency regulating workplace health and safety, published a Regulatory Management Opinion Analysis (RMOA) in April 2023[8] about PFAS. There is no single global definition of PFAS adopted, and the definition provided by the HSE differentiates from the OECD definition which EU has based their PFAS restriction proposal on. In the HSE's report PFAS is defined as: Fluorinated substances that contain at least one fully fluorinated methyl carbon atom (without any hydrogen, chloride, bromide, or iodine atom attached to it), or two or more contiguous perfluorinated methylene groups (-CF2-). This definition means that many fluoropolymers are excluded from the definition provided by HSE. The rationale for the definition is that those substances containing only a -CF2- -group are not considered to degrade into arrowheads that raise concerns to human health or to the environment. Different PFAS definitions within the EEA and the UK would cause confusion and potentially complicate trade and communication within the supply chain.

[6] OECD, 2006. OECD definition of polymer. OECD Environment, Health and Safety Publications. Available at: https://www.oecd.org/env/ehs/oecddefinitionofpolymer.htm (Accessed in April 2023).

[7] A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers (wiley.com) (Assessed in June 2023)

8 Analysis of the most appropriate regulatory management options (hse.gov.uk) (Assessed in June 2023)

In May 2017, The German authorities proposed criteria for identifying such chemicals in the regulatory context of EU REACH Regulation (EC) No 1907/2006. Substances meeting these criteria are referred to as either persistent, mobile, and toxic (PMT) or very persistent and very mobile (vPvM) substances. Recently, the EC has published a Delegated Regulation[9] amending CLP Regulation, which sets out new hazard classes and criteria for the classification, including of PMT and vPvM substances and mixtures. Many PFAS are efficient surfactants or surface protectors because of the perfluoroalkyl moiety's high chemical and thermal stability as well as its ability to repel water and oil. As a result, they have been produced in large quantities and used in a variety of industrial, commercial, and consumer applications since the late 1940s.[10, 11, 12]

Certain members of the PFAS chemical family have already been (or are currently in the process of being) restricted under REACH: PFOA, PFHxA, PFHxS, C9-C14 PFCA. Other members of the group are under authorisation procedures (HFPO-DA, PFDA, PFNA), or recognised as SVHC (PFBS). Measures on certain members of the PFAS group are in place also under the POPs Regulation, Food Contact materials legislation, new Drinking Water legislation and F-Gas Regulation. The aim of the broad restriction is to move away from this “piecemeal approach”, which has led to “regrettable substitution” of restricted substances by other members of the PFAS chemical family.

Based on the UN GHS and CLP criteria, **many PFAS substances are not classified as hazardous, leading to the fact that the safety data sheets of the chemical mixtures often do not contain information about the PFAS content**. Moreover, **there is no obligation today to forward information about PFAS in articles (except for some PFAS such as PFOA and its salts which were added recently in the Candidate list for authorization under REACH[13]).** It is a very difficult and extensive task to investigate which ones of the thousands of handled components and equipment contain PFAS, how much PFAS in that case, whether PFAS is critical for the application, what alternatives are available and, in that case when in time.

No CAS-numbers at all are included in the PFAS restriction proposal. While this can be understood from the perspective of also wanting to cover substances which do not yet exist, it significantly complicates communication with suppliers further. **The chemical identifiers (e.g., EC and CAS-numbers) are the main identification method in communication throughout the supply chain.** The technical solutions for communication and data storage are built around the EC numbers (EINECS, ELINCS, etc.), and CAS-number approach ensuring all parties communicate about the same substance. Moreover, identification through EC and CAS-numbers enables important compliance communication taking place between administrative personnel without deeper understanding of chemistry and chemical structures. The amount of compliance communication already taking place is much larger than access to staff educated in chemistry, who mostly work with other work tasks than collecting compliance information from thousands of suppliers. The lack of chemical identifiers is a problem even for people with chemistry degree, as many duty-holders struggle understanding whether a substance is within the proposed restriction scope or not - only based on the definition.

9 COMMISSION DELEGATED REGULATION (EU) 2023/707 of 19 December 2022 amending Regulation (EC) No 1272/2008 as regards hazard classes and criteria for the classification, labelling and packaging of substances and mixtures (OJ, 31/03/2023, L 93/7).

10 Banks, R.E., Smart, B.E., Tatlow, J.C., 1994. Organofluorine chemistry: Principles and commercial applications. New York (NY): Plenum. 670 p. ISBN 978-1-4899-1202-2.

11 Kissa, E., 2001. Fluorinated Surfactants and Repellents, 2nd Edition, CRC Press. ISBN 9780824704728.

12 Buck, R.C., Franklin, J., Berger, U., Conder, J.M., Cousins, I.T., de Voogt, P., Jensen, A.A., Kannan, K., Mabury, S.A., van Leeuwen, S.P., 2011. Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integr. Environ. Assess. Manag.* 7, 513−541.

13 https://echa.europa.eu/candidate-list-table

As demonstrated, information collection has been done for the battery cell and partly for manufacturing equipment to Northvolt's best ability in the timeframe provided but **it is not possible to collect the information regarding purchased components and equipment during the timeframe of this** PFAS **public consultation ending in September 2023. As many PFAS uses have not been identified on time for this public consultation, there is very high potential that there will be critical applications that have not been precisely addressed in this submission to the public consultation. [CONF.]. Considerably more time than 6 months would be required to collect the requested information.**

Reference to other organisations' input to the public consultation

In addition to Northvolt's own input into the public consultation, Northvolt is referring to the public consultation submissions of other organisations with deeper knowledge on specific PFAS related topics.

- **RECHARGE**: Already submitted input and the additional inputs expected to be submitted on technical and other aspects related to PFAS role for the EU battery industry as whole.
- **Cefic:** Input that is expected to be submitted related to PFAS role in chemical process equipment and other process equipment where powders, liquids and other materials need to be kept enclosed and where contamination from the equipment is to be minimized.
- **ACEA:** Already submitted input and additional inputs expected to be submitted related to PFAS role in the automotive industry.
- **Orgalim:** Input that is expected to be submitted related to PFAS role in manufacturing equipment and in articles in general.
- **VDMA:** Input that is expected to be submitted related to PFAS role in manufacturing equipment.
- **Teknikföretagen** (Swedish Engineering Industries) Input that is expected to be submitted related to PFAS role in manufacturing equipment and in articles in general.
- **Svenskt Näringsliv** (Confederation of Swedish enterprise) Input that is expected to be submitted related to PFAS role for Swedish industry.
- **Fluoropolymer Group (Plastics Europe):** Input expected to be submitted related to definition of fluoropolymers, describing that they differ from other PFAS and have specific toxicological and environmental profiles. Also providing various applications and use purposes of fluoropolymers.

Methodology

This Socio-Economic Analysis (SEA) aims to identify and to assess in both qualitative and (when feasible) quantitative terms the socio-economic impacts that are expected to occur in case of a REACH restriction to this group of substances. The SEA does not only cover the use of PFAS in Lithium-ion battery cells, packs, and systems, but also the importance of PFAS used at different stages of the manufacturing and recycling process of Lithium-ion battery cells, packs and systems. **A detailed questionnaire has been provided to Northvolt** to gather information and data on PFAS for battery cells and systems in the EEA to be affected by a potential REACH restriction.

The long-term market share covered by this survey is approximated in the range of 10 to 20% of the EEA market based on the estimation of the likely production capacities in the long term (~2030). **The estimates reported in this socio-economic analysis should be considered as a minimum (lower bound) of the expected impacts of a restriction for European manufacturers of Lithium-ion battery cells and scalable battery systems produced with PFAS.**

From a geographical perspective, this analysis focuses on the European Economic Area (EEA) territory, comprising the European Union (EU-27), Iceland, Liechtenstein, and Norway. For the purposes of estimating economic impacts, it has been decided to use a **4-year time horizon**, which is the time period suggested by SEAC when there is no alternative available in general (SAGA).[14, 15]

In other terms, the SEA accounts for the costs to the EEA society in the event PFAS substances are prohibited from being manufactured, used, and placed on the market, and/or for the socio-economic costs of a complete ban (REACH restriction) starting from the year 2027 (year of the entry into force of the proposed restriction plus 18 months of transition period).

Future monetary values have been estimated by using the concept of net present value (NPV), adopting a 3% annual discount rate, which is the standard discount rate adopted by the European Commission and European agencies (e.g., ECHA) in impacts assessments.[16] **All monetised values have been adjusted to a base year, assumed to be 2027**. Information and data have been aggregated and anonymised. Statements and estimations from the participating company are as close to real data or perception of future changes as possible.

The assessment has been conducted in accordance with the existing official guidance from ECHA under REACH. ECHA has developed a solid methodology for conducting socio-economic assessments in the context of the REACH Regulation, with the support of a dedicated committee (SEAC). More specifically, this methodology is consistently applied for REACH applications for authorization of Substances of Very High Concern (SVHC), and REACH restrictions with a view of forecasting through the SEA the impacts of the different regulatory options.

2.2. Overview of Lithium-ion battery products and their value chain

General overview of the Lithium-ion battery market

The Lithium-ion battery industry has experienced rapid growth in recent years, driven by the global transition towards electric passenger light duty vehicles. Lithium-ion batteries have emerged as the dominant technology in the electric vehicle market due to their potential to power energy storage systems and electric vehicles (EVs) while reducing greenhouse gas emissions. They offer a longer lifespan and higher power density compared to traditional batteries, making them a preferred choice for various industry- and consumers products.

Lithium-ion batteries were first proposed in the 1970s by M.S. Whittingham and were later introduced by Sony in 1991. Today, they are widely used in transportation, consumer electronics, and grid energy storage. Within the transportation sector, Lithium-ion batteries are primarily used in electric vehicles, such as cars, bikes, buses, and forklifts. EVs can be categorized into four types, including battery electric vehicles (BEV), plug-in hybrid electric vehicle (PHEV), hybrid electric vehicle (HEV), and fuel cell

[14] https://echa.europa.eu/documents/10162/13637/ec_note_suitable_alternative_in_general.pdf/5d0f551b-92b5-3157-8fdf-f2507cf071c1

[15] https://echa.europa.eu/documents/10162/0/afa_seac_surplus-loss_seac-52_en.pdf/5e24c796-d6fa-d8cc-882c-df887c6cf6be?t=1633422139138

[16] European Commission, 2021. Better Regulation Guidelines and Toolbox. https://commission.europa.eu/document/download/9c8d2189-8abd-4f29-84e9-abc843cc68e0_en?filename=br_toolbox-nov_2021_en.pdf

electric vehicle (FCEV)[17]. Investing in production facilities is crucial, especially with political goals of Net Zero emission EU and market demands in mind.

The emergence of the Lithium-ion batteries is also an answer to the European Union's ambitious goals to reduce carbon emissions and achieve climate neutrality by 2050, with a focus on reducing emissions from the transportation sector, which accounts for approximately 30% of total emissions. EVs are seen as a viable alternative to traditional fossil fuel vehicles and have seen an increasing trend in the European market, with 550,000 BEVs sold in 2019, accounting for approximately 2% of new vehicle registrations. However, the total number of EVs registered in European countries has reached over 12 M units, indicating a significant increase in adoption. The EU has implemented policies and regulations, including the Energy Technology and Directive 2014/94/EU directive to accelerate the development of low-carbon technology and establish alternative fuel infrastructure. Moreover, the Circular Economy Action Plan proposes a regulation on batteries and waste batteries to replace the existing Directive 2006/66/EC on batteries and accumulators. The European Parliament and Council adopted their positions on the regulation, emphasizing due diligence, supply-chain sustainability, and boosting the reusability and recyclability of batteries. The proposal introduced measures to ensure that all batteries sold in the EU market are produced sustainably, including rules on carbon footprint, collection rates, recycled content, and durability criteria, as well as a labelling system and a Battery Passport for larger batteries by 2026 to ease recycling and repurposing. A provisional agreement between the Parliament and Council was reached during the trilogue held under the Czech presidency on 9 December 2022. The regulation will be mandatory for all batteries entering the single market by 2027. The EU reported that Lithium-ion batteries placed on the European market totalled 74,906 tonnes in 2019 (of which ca. 49% are related to EEE applications, and 51% are industrial and automotive batteries) with recycling capacity ranging from 54,200 to 81,500 tonnes per year in five European countries (BE, DE, FI, FR, CH), mostly using a combination of mechanical separation, pyrometallurgical, and hydrometallurgical methods.[18]

Many competitor producers of Lithium-ion batteries are located in Asia. Korean and Japanese companies are notable; however, Chinese companies are likely to boost competition in the future. Contemporary Amperex Technology Co Ltd. (CATL), a Chinese company, currently holds the top position as the largest Lithium-ion battery manufacturer for electric vehicles in the world. As of 2021, it had a market share of 32.6%, which translated to producing 96.7 GWh out of the global 296.8 GWh. This represents a remarkable year-on-year growth of 167.5%. In 2022, CATL's dominance grew even more as its market share increased to 37%.[19] Asian battery manufacturers are localising their production in the EEA. Benchmark Mineral Intelligence (BMI) estimates that Europe should have a manufacturing capacity of 1,200 GWh by 2031 if current plans come to fruition; Asian companies with factories in Europe, helped by their track record and offtake agreements, are expected to provide 44% of that 1 200 GWh.[20] The forecasted high demand for EVs and, in turn, for Lithium-ion batteries implies that industry actors will invest more over time to expand their production capacities. Indeed, this is also the ambition of Northvolt, in case the market moves as expected and sales increase, by investing more in facilities and

[17] Noudeng, V., Quan, N. V., Xuan, T. D., 2022. A Future Perspective on Waste Management of Lithium-Ion Batteries for Electric Vehicles in Lao PDR: Current Status and Challenges. *International Journal of Environmental Research and Public Health*, 19(23), 16169.

[18] Noudeng, V., Quan, N. V., Xuan, T. D., 2022. A Future Perspective on Waste Management of Lithium-Ion Batteries for Electric Vehicles in Lao PDR: Current Status and Challenges. *International Journal of Environmental Research and Public Health*, 19(23), 16169.

[19] Doll, S., 2022. CATL continues reign as the world's largest EV battery manufacturer for a fifth straight year. Available at: https://electrek.co/2022/02/08/catl-continues-reign-as-the-worlds-largest-ev-battery-manufacturer-for-a-fifth-straight-year/ (Accessed in May 2023).

[20] Carey, N., Waldersee, V., 2022. Europe leans on Asia for 'homegrown' EV batteries. *Reuters*. Available at: https://www.reuters.com/technology/europe-leans-asia-homegrown-ev-batteries-2022-11-03/ (Accessed in March 2023).

plants in the EEA. It is strategically important for the EU to have EEA-based Lithium-ion batteries producers to achieve supply chain security and advance the region's competitiveness. Moreover, EEA-based plants decrease transportation costs and time delays, and allow manufacturers to retain control on quality and design. The need for EEA-based producers also addresses the risks for private investors in the Lithium-ion batteries market in the EEA.

However, a recent study by Transport & Environment[21] found that 68% of Europe's planned battery production facilities, known as gigafactories, are at risk of delay or cancellation due to a lack of political support and investment. The study examined 38 large-scale battery cell production facilities planned in Europe and found that only 12 have begun construction or are operational. This situation could lead to planned capacity by Tesla in Berlin, Northvolt in northern Germany, and Italvolt near Turin, Italy to potentially be redirected towards the US instead. The delay in building these gigafactories could have serious consequences on the EU's ability to meet its climate goals and become a leader in the electric vehicle market. Transport & Environment's research further quotes BloombergNEF data indicating a significant decline in Europe's global share of new investments in Lithium-ion battery production, dropping from 41% in 2021 to only 2% in 2022. Meanwhile, battery investments in the US and China are on the rise, and some European companies have already indicated plans to expand in America. The study further suggests that due to limited resources for scaling up production and the scarce supply of raw materials, the competition between the US and Europe in the battery race is becoming a zero-sum game. Therefore, there is a pressing need for increased investment in battery production to enable Europe to fulfil the rising demand for batteries for electrification, including for electric vehicles.

Northvolt

Northvolt is a European company that was established in 2016 with a vision to facilitate the shift towards a sustainable, low-carbon future. As a manufacturer, Northvolt specializes in producing high-performance rechargeable Lithium-ion cells, available mainly in prismatic formats, but also cylindrical and pouch formats. Cylindrical cells are suitable for a wide range of applications, while the prismatic cells are tailored to meet the specific requirements of customers' applications. Pouch cells are currently used for cell development and testing but are positioned for commercial applications in the future such as Northvolt's next generation lithium metal technology line. In addition to producing cells, Northvolt also develops scalable battery systems that can be used to power a wide range of applications, and it is scaling battery recycling in parallel to the ramp-up in battery manufacturing capacity, closing the loop on batteries with an in-house program for battery recycling (Revolt). Northvolt's facilities include, for example a demonstration and pilot plant, R&D campus, cell manufacturing facilities, a cathode active material production plant, recycling facilities, and an assembly plant for battery packs and energy storage solutions. Many of its facilities run on 100% renewable energy.

Northvolt's main outputs

The main outputs of Northvolt are:

- Rechargeable Lithium-ion battery cells (varying formats: prismatic, cylindrical and pouch).
- Rechargeable Lithium-ion battery system solutions (varying solutions including, battery modules, battery packs and complete battery systems).

[21] Transport and Environment, 2023.Two-thirds of European battery production at risk – analysis. Available at: https://www.transportenvironment.org/discover/two-thirds-of-european-battery-production-at-risk-analysis/ (Accessed in March 2023).

- Rechargeable Lithium metal battery cells (pouch cell format) and lithium metal battery modules.
- Metals recovered through recycling of end-of-life batteries and battery manufacturing waste. The metals can be used in the production of cathode active material, or supplied to market.
- Chemicals used in the Lithium-ion battery cell: manufacturing of battery materials.

In a chemical manufacturing unit, production of off-spec materials and by-products is unavoidable. However, with appropriate management, these materials can be recycled or upcycled. At Northvolt:

- Sodium sulfate (Na_2SO_4) will be recovered and purified at Northvolt cathode active material production plant of Northvolt Ett, and sold for its use in fertilizer manufacturing.
- Other chemicals such as metal-containing materials from the production of the cathode active material.

Northvolt's facilities and legal entities

Northvolt's facilities and legal entities are located in numerous countries. To meet the increasing demand for electric vehicles, which have become popular in Europe, Northvolt has established Europe's largest battery factory in Skellefteå (Northvolt Ett), Sweden. Northvolt Ett is currently ramping up production capacity, with the goal of ultimately producing 60 GWh/year. The company has a scalable battery systems assembly manufacturing unit in Poland where modules and packs are built using Lithium-ion cells. Northvolt AB has a subsidiary located in the United States that specializes in the production of lithium metal battery cells and modules. The company is targeting the aviation industry with its lithium metal battery technology.

Northvolt has announced ambitions to establish additional manufacturing facilities in Sweden (Borlänge), as well as a joint venture manufacturing facility with Volvo Cars in Gothenburg. Northvolt's long-term plan also involves building a manufacturing plant in Germany (Heide). Altogether, Northvolt is targeting an annual production capacity of approximately 150 GWh in Europe by 2030. The possibility of building cell production facilities in North America is currently also being considered by Northvolt.

Northvolt is committed to sustainability and takes recycling seriously. The company therefore has built a recycling facility adjacent to its cell manufacturing unit in Skellefteå, Sweden, with start of production 2023, allowing it to extract valuable metals from used cells and from battery manufacturing waste from its neighboring facility for use in the production of new battery cells. Fully built, Revolt Ett will recycle some 125,000 tons of battery materials per year and be one of the world's largest recycling plants of its type, recovering lithium, nickel, manganese, and cobalt. This approach helps to minimize the use of fresh raw materials and reduce the environmental impact of battery production. Northvolt's business comprises multiple manufacturing stages, including large-scale production of battery chemicals, the assembly and manufacturing of Lithium-ion battery cells and larger battery units like packs and modules, as well as larger battery storage units, and recycling.

Northvolt group consist of several legal entities, some of which have been mentioned above, that are now at various stages of development:

- **Northvolt Ett (SE – Skellefteå)**. Ramping up to 60 GWh/year cell production, with on-site recycling. It is powered by 100% fossil-free energy.
- **Northvolt Labs (SE – Västerås)**. R&D facility and demonstration plant, manufacturing cell samples for customers ahead of large-volume manufacturing. The cell industrialisation campus has full upstream and downstream production capacities. Additional on-site facilities provide complete cell safety and validation capabilities. The campus is powered by 100% fossil-free energy.

- **Northvolt Revolt AB (SE – Västerås/Skellefteå)** A pilot recycling plant provides a platform for process innovation and optimization in Västerås. Revolt full scale recycling plant in Skellefteå is anticipated to enter production towards the end of 2023.
- **Hydrovolt (NO - Fredrikstad)** Battery recycling operations joint venture between Northvolt and Hydro.
- **Northvolt AB (SE – Stockholm)**. Sales, supply chain, HR, and other global functions.
- **Northvolt Dwa Industrial (Systems) (PL – Gdansk)**. Production started in 2019. Assembly plant for battery modules and packs with a battery systems annual production capacity of 400 MWh.
- **Northvolt Dwa ESS (Systems) (PL – Gdansk)**. Production start during 2023. Assembly plant for battery modules and packs with a battery systems annual production capacity of 13 GWh.
- **Northvolt Systems (SE – Stockholm)**. R&D facility, assembly of battery systems.
- **Northvolt Fem (SE - Borlänge)**. An upstream cathode active material manufacturing plant under development utilising 100% fossil-free energy. It is expected to have a cathode active material production of 100 GWh.
- **Nortvolt Drei (DE – Heide Region)**. Planned cell manufacturing gigafactory, ramping up to 60 GWh/year cell production. The project is in discussion within a region with one the cleanest energy grid in Germany.
- **NOVO (SE – Gothenburg):** Joint venture between Northvolt and Volvo with a plan to have plant ready for production start in 2025. Projected maximum capacity is at 50 GWh/year.
- **Cuberg (US – California San Leandro).** This entity combines next-generation lithium metal cell technology, world-class R&D expertise and a global manufacturing capacity to enable new modes of all-electric transportation, and is currently geared towards developing battery solutions for electric aviation. The R&D phase is active today and there is a plan to start production in California.
- **Aurora (PT - Setúbal)** Joint Venture with Galp. Planned lithium conversion plant set to have an initial annual production capacity between 28,000 and 35,000 tons of battery-grade lithium hydroxide.

Northvolt's impact, growth, and trends

With these plans in place, Northvolt is poised to make a significant impact in the field of energy storage, paving the way for a more sustainable future. [CONF.].

Northvolt Ett's strategy prioritizing sustainability is having a positive impact, as evidenced by a Life Cycle Assessment indicating a carbon footprint of approximately one third that of comparable industry reference cells. This reduction is largely due to Northvolt Ett's use of 100% hydropower and wind power. However, the company aims to reduce its carbon footprint to 10 kg CO_2 e/kWh by 2030. By demonstrating a more sustainable approach to battery manufacturing, Northvolt Ett is contributing directly to Europe's transition to a cleaner future, with commercial deliveries beginning.[22]

In March 2023, after a monthly average growth of 100 employees over the past year, the company already employed approximately [CONF.] people. Northvolt has established partnerships with some of Europe's leading automotive manufacturers and industry players seeking to transition to an all-electric

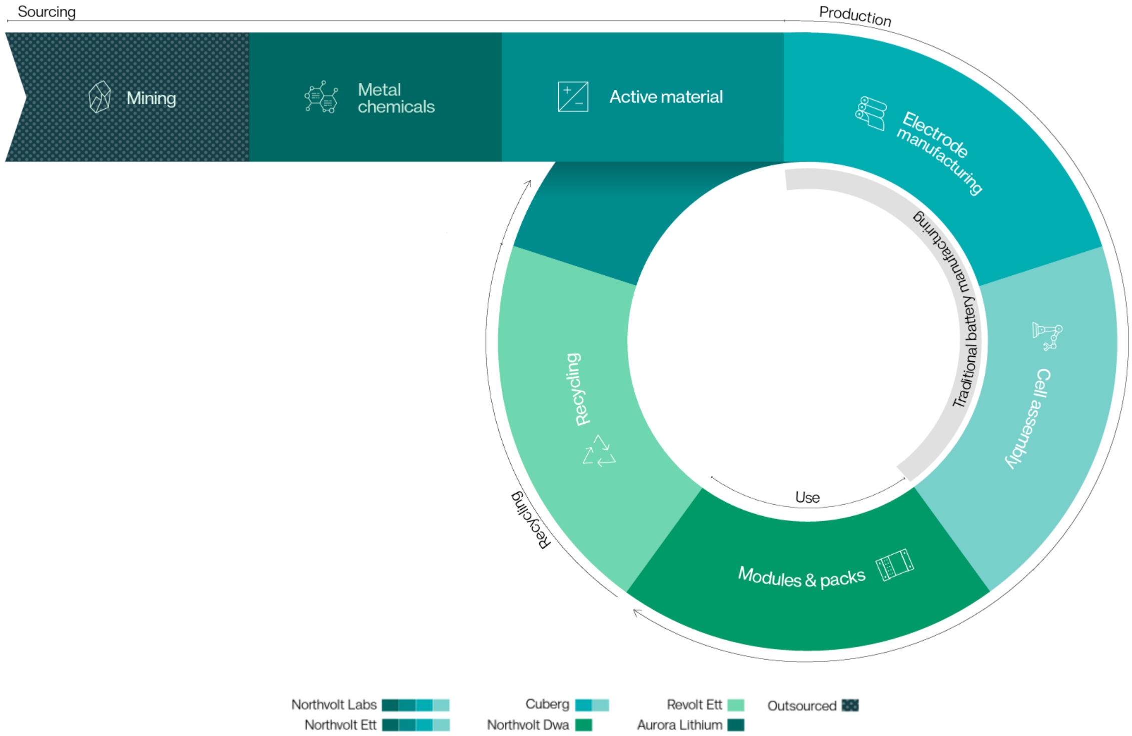
[22] Northvolt, 2021. Sustainability Report 2021. Available at: https://www.datocms-assets.com/38709/1655449087-northvolt-sustainability-report-2021.pdf (Accessed in March 2023).

future, namely BMW, Volkswagen, Volvo Cars, Scania, and Fluence. Northvolt has also seen a remarkable demand for its sustainable batteries, which has led to the securing of cell supply agreements worth 50 billion EUR (rounded)[23] by March 2022. Currently, the company's focus is on scaling up production to establish an annual cell production capacity of approximately 150 GWh in Europe by 2030, along with appropriate recycling capacity to ensure a circular system for batteries. Northvolt is fully committed to building and delivering battery solutions that contribute towards creating a cleaner and better world.[24, 25]

Value chain overview

Northvolt actively works with suppliers, with a particular focus on materials and equipment, and strategic partners to drive positive change throughout the value chain and establish local battery ecosystems. Integrating several typically separate steps in a battery value chain under one roof makes Northvolt unique. The figure below highlights the steps in the typical supply chain of Lithium-ion battery cells performed by Northvolt. This vertical integration across the battery supply chain enables complete product control, traceability, sustainability, and structural cost advantages. It permits Northvolt to embrace new methods, innovation, and R&D to advance products and solutions and to facilitate its commitment to sustainable and ethical sourcing of raw materials and fossil-free energy in cell production.

The typical supply chain for Lithium-ion battery products using PFAS is as follows:



Source: Northvolt, 2023

[23] Using the ECB exchange rate of 7 March 2023 (1 EUR = 1.0665 USD) based on 55 billion USD.

[24] Northvolt. 2021. Sustainability Report 2021. Available at: https://www.datocms-assets.com/38709/1655449087-northvolt-sustainability-report-2021.pdf (Accessed in March 2023).

[25] Financial Times, 2023. Northvolt: the Swedish start-up charging Europe's battery ambitions. Available at: https://www.ft.com/content/577920d3-1c60-4105-9503-80e655280d3a (Accessed in March 2023).

- **Battery raw materials** (such as Cobalt, Graphite, Lithium, Manganese, Nickel) **as well as PFAS are sourced from Europe and from around the world.** Northvolt is committed to sourcing these materials from ethical and responsible suppliers, and has developed a supplier code of conduct to ensure that the suppliers meet Northvolt's standards. Also recycled raw materials are used;
- **The raw materials are then processed** into active materials that are used in the battery manufacturing process. The active materials for the battery cells, such as the cathode active materials, are synthesized by Northvolt from the battery raw materials;
- **Lithium-ion battery cells and electrodes can be directly produced by active material manufacturers themselves** ("integrated manufacturers") or **third-party manufacturers**. Manufacturing a battery from scratch in this way relies on chemical processes to produce electrode material. This initial upstream phase is something most cell manufacturers customarily outsource by procuring electrode from third parties. However, Northvolt has both the electrode manufacturing and the cell assembly steps integrated in-house;
- **The assembled cells are then sold as they are for the customer to integrate in their products, such as EVs. Alternatively, Northvolt connects and packages battery cells into battery modules, or bigger battery packs, which can be sold as they are for the customer to integrate in their products;**
- Northvolt's portfolio contains also **battery systems containing battery modules and packs.** These are ready-to-use products that can be sold as such to the customers to start using for industrial applications and stationary energy storage.
- Batteries are then used for energy storage in various applications, such as EVs, passenger cars, commercial vehicles (CVs),
- The final stage of the value chain involves **recycling of batteries** to recover valuable materials and reduce waste. Northvolt aims at recycling in-house battery manufacturing waste and market volumes (such as end-of-life batteries) in own recycling facilities. Recovered metals are used in cell production, thereby creating a circular battery industry.

Northvolt produces rechargeable Lithium-ion battery cells, battery modules and packs, and larger battery units, which contain PFAS substances/parts. All products are currently manufactured in Sweden and Poland.

PFAS upstream supply

[CONF.]

[CONF.]

Manufacturing of active material and battery cells

Manufacturing active material for battery electrodes is a large-scale chemical process with high safety standards requiring reliable process equipment. Manufacturing of battery cells requires very controlled conditions, such as clean and dry rooms to avoid contamination.

The company uses specially designed equipment to manufacture these products. This specialized equipment used in the manufacturing process, and many parts and spare parts of this equipment are made from or coated with PFAS materials to ensure the required performance, maintain closed systems for safety reasons, and prevent contamination during the manufacturing process. [CONF.].

Manufacturing of bigger battery units and integrating batteries into products

The battery cells used in the bigger battery units are intended to come mainly from Northvolt's own battery cell production. [CONF.], to be assembled into modules and packs at a facility located at Northvolt Systems facility in Gdansk, Poland. Some of these cells also find their way to the R&D facility in Sweden. [CONF.].

Northvolt's customers are mainly in the automotive industry, who use the battery cells [CONF.] in their electric vehicle battery packs, while the modules and packs are also used in other systems that require rechargeable batteries. Battery packs are utilized in various products, by OEMs in the industrial sector and for stationary energy storage purposes, as an example in mining equipment, in mobile energy storage replacing diesel engines in construction sites or concerts as well as in battery units supporting integration of renewable energy and balancing the grid load. The products are shipped and used in many countries within and beyond EEA.

Recycling operation (Revolt)

Northvolt's recycling operation (Revolt) is divided in four process steps: discharge, dismantling, crushing and sorting (C&S) and hydrometallurgy. No PFAS chemical or materials are added to these processes.

Revolt does not intentionally add any PFAS to the feed material and the recycling process. Cells/modules/packs are sourced to be recycled at Revolt. These are expected to contain PFAS, which are well known to be used in vehicle batteries. Revolt receives feed material containing PVDF from various battery manufacturing stages when taking in off-spec materials/waste from battery manufacturing units. Batteries (cells/modules/packs) at end-of-life are taken in from customers, partners, and the market. The lifetime of Lithium-ion batteries used in electric vehicles ranges from 5-15 years, and these are the time frames to be considered in recycling operations.

It is in 'crushing and sorting' where the battery cell is separated into components. Components made of or containing PFAS follow certain streams in Revolt. The PFAS used as a binder on the cathode foil will end up in the hydrometallurgical process.

[CONF.]. Any fractions that contain PFAS substances are treated in high temperatures or disposed of through combustion by the receiving partners.

The process equipment used at Revolt contains PFAS in the same way and for the same reasons as in any other chemical process equipment. See other sections for more details.

2.3. The use of PFAS in Lithium-ion batteries and systems

2.3.1. Market trends and developments

Batteries can be classified as either primary or secondary, and according to their use, technology, or size. The current Batteries Directive[26] differentiates between portable, automotive, and industrial batteries. Different battery types vary in chemical composition and construction, and can raise issues regarding resource availability, toxicity, safety, production, recycling, and disposal impacts. Rechargeable battery types include typically lead-acid, Lithium-ion, nickel-metal hydride, and nickel-cadmium

[26] OJ L 266, 26.9.2006, p. 1–14.

batteries.[27] Since their introduction to the commercial market in the early 1990s, Lithium-ion batteries have gained popularity as a widely used form of energy storage due to their accessibility and reliability. They are extensively used in portable devices, hybrid, and electric vehicles. Lithium-ion batteries have advantages such as low cost per cycle and effective storage of renewable energy, which makes them potential candidates for large-scale storage systems. Additionally, Lithium-ion technology is quickly gaining market share in the power tools industry due to its higher energy density, comparable high-power density, and overall performance advantages over alkaline batteries.[28, 29]

According to RECHARGE, the European industry association for advanced rechargeable and lithium battery manufacturers, approximately 150,000 tons of Lithium-ion batteries, including portable, industrial, and EV batteries, were made available in the European market in 2020. The weight of PVDF in these batteries was less than 1% of the total weight of the Lithium-ion batteries. It is estimated that the PFAS used in batteries in Europe in 2020 were mainly polymers, with PVDF being the predominant type, totalling between 11,500 and 22,000 tons. This amount is anticipated to increase significantly in the coming years and may reach 15,000 to 20,000 tons before 2030.[30]

Over the next decade, the demand for Lithium-ion batteries is expected to soar globally, increasing from about 700 GWh in 2022 to around 4.7 TWh by 2030. The mobility sector, particularly electric vehicles (EVs), will account for the majority of demand in 2030 - about 4,300 GWh. This is driven by sustainability regulations such as Europe's "Fit for 55" program, the US Inflation Reduction Act, India's Faster Adoption and Manufacture of Hybrid and Electric Vehicles Scheme, increased consumer demand for greener technologies, and major automakers announcing targets to ban internal combustion engine (ICE) vehicles by 2035. Battery energy storage systems (BESS) will also see a CAGR of 30%, with GWh required for BESS applications comparable to the GWh needed for all applications today. China is expected to account for a large portion of Lithium-ion demand in 2025 (45%) and 2030 (40%), although growth is expected to be highest in the EU and the US driven by government initiatives to promote EV adoption and the increasing focus on renewable energy as well as the planned phase out of the combustion engines by 2035. To meet the surging demand, at least 120 to 150 new battery factories will need to be built globally by 2030. The projected surge in demand for Lithium-ion batteries is expected to increase revenues along the entire value chain from about 77 billion EUR[31] in 2022 to over 363 billion EUR[32] in 2030. Active materials and cell manufacturing are expected to have the largest revenue pools. Recycling is also an option for sourcing battery materials, and although the recycling segment is expected to be relatively small in 2030, it is projected to grow more than three-fold in the following decade as more batteries reach their end-of-life.[33]

---

27 European Parliamentary Research Service (EPRS), 2022. New EU regulatory framework for batteries: Setting sustainability requirements. Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/654193/EPRS_BRI(2020)654193_EN.pdf (accessed in March 2023).

28 Assad, M., & Rosen, M. A. (Eds.), 2021. Chapter 14 - Energy storage, Design and Performance Optimization of Renewable Energy Systems, Academic Press, 205-219, ISBN 9780128216026, https://doi.org/10.1016/B978-0-12-821602-6.00016-X.

29 Jörissen, H. Frey, 2009. ENERGY | Energy Storage, Encyclopedia of Electrochemical Power Sources. Elsevier, 215-231, ISBN 9780444527455, https://doi.org/10.1016/B978-044452745-5.00090-3.

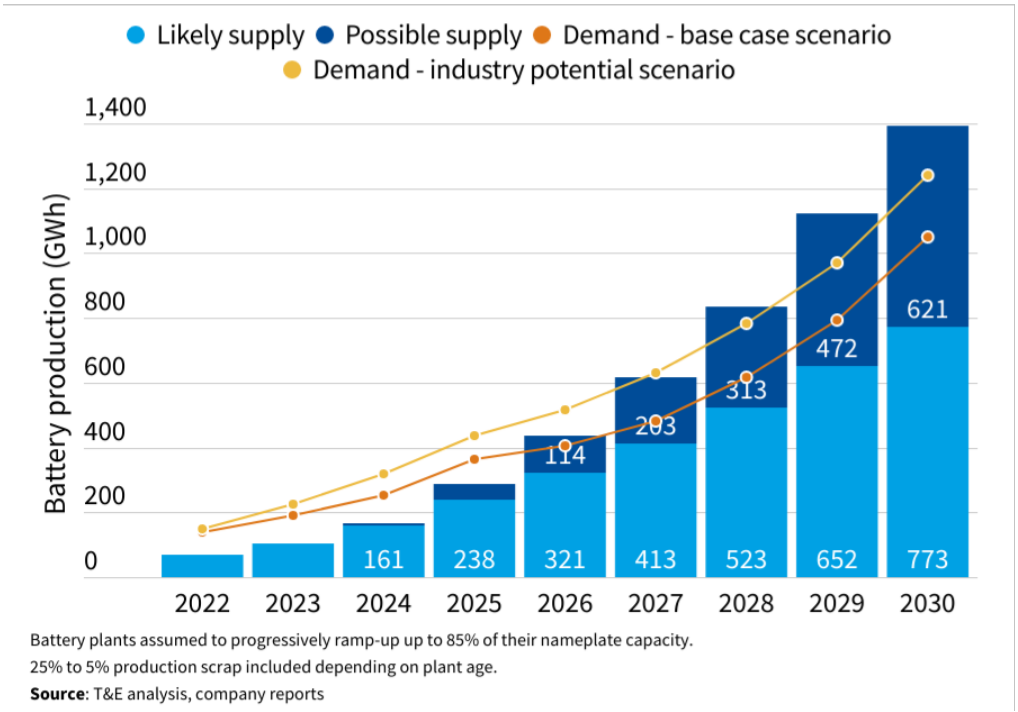
30 RECHARGE, 2021. PFAS restriction proposal. RECHARGE statement for 2nd Call for Evidence – October 2021. Available at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjftK32143-AhUN5aQKHesFCEMQFnoECAgQAQ&url=https%3A%2F%2Frechargebatteries.org%2Fwp-content%2Fuploads%2F2022%2F09%2FCall-for-Evidence_RECHARGE-_-PFAS-restriction-V1.pdf&usg=AOvVaw2RQVAPBruRShloTBs31vSg (Accessed in March 2023).

31 Using the ECB exchange rate of 5 May 2023 (1 EUR = 1.1014 USD) based on 85 billion USD.

32 Using the ECB exchange rate of 5 May 2023 (1 EUR = 1.1014 USD) based on 400 billion USD.

33 Fleischmann, J., Hanicke, M., Horetsky, E., Ibrahim, D., Jautelat, S., Linder, M., Schaufuss, P., Torscht, L., van de Rijt, A., 2021. Battery 2030: Resilient, sustainable, and circular. McKinsey & Company. Available at:

Figure 1: Battery cell demand and supply scenarios in Europe.



Source: this is a copy paste of Figure 2 in Transport and Environment (2023)[34]

In 2022, 50% of the EU demand was met by EU battery production, with the majority originating from LG Chem in Poland and Samsung SDI in Hungary. According to Transport and Environment's industry potential scenario, demand would only be met in 2028 if all uncertain projects materialise (Figure 1). Despite the potential for around 50 planned gigafactory projects to come online by 2030, the industry potential scenario indicates that if any of the projects, including newer ones, fail to materialize, Europe may not achieve self-sufficiency in battery cells until 2030. The analysis identifies that a restriction on PFAS for batteries could pose a risk to the industry, potentially disrupting companies' plans in Europe and impacting the ambition of the region's EV and battery projects. The analysis further highlights that around 68% of the potential battery cell supply in Europe is at risk of delay, scaling down, or not happening at all, with 16% at high risk and 52% at medium risk. Therefore, unless further action is taken, Europe may not be able to meet its battery cell demand until 2030 (Figure 2).[35, 36]

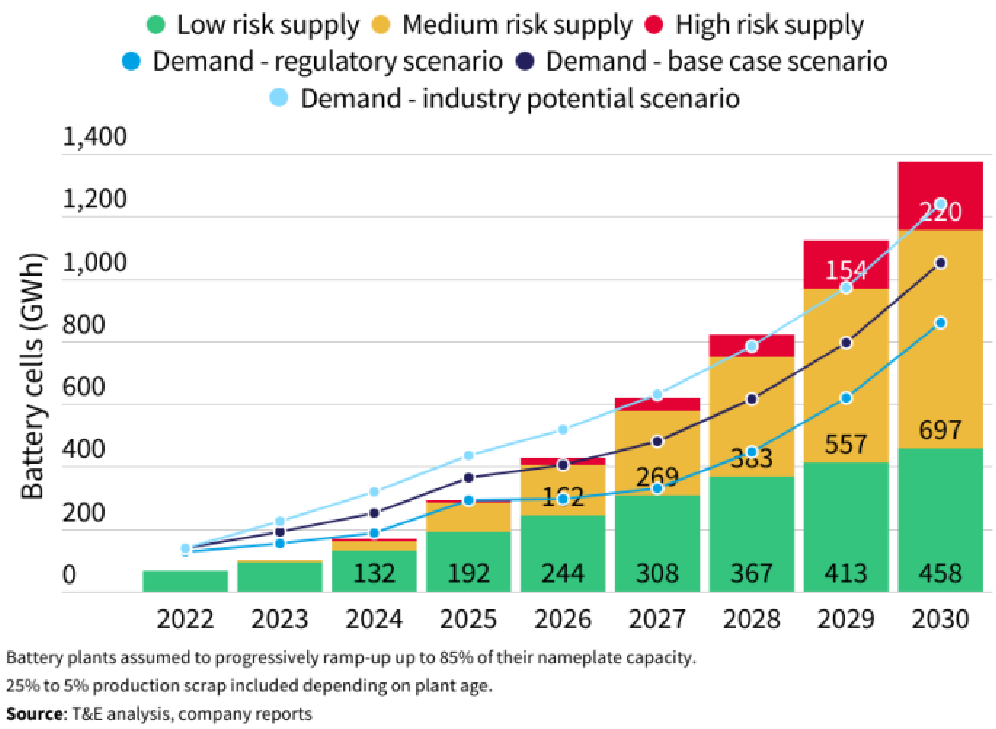
https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular (Accessed in May 2023).

[34] Transport & Environment, 2023. A European Response to US IRA How Europe can use its soft and financial powers to build a successful electric vehicle value chain. Available at: https://www.transportenvironment.org/wp-content/uploads/2023/01/2023_01_TE_Raw_materials_IRA_report-1.pdf (Accessed in April 2023).

[35] Transport & Environment, 2023. A European Response to US IRA How Europe can use its soft and financial powers to build a successful electric vehicle value chain. Available at: https://www.transportenvironment.org/wp-content/uploads/2023/01/2023_01_TE_Raw_materials_IRA_report-1.pdf (Accessed in April 2023).

[36] Transport and Environment, 2023.Two-thirds of European battery production at risk – analysis. Available at: https://www.transportenvironment.org/discover/two-thirds-of-european-battery-production-at-risk-analysis/ (Accessed in May 2023).

Figure 2: Battery cell production output and demand scenarios in Europe.



Source: this is a copy paste of Figure 6 in Transport and Environment (2023)[37]

Batteries contain critical raw materials such as antimony in lead-acid batteries, rare earth elements in nickel-metal hydride batteries, and cobalt and natural graphite in Lithium-ion batteries. As the demand for electric vehicle batteries and energy storage increases, the EU will require up to 18 times more lithium and five times more cobalt by 2030, and almost 60 times more lithium and 15 times more cobalt by 2050 compared to the current supply for the entire EU economy. However, mining and exploiting these battery minerals can have adverse environmental impacts such as pollution of local water, soil and air, ecosystem and landscape degradation, and human rights violations, including poor worker protection. Cobalt is a prime example, with almost half of the world's cobalt reserves located in the Democratic Republic of Congo (DRC), where over two-thirds of global cobalt production takes place. Approximately 20% of cobalt sourced from the DRC is from artisanal mines, where child labour and human rights abuses are prevalent. Although the risks are greatest in the DRC, a recent report by the European Commission's Joint Research Centre highlighted other EU suppliers of battery materials, including China, South Africa, and Brazil, as raising concerns about responsible sourcing. To address these issues, the EU Conflict Minerals Regulation[38] requires companies to conduct due diligence on their supply chains to identify and address any risks related to conflict minerals, including cobalt. The regulation requires companies to trace the origin of their cobalt and ensure that it is not sourced from mines associated with human rights abuses or other unethical practices. By implementing such regulations, companies can help to reduce the demand for conflict minerals, promote responsible sourcing

[37] Transport and Environment, 2023.Two-thirds of European battery production at risk – analysis. Available at: https://www.transportenvironment.org/discover/two-thirds-of-european-battery-production-at-risk-analysis/ (Accessed in May 2023).

[38] OJ L 130, 19.5.2017.

practices, and contribute to the overall efforts to improve human rights and promote sustainable development in the region.[39]

Battery electric vehicles (BEVs) emit lower emissions during the use phase compared to internal combustion engine vehicles (ICEs) and are the most effective decarbonization option for passenger cars. Even in the worst-case scenario without low-carbon electricity, BEVs emit about 50% lower emissions in Europe and 72% lower emissions in the United States compared to ICE vehicles. With low-carbon electricity during the use phase, BEVs achieve even better life-cycle carbon footprints than ICE vehicles, with about 77% lower emissions in Europe and 88% lower emissions in the United States. However, BEVs have double the material and manufacturing emissions per vehicle compared to ICE vehicles, which are responsible for 40 to 95% of total life-cycle emissions of BEVs, depending on the grid electricity used for charging. Decarbonizing production, primarily for battery, aluminium, and steel, is therefore critical for BEVs.[40]

2.3.2. Policy trends

On 14 October 2020, the European Commission released its Chemical Strategy for Sustainability towards a Toxic-Free Environment. This strategy includes prioritizing certain harmful chemicals for restriction, which will be accomplished through grouping substances together rather than regulating them individually. This type of restriction is commonly known as a "horizontal restriction''. However, merging all PFAS into one group of substances ignores the fact that these substances have very different toxicological profiles. While fluoropolymers can be considered PFAS based on their structure, they possess unique properties that distinguish them from other PFAS substances. Fluoropolymers are high molecular weight polymers and have distinct physicochemical properties that make them a separate class within PFAS. Fluoropolymers that meet the OECD polymer of low concern criteria are by OECD considered to have insignificant environmental and human health impacts, as they are non-toxic, biocompatible, non-soluble, and immobile molecules.[41]

A restriction on PFAS without a derogation for batteries could have significant implications for Europe's ability to achieve its net-zero economy goal by 2050 as outlined in the European Green Deal. The Green Deal aims to transition the European Union and its Member States to a sustainable economy with reduced reliance on fossil fuels. Batteries play a crucial role in achieving objectives related to low-emission mobility, decarbonized energy generation, and digitalization, as highlighted by the European Commission. The European Commission recognizes batteries as a strategic value chain and acknowledges their importance in enabling sustainable development, green mobility, clean energy, and climate neutrality. They are particularly vital in the shift toward electric vehicles.[42]

[39] European Parliamentary Research Service (EPRS), 2022. New EU regulatory framework for batteries: Setting sustainability requirements. Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/654193/EPRS_BRI(2020)654193_EN.pdf (Accessed in March 2023).

[40] Fleischmann, J., Hanicke, M., Horetsky, E., Ibrahim, D., Jautelat, S., Linder, M., Schaufuss, P., Torscht, L., van de Rijt, A., 2021. Battery 2030: Resilient, sustainable, and circular. McKinsey & Company. Available at: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular (Accessed in May 2023).

[41] RECHARGE, 2021. PFAS restriction proposal. RECHARGE statement for 2nd Call for Evidence – October 2021. Available at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjftK32143-AhUN5aQKHesFCEMQFnoECAgQAQ&url=https%3A%2F%2Frechargebatteries.org%2Fwp-content%2Fuploads%2F2022%2F09%2FCall-for-Evidence_RECHARGE-_-PFAS-restriction-V1.pdf&usg=AOvVaw2RQVAPBruRShloTBs31vSg (Accessed in March 2023).

[42] RECHARGE, 2023. Application for derogations from PFAS REACH restriction for specific uses in batteries – First submission. Submission number: cb6a7d0a-caa1-42fa-a806-f7410538f8b9.

On 27 October 2022, the European Parliament and Council agreed to end the sale of new CO_2-emitting cars in Europe by 2035. The EU Regulation on CO_2 emissions for new cars and vans was adopted by MEPs on 16 February 2023, with Germany initially holding up the adoption over concerns regarding the role of synthetic fuels (e-fuels). Germany initially demanded that e-fuels, which were included only in the non-binding recitals of the final text, be given a certain and definitive place in the future of road transport decarbonisation. However, the blocking minority was resolved when the European Commission pledged to propose a Delegated Act by Autumn 2023. E-fuels remained in Recital 11 of the final text, which was finally endorsed by Council on 28 March 2023. On 25 April 2023, the Regulation was published in the Official Journal and enters into force on the twentieth day thereafter. As an intermediate step towards zero emissions, new CO_2 standards will require average emissions of new cars to come down by 55% by 2030, and new vans by 50% by 2030. This is the first step in adopting the 'Fit for 55' legislative proposals by the European Commission, demonstrating the EU's commitment to reaching its climate goals. This will accelerate the production and sale of low- and zero-emission vehicles, making the EU's transport system more sustainable and providing cleaner air for European population. The agreement is an important step in delivering the European Green Deal, and the commitment to reach climate neutrality by 2050. In addition, most EU Member States have signed the COP26 declaration on accelerating the transition to 100% zero emission cars and vans, aiming for all sales of new cars and vans being zero emission globally by 2040, and by no later than 2035 in leading markets.[43] The signatories have also declared their support to make zero emission vehicles accessible, affordable, and sustainable in all regions by 2030. In this context, Northvolt's Lithium-ion batteries are important for zero-emission vehicles. Northvolt's batteries are designed to be more sustainable and efficient than traditional batteries, with a lower carbon footprint throughout their lifecycle. They are made using renewable energy sources, such as wind and hydroelectric power, with Northvolt aiming to recycle as much of their materials as possible. By providing a more sustainable energy storage solution, Northvolt is helping to reduce greenhouse gas emissions and support the transition to a low-carbon economy and its focus on sustainability and circularity aligns with the objectives of the European Green Deal, making Northvolt an important player in the transition to a greener and more sustainable future.[44]

Given the important role batteries play in the roll-out of zero-emission mobility and the storage of intermittent renewable energy, they are a crucial element in the EU's transition to a climate neutral economy. The topic of batteries is relevant to several policy areas such as energy, transport, climate action, waste, and resources. The EU's shift to a climate-neutral economy depends heavily on the development, production, and use of batteries, particularly for zero-emission mobility and the storage of renewable energy. Batteries are also crucial in powering the digital economy and portable electronics. Battery demand is expected to increase significantly by 2030 due to the electrification of transportation and deployment in electricity grids, and the EU could account for 25% of that demand.[45] However, battery manufacturing, use, and disposal pose several environmental and social challenges. In 2017, the European Commission established the European Battery Alliance to support innovative solutions and manufacturing capacity in Europe, and in 2018, it adopted a strategic action plan on batteries. In December 2020, a proposal for a regulation on batteries and waste batteries was introduced to update EU legislation and ensure the sustainability and competitiveness of EU battery value chains. The proposal is part of the European Green Deal and related initiatives, including the circular economy action

[43] COP26 declaration on accelerating the transition to 100% zero emission cars and vans. Available at: https://acceleratingto-zero.org/the-declaration/ (Accessed in April 2023).

[44] European Commission, 2022. Zero emission vehicles: first 'Fit for 55' deal will end the sale of new CO2 emitting cars in Europe by 2035. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6462 (Accessed in March 2023).

[45] McKinsey, 2023. Battery 2030: Resilient, sustainable, and circular. Available at: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular (Accessed in May 2023).

plan and industrial strategy, which prioritize addressing batteries as a high-potential sector for circularity.[46]

There are currently numerous battery cell production sites in Europe, either in planning, under construction, or already in operation. These sites represent significant investments totaling over 44 billion EUR and provide more than 47,000 jobs. They offer the potential for Europe to achieve self-sufficiency in battery cells as early as 2028 through an integrated value chain. However, without derogations for PFAS in batteries, these production sites could be forced to halt operations in Europe.[47]

3. ANALYSIS OF ALTERNATIVES

3.1. Aim, scope and methodology

This section provides a closer look at the **use, function, and requirements** of PFAS-based Lithium-ion battery cells and systems. It outlines the **available alternatives** and the technical obstacles that prevent substitution, before exploring the challenges related to the development process of **new substances**. The analysis of alternatives concludes that today **there are no appropriate chemical alternatives** that could substitute PFAS applications in Lithium-ion battery cells and systems.

3.2. Function and technical performance of PFAS vs non-PFAS alternatives in Lithium-ion batteries and systems

The wet electrode production method for Lithium-ion battery application has developed since the 1980s. One of the earliest wet electrode production methods for Lithium-ion batteries was introduced by John Goodenough and his team at the University of Texas at Austin. Their approach involved mixing lithium cobalt oxide powder with a polymeric binder and a solvent to create a slurry that was then coated onto a metal foil to produce the cathode electrode. Since then, the wet electrode production method for Lithium-ion batteries has gone through significant development and optimisation, with many improvements made to the slurry composition, coating process, and drying conditions to enhance the performance and reliability of the battery. Nowadays, after 40 years since the development, wet electrode production remains a widely used method for producing high-performance Lithium-ion batteries, with ongoing research and development aimed at further improving the process. **Northvolt has applied the wet electrode method to secure stable slurry and durable electrode with desired characteristics, and a long-life cell with high performance.**

In line with the proposed PFAS restriction, Northvolt conducted an internal inquiry to summarize where these substances are used. Specific PFAS substances are essential because of their unique properties, such as their thermal and chemical resistance, processibility, and electrochemical stability. Due to their unique properties, PFAS are used in key components for all high performance and lithium battery technologies. **The Lithium-ion battery industry is dependent on some of the most common fluoropolymers on the market, such as PVDF, [CONF.], and PTFE**. The different PFAS used by Northvolt, as well as the key applications that rely on these substances, are noted in the table below.

[46] European Parliamentary Research Service (EPRS), 2022. New EU regulatory framework for batteries: Setting sustainability requirements. Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/654193/EPRS_BRI(2020)654193_EN.pdf (Accessed in March 2023).

[47] RECHARGE, 2023. Application for derogations from PFAS REACH restriction for specific uses in batteries – First submission. Submission number: cb6a7d0a-caa1-42fa-a806-f7410538f8b9.

Table 1: Summary table of PFAS used by Northvolt in different applications, as well as the function of each PFAS, the provided technical performance, and the availability of alternatives for the corresponding application.

PFAS used	Application	Function	Technical performance	Alternatives available today?
PVDF ([CONF.])	Cathode electrode	Binder (hold active material particles within the electrodes together to maintain a strong connection between the electrode and the current collectors)	Ability to facilitate the transfer of lithium ions; high thermal stability; chemical resistance; good mechanical properties; good adhesion; good dispersive capabilities; good solubility; high electrochemical stability	No
[CONF.]	Cell applications (gaskets, seal gaskets, etc.)	Ensure the life expectation of the final battery cell. E.g., prevent leakage of the electrolyte from the inside and penetration of moisture from the outside	Good mechanical properties; high resistance to chemicals; high thermal resistance; low friction; non-stick properties	No – [CONF.]
PTFE	Battery manufacturing equipment and spare parts	Sealing components; protective coating for equipment parts	Chemically inert; chemically resistant; chemical stability; thermal resistance	(1) No – parts/ equipment used in harsh or abrasive conditions, such as with NMP and electrolyte. (2) Some applications could potentially be replaced – [CONF.]
[CONF.]	[CONF.]	[CONF.]	[CONF.]	[CONF.]
[CONF.]	[CONF.]	[CONF.]	[CONF.]	[CONF.]
[CONF.]	[CONF.]	[CONF.]	[CONF.]	[CONF.]
[CONF.]	[CONF.]	[CONF.]	[CONF.]	[CONF.]
PFAS	(1) As a component in battery cells, it will in consequence be present in the feed material of the recycling process.	(1) In the recycling process of PFAS-containing products. (2) Prevent leakage from and contamination by equipment	(2) Inert; temperature resistant; chemically resistant	(1) Amount of PFAS dependent on the material and battery cell content coming in for the recycling process. (2) Some applications could potentially be replaced – [CONF.]

	(2) In recycling process equipment			

Source: Northvolt, 2023

The process technique and equipment used at the company's facilities are based on existing knowledge on the market. In most cases, there are no alternatives on the market available today. In cases where there are possible alternatives, these need to be tested for their functionality and safety. **The applications below discuss the function and technical performance of PFAS in Lithium-ion batteries and systems, as well as in the manufacturing and recycling processes. The sub-sections below also consider the availability of alternatives and their performance for the respective application.**

3.2.1. PVDF in the cathode electrode

PVDF is used as a binder in the cathode electrode. This section first discusses some properties of PVDF that can be tweaked by copolymerisation, before turning to the function and technical performance of PVDF in the cathode electrode.

PVDF and copolymerisation

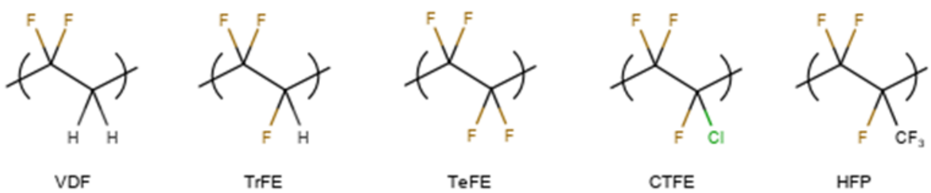
The **polyvinylidene difluoride (PVDF)** homopolymer is a semicrystalline thermoplastic with a high melting point (155 to 192°C), and a glass transition temperature between -40 and -30°C. PVDF properties can be tweaked through copolymerisation (see Figure 3 below). Copolymerization is a systematic way to modify the properties of PVDF. It typically relies on radical copolymerization, producing random copolymers. Common comonomers include:

- HFP: Hexafluoropropene
- TFE (can refer to either TrFE or TeFE): TrFE- Trifluoroethylene, TeFE- Tetrafluoroethylene, CTFE- Chlorotrifluoroethylene.

PVDF modifiers are copolymers, for example, VDF-TeFE. When used with PVDF, it helps to improve electrode flexibility and durability, and leads to less electrode cracking and less slurry gelation. [CONF.].

Examples of the properties that can be tweaked through copolymerisation include molar mass and the number of defects, among others. PVDF is typically 50 to 70% crystalline, with three main crystal polymorphs (α, β, and γ, see Figure 3). α is kinetically favoured, β is the thermodynamically most stable one, and γ can be formed by introducing moderate stress to the polymer. The degree of crystallinity and the ratio of different polymorphs can thus be controlled by temperature and pressure during synthesis.

Figure 3: Copolymerization.



Source: Northvolt, 2023

[CONF.].

PVDF as a binder

In order to manufacture an electrode, an active material mass is prepared, by mixing active material, conductive additives (when needed), and a binder. The active material mass is subsequently coated onto a metallic current collector. **PVDF is used as a binder in the cathode electrode**. Binder materials hold active material particles within the electrodes together to maintain a strong connection between the electrode and the current collectors. Binding materials are normally inert and have an important role in the manufacturability of the battery and in the battery performance.

An approximate quantity of PVDF-based materials lies between 0.5 to 3 wt% ([CONF.]) for a battery cell used by vehicle industry. Cell capacity retention is closely correlated to the amount of PVDF, especially for active materials with high volume expansion. Due to the low electronic conductivity of PVDF, higher amounts of PVDF decrease the electrode's rate capability and could lead to higher electrode resistivity and DC-IR (direct current internal resistance). **The widespread use of PVDF as a binder in the mass production of Lithium-ion batteries is due to its technological advantages (discussed below), making it a highly valuable material for Lithium-ion batteries:**

- **Ability to facilitate the transfer of lithium ions.**
- **High thermal stability:** PVDF has a high melting point and is resistant to thermal degradation, making it an excellent material for use in high-temperature applications. High temperatures are commonly used for curing and drying during electrode fabrication and also for the operation of the battery at various temperatures.
- **Chemical resistance:** PVDF is highly resistant to chemicals, including acids, alkalis, and solvents, which makes it suitable for use in harsh environments. The cathode binder should not react with any other components or intermediates formed during operation.
- **Good mechanical properties:** PVDF has excellent mechanical strength, stiffness, hardness, and toughness, making it ideal for use in applications that require high durability and resistance to wear and tear. This is because the cathode binder must be able to withstand the forces that result from the expansion and contraction of active materials during charge/discharge cycles.
- **Good adhesion:** PVDF has good adhesion to other materials, including metal foils, the active material, the conductive additive, and the current collector metal, which makes it an excellent binder for Lithium-ion battery electrodes. High adhesion ensures excellent binder distribution on the active material surface and high homogeneity within the electrode coating.
- **Good dispersive capabilities:** This is important to help distribute the slurry evenly over the current collector metal during fabrication.
- **Good solubility:** PVDF has good solubility in organic solvents such as NMP.
- **High electrochemical stability:** This is an essential property as it enables the binder to function for long periods and over numerous cycles without degradation of the battery. In particular, the cathode binder must remain stable at the high and low voltage potentials experienced by the cathode. PVDF is the only proven material that can sustain a large voltage range from 0 to 5V at industrial scale for various battery designs (cylindrical, prismatic, and pouch cell) and high-capacity cells. This stability guarantees its safe use in the electrochemical environment of the lithium cell.

To manufacture cells, a technique is used that requires the use of PVDF as a binder in cathode slurry manufacturing, which is a critical step of electrode processing. **PVDF is essential to the dispersion of cathode active material into a homogeneous and stable slurry** (using N-methyl-2- pyrrolidone, NMP, as a solvent). Once the slurry is coated and dried into an electrode, PVDF provides electrochemical stability and mechanical integrity to the electrode, which is critical to secure cell performance and safety.

PVDF is used at slurry mixing to produce cathode electrode, which goes into the cell during cell assembly. The following highlight the relevant stages of production:

1. PVDF powder + NMP → Binder solution
2. Binder solution + Active material → Cathode slurry
3. Cathode slurry → Electrode coating + NMP (evaporation)
4. Cathode electrode → Calendering → Notching → Cell assembly

[CONF.]:

- [CONF.]
- [CONF.]
- [CONF.].

The primary role of the binder is to create interconnectivity and adhesion between the electrode's active materials and the current collectors. This ensures the mechanical integrity of the solid electrode without significantly impacting electronic or ionic conductivity and is crucial for achieving a very long cycling lifespan in Lithium-ion batteries. Without the right type and amount of binder, the active material particles will lose connections leading to electrode degradation during cycling and consequently lower performance and lifetime of the battery. The binder therefore plays a crucial role in ensuring the integrity of the electrode and the overall performance of the battery. **The PVDF binder also acts as an interface between the composite electrode and the electrolyte; the PVDF binder therefore protects the composite electrode from corrosion and the electrolyte from depletion, while facilitating ion transport across this interface**.

Without PVDF it is not possible to manufacture a Lithium-ion battery cell until alternatives are found and validated.

Alternatives to PVDF

There are no alternatives to PVDF in NMP wet solvent-based cathode manufacturing, which is the current industry standard, available today. **As it stands, if PVDF would be completely banned to be used, it would not be possible to manufacture a high-performance Lithium-ion battery for a number of years until alternatives are found and validated**.

Next generation Lithium-ion battery developments are focused on producing **cathodes using a dry process**, which avoids the need for the NMP solvent. This dry process will significantly reduce energy consumption and lead to a lower environmental footprint. However, **the dry process requires the use of PTFE or PVDF as the cathode binder material**. [CONF.].

[CONF.]:

- [CONF.]
- [CONF.]
- [CONF.].

The GIGAGREEN research project, funded by the European Commission, focuses on finding **dry and water-based alternative binder systems** for the positive electrode. The proposed solution involves using different polymers such as carboxymethyl cellulose (CMC)/styrene butadiene rubber (SBR), poly(acrylic acid), sodium alginate, polyurethanes, and catechol-bearing polymers.[48] **Initial studies**

[48] Funding & tenders, 2018. Towards the sustainable giga-factory: developing green cell manufacturing processes (GIGAGREEN). Available at: https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/how-to-participate/org-details/999999999/project/101069707/program/43108390/details

suggest that these aqueous binder systems may have good adhesion properties, but further research is necessary to determine whether the alternatives have the required chemical, mechanical, and electrical properties.[49] The use of water-based CMC/SBR technology raises concerns about its ability to match the performance of today's positive electrode active materials. Additionally, there are concerns about the use of water in the slurry production and electrode coating, drying, and calendaring processes, especially if the water is not completely removed before battery assembly.

These new material and process technologies are currently at a low technological readiness level (TRL); they need significant time and investment to be upscaled from an R&D pilot environment to mass production scale. [CONF.].

[CONF.]. The suppliers manufacturing PVDF will be affected by a restriction as they cannot use any PFAS-based polymerisation aids. However, most of the suppliers have replaced the PFAS-based polymerisation aids to **non-PFAS polymerisation aids** and still obtain PVDF. This lowers the emissions for these manufacturing units, which also Northvolt benefits from lowering the CO_2 impact of the final cell. The industry has implemented several initiatives, including abatement technologies and the development of non-fluorinated alternatives for PTFE and PVDF. Over 50% of fluoropolymers are no longer required to use fluorinated surfactants during the manufacturing stage. Yet, PVDF is still part of the final cell and eventually also the waste stream.

3.2.2. PFAS ([CONF.]) in cell applications – gaskets, seal gaskets, and other parts

PFAS, [CONF.], is used in several applications of the cell, such as gaskets, seal gaskets, and seal balls. This material is used based on its good mechanical properties, high resistance to chemical reactions, high thermal resistance, low friction, and non-stick properties. These unique properties are required to ensure the life expectancy of the final battery cell. Seal gaskets, for example, are critical components in Lithium-ion cells to prevent leakage of the electrolyte from the inside and penetration of moisture from the outside.

Inadequate sealing performance can cause electrolyte leakages and eventually short circuits, leading to severe safety issues such as thermal runaway. Thermal runaway is the process of uncontrolled heat release and rapid temperature rise. More heat prevails in the cell than heat can be dissipated due to unintended high local or overall temperatures caused by abusive environment or operations conditions. This initiates self-cascading, exothermic decompositions, and combustions reactions, which self-heat the cell up to a point of no return. This will lead to cell venting, vent-with-flame, ejection of cell parts, fire and even explosion.

Parts made of PFAS ([CONF.]) used in prismatic cells constitutes <0.1% of the total weight of the cell. Depending on the design of the cell, the parts made of PFAS ([CONF.]) can constitute as low as <0.05% of the total weight if the cell, PFAS ([CONF.]) in cylindrical cells can be up to 0.6% of the total weight of the cell.

Alternatives to PFAS ([CONF.])

As of today, there is **no possibility to replace PFAS ([CONF.]) for parts intended for use in high performance rechargeable lithium-ion batteries to be used by automotive- and energy storage industry due to its unique properties,** especially the resistance of chemical reaction to electrolyte and its elastic recovery of clamping. According to the research conducted by one of Northvolt's suppliers, PFAS

[49] Cholewinski, A., Si, P., Uceda, M., Pope, M., Zhao, B., 2021. Polymer Binders: Characterization and Development toward Aqueous Electrode Fabrication for Sustainability. *Polymers*, 13(4), 631. Available at: https://www.mdpi.com/2073-4360/13/4/631

([CONF.]) is the only material capable of preserving its sealing capabilities under conditions of high temperature and compression. Furthermore, it boasts unparalleled resistance to both chemical and heat exposure.

Moreover, automotive parts are subject to rigorous performance and safety standards that require suppliers to use materials that meet certain specifications and requirements. The compression test is one of many important tests that needs to be performed for seal gaskets; this is performed according to ASTM D395. This test measures the ability of parts to retain their elastic properties after being compressed in air or liquid media. Nevertheless, the most important standard that Northvolt should comply with is the requirement from automotive customers, regarding safety, environment, performance, and quality. Specifically fast charging and discharging specification requires extremely high electrical current which causes high temperature on current path and increase risk of failure of sealing functionality. Any replacement for PFAS ([CONF.]) would need to meet the standards and certification requirements set by the automotive industry, such as [CONF.]. It is a challenge to find a material or develop a new material that can meet all of the necessary criteria.

[CONF.]. According to the suppliers, there are no equally performing alternatives for PFAS [CONF.] in automotive applications and in other high-performance Lithium-ion battery applications. [CONF.].

3.2.3. PTFE in the battery manufacturing and recycling equipment and in spare parts

Polytetrafluoroethylene (PTFE) is a synthetic fluoropolymer of tetrafluoroethylene (well known as Teflon). PTFE is also well known as a material that is chemically inert and is among the most chemically resistant polymers. It has very good thermal resistance and electrical insulation properties which are also needed in the manufacturing process of Lithium-ion batteries. Therefore, PTFE is the material that can be used in a harsh environment and maintain the chemical resistance that is needed for tight (closed) systems for chemical processes. PTFE is non-flammable material, compatible with Northvolt's process, helping to mitigate or reduce potential fire risks in the production environment. The use of chemically resistant PTFE is encouraged by the fact that CMR (carcinogenic, mutagenic, toxic to reproduction) substances are being used in battery production bringing the legal requirement to handle the CMR substances in fully closed systems as far as technically possible.

To manufacture and recycle Lithium-ion cells, specially designed equipment such as chillers and machines requiring spare parts, are used in all of Northvolt's facilities. At Northvolt, chemicals are manufactured, used, and transported within various process steps.

Many equipment and spare parts require PTFE, for example, in linings, tubes, piping gaskets, O-rings, sealants, thread sealant (tape), and mesh filters. [CONF.].

PTFE is also used as a protective coating for equipment parts such as tanks and pipelines that are subject to harsh or abrasive conditions ([CONF.]), which can otherwise undergo premature degradation and contaminate the production.

Removing PTFE from the equipment and the spare parts would have a big impact on the processes where chemicals are handled:

- Without PTFE there is a risk of exposure to workers and the environment due to increased risk of leakages of hazardous powders and liquids caused by malfunction of equipment. For example, electrolyte can generate hydrogen fluoride (HF). [CONF.].
- PTFE is important in avoiding contamination of the processed materials which could at the end contaminate the battery cells. If contaminated, the battery malfunction can lead to smoke and fire initiated from inside the battery cell.

- The frequency of maintenance stops increases if less durable sealant materials are used. Maintenance stops increase the risk of exposure to the environment and in the workplace and lead to large quantities waste material from the process while stopping and restarting the manufacturing process.
- The amount of waste from the maintenance stops increases because of the more frequent maintenance stops. An increased amount of waste can also be expected from equipment parts that wear out faster when they are not protected by PTFE.

It is clear that without a suitable replacement for PTFE, Northvolt faces significant potential challenges that could hinder the operations, raise costs, compromise safety, and increase the environmental impact. However, quantifying the exact time and cost increases in maintenance, as well as reduced life expectancy of the equipment, would require a more in-depth analysis of the operations and the alternatives available.

Alternatives to PTFE

There are no alternatives to PTFE for the larger part of the equipment and spare parts used at Northvolt's facilities. Several parts of the manufacturing and recycling environment need to stay in a closed system; no contamination of the product in the cell manufacturing process (no contamination of the active materials and during the cell assembly process), and no exposure of workers to hazardous chemicals (during active material manufacturing, cell assembly, and recycling) can be allowed.

Where NMP and electrolyte are used, PTFE is needed in equipment and parts, such as gaskets, linings, fittings, tanks, and more; **no other material works to contain these hazardous chemicals**. If Northvolt would have to replace PTFE with any material that shows a worse resistance, for example to HF, it would be a major safety and health concern.

[CONF.]

There are parts [CONF.] where **PTFE material is the only available substance on the market to achieve the required performance**. This is because it does not react in high temperatures or with the chemicals used in the manufacturing process and with the electrolyte that ends up in the final cell.

In some parts ([CONF.]) of the process there may be possible alternatives, however, further investigation is required to understand the safety of replacement, the quantity that can be replaced, and the time needed for substitution.

[CONF.]

[CONF.]

[CONF.]

3.2.4. [CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

3.2.5. [CONF.]

[CONF.]

[CONF.]

3.2.6. [CONF.]

[CONF.]

[CONF.]

3.2.7. [CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

3.2.8. PFAS in the recycling process of PFAS-containing products

PFAS is present in the feed material (such as end-of-life Lithium-ion batteries and off-spec material from battery production) for the recycling process of Lithium-ion battery cells. However, the final product of the recycling – the valuable metals obtained though the hydrometallurgical process do not contain any PFAS and are sent back to Northvolt's upstream facility for the use in the production of new Lithium-ion cells.

Some equipment in the recycling process also contains PFAS (such as PTFE seals and tank linings) in the same way and for the same reasons as for any industry handling powders and liquids that cannot be allowed to leak out from the equipment or to be contaminated by the equipment material. The technological advantage of PFAS in this equipment is that they are inert, temperature resistant, and chemically resistant to aggressive materials such as electrolytes.

The waste batteries or waste material from battery manufacturing goes through a series of four process steps during recycling. These steps include discharge, dismantling, crushing and sorting (C&S), and hydrometallurgy.

[CONF.]

1. [CONF.]
2. [CONF.]

[CONF.]

3.3. Assessment of potential alternative battery technologies

There are several alternative battery technologies that are being developed and researched as potential replacements for Lithium-ion batteries – which are described below. However, the battery chemistries have different properties making them suitable for different types of applications. Moreover, most of these technologies are still in development and are not commercially available yet. In addition, and as discussed below, alternative battery technologies may also rely on PFAS for their functioning or may not have the required performance standards.

Solid-state batteries

Table E.134 in Annex E of the draft PFAS restriction states that there *"may be some non-pfas alternatives for solid state batteries"* for the Lithium-ion battery category. **However, this is incorrect as both PTFE and PVDF will be utilized in the manufacturing of solid-state batteries,** and there is also significant investment needed to develop solid state technology and manufacturing capabilities[50] [51]. Since 2011, a French company has been engaged in development of the design, development, and commercialization of all-solid-state batteries. The Lithium-metal-Polymer (LMP®) technology developed by this company utilises entirely solid electrolytes, unlike conventional Lithium-ion batteries that use liquid electrolytes. In theory, this solid-state approach offers significant advantages, including increased energy densities and enhanced safety. The architecture of this battery is built on the mastery of polymers as electrolytes and effective management of their chemical interfaces. Notably, this technology meets the environmental standards, as it does not require solvents or heavy metals such as cobalt, nickel, or cadmium, making it a cleaner alternative.

Solid-state batteries, which use a solid electrolyte instead of a liquid one, are well-suited for energy-dense anodes such as lithium metal and silicon, and have the potential to significantly increase the driving range of electric vehicles. Solid-state batteries utilise a solid ionic conductor as a replacement for the liquid electrolyte polymer separator. This solid electrolyte is in the form of a thin and compact layer that separates the cathode and anode. Additionally, it must be integrated into the porous cathode and anode layers to enable ionic conduction pathways within these layers. To meet the high-capacity demands of the EV market, it is crucial to implement large-scale manufacturing methods for solid-state batteries. This involves adopting coating and processing techniques that are similar to those used in solid oxide fuel cells and conventional batteries. For example, solid electrolyte powder may be added to the cathode slurry prior to coating so that it is present within the cathode after drying. This means that **switching to solid-state battery does not suppress the need of PVDF as a cathode binder**.

[50] MIT Technology Review, 2023. What's next for batteries. Available at: https://www.technologyreview.com/2023/01/04/1066141/whats-next-for-batteries/ (Accessed in May 2023).

[51] Motortrend, 2023. Solid State Battery Tech for EV Cars: Challenges Lie Ahead. Available at: https://www.motortrend.com/features/solid-state-ev-car-batteries-challenges/ (Accessed in May 2023).

While microstructure, interfaces, and thickness control are important for achieving long battery life-times, processing speed is key to achieving cost-effectiveness and scalability. Moreover, in some cases, producing the thin conductive solid electrolyte layer which separates anode and cathode will even require more PVDF to fabricate the separator layer using solid electrolyte particles and PVDF as a binder.[52] **PFAS are foreseen to be increasingly important for the next generation of solid-state batteries; both LiTFSI (lithium salt used for the electrolyte and the cathode) and PVDF (polymer used for the mechanical strength of the electrolyte) are crucial for the functioning of this alternative battery technology**.

While solid-state batteries are still at a low level of technological readiness, it is inaccurate to label them as "non-PFAS alternatives to Lithium-ion batteries." Solid-state batteries are still in the early stages of development and face several technical and economic challenges before they can be considered viable alternatives to Lithium-ion batteries. Some of the challenges include the need for further development of solid-state electrolytes, which can provide high ionic conductivity at room temperature, and the high cost of materials and manufacturing processes. In fact, solid-state batteries use dry processes to manufacture electrodes, and PTFE's superplastic phase makes it a preferred choice for this purpose. Unlike liquid cathodes, where a larger amount of PTFE is required, only a small amount of PTFE (around 1 – 2%) is needed for dry process electrodes for lithium rechargeable batteries, as the active material has a much lower surface area than carbon black. While there are some alternatives to PTFE with thermoplastic polymers for dry processes, the process is much more complicated and not yet fully developed. Nonetheless, both PTFE and PVDF will be utilized in the manufacturing of solid-state batteries.[53]

Dry Coating

The latest advancements in next-generation Lithium-ion batteries are centred around developing cathodes using a dry process that eliminates the need for NMP solvent. This dry process offers significant benefits such as reduced energy consumption and a lower environmental footprint. However, **it does require the use of materials such as PTFE or PVDF** as the cathode binder, which play a critical role in binding the cathode components together. By utilising pressure and temperature changes, the mixture can adhere to the foil. This method can reduce costs and fabrication times, while also being more environmentally friendly than other options.[54] It can significantly simplify the manufacturing process, reconstruct the electrode microstructures, and increase the material compatibilities. The emerging dry battery electrode technique therefore provides promising prospects for the battery industry.[55]

However, there are challenges associated with dry coating, including issues with uniformity and large-scale production. If the coating is not uniform, hot spots can form in the battery electrodes, which can cause battery degradation, potential short circuits, and even catastrophic battery failure. To avoid this, the dry mix must be uniform throughout the mixture volume prior to coating. Advanced 3D electrodes

[52] Hatzell, K., Zheng, Y., 2021. Prospects on large-scale manufacturing of solid state batteries. *MRS Energy & Sus-tainability* 8, 33–39.

[53] RECHARGE, 2021. PFAS restriction proposal. RECHARGE statement for 2nd Call for Evidence – October 2021. Available at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjftK32143-AhUN5aQKHesFCEMQFnoECAgQAQ&url=https%3A%2F%2Frechargebatteries.org%2Fwp-content%2Fuploads%2F2022%2F09%2FCall-for-Evidence_RECHARGE-_-PFAS-restriction-V1.pdf&usg=AOvVaw2RQVAPBruRShloTBs31vSg (Accessed in March 2023).

[54] Electric & hybrid vehicle technology international, 2021. Why dry coating electrodes is the future of the electric vehicle battery industry. Available at: https://www.electrichybridvehicletechnology.com/opinion/why-dry-coating-electrodes-is-the-future-of-the-electric-vehicle-battery-industry.html (Assessed in March 2023).

[55] Lu et al., 2022. Dry electrode technology, the rising star in solid-state battery industrialization. *Matter* 5. Available at: https://www.sciencedirect.com/science/article/pii/S259023852200011X

may help mitigate some of these challenges. However**, significant investments are required to optimize the dry coating process**.[56] Ensuring compatibility with current wet method production methods and equipment also requires large investments and scaling-up manufacturing towards the use of dry battery electrodes would require new facilities. In addition, there remains a lack of research on applying dry battery electrodes in practical batteries.[57] **This alternative battery technology is therefore not ready for large scale industrialisation**: 2028 has been calculated as the average year for large-scale industrialisation of dry coating. Incremental improvements are expected for the roll-to-roll speed of the coating equipment at which electrodes are produced.[58]

<u>Sodium-ion (Na-ion) batteries</u>

Sodium-ion cells have recently emerged as an early stage sustainable battery technology showing promise for specific applications due to sodium-ion cells offering significantly lower energy densities than NMC-based Lithium-ion batteries. The sodium-ion characteristics of low energy density combined with low cost, makes them suitable for ESS and short-range mobility applications (where the lower cost is more important than energy density), but they are not able to meet the high driving range demands of most Western EVs in the same way as NMC-based cells can and are thus not able to substitute the latter.

Sodium ion batteries are not industrialized yet but aim to complement Lithium-ion batteries by offering significantly lower cost for less energy density. Sodium ion shows a first product market fit for stationary energy storage and light-weight or short-range mobility where the lower cost is more important than energy density.

Sodium-ion batteries are grouped into two different cathode types, namely Prussian Blue analogues (PBA) and sodium layered metal oxide (LMO). Other cathode using sodium such as polyanionic cathodes exist but did not yet create commercial traction. All cathode types have in common that they use sodium as the ion transporting charge between cathode and anode.

Batteries using LMO cathodes share a lot of similarities with conventional Lithium-ion batteries and stand out with their compatibility with existing cathode and cell manufacturing setups, allowing for a faster market introduction. The benefit of using a similar product design and production process also means that LMO-based sodium ion batteries rely on PFAS-based components as much as Lithium-ion batteries, meaning switching to **LMO-based sodium-ion batteries does not suppress the need of PVDF and other PFAS-based components.**

The electrode of batteries using PBA cathodes on the other hand can be designed without PFAS-based components, since the electrode can be produced using water, carboxymethyl cellulose, styrene-butadiene rubber and carbon. However, PBA-based batteries are very hygroscopic and can't be produced without adjusting the commonly known battery production process. PBA-based batteries are currently in product development and are expected to come to market shortly after LMO-based sodium-ion batteries due to said manufacturing difficulties. Once commercialized several years from now, **PBA-based sodium-ion batteries are expected not to use PFAS-based components in their electrode.**

[56] Electric & hybrid vehicle technology international, 2021. Why dry coating electrodes is the future of the electric vehicle battery industry. Available at: https://www.electrichybridvehicletechnology.com/opinion/why-dry-coating-electrodes-is-the-future-of-the-electric-vehicle-battery-industry.html

[57] Lu et al., 2022. Dry electrode technology, the rising star in solid-state battery industrialization. *Matter* 5. Available at: https://www.sciencedirect.com/science/article/pii/S259023852200011X

[58] Mauler, Lou, Duffner, and Leker (2022). Technological innovation vs. tightening raw material markets: falling battery costs put at risk. *Energy Advances* 1, 136. Available at: https://pubs.rsc.org/en/content/articlepdf/2022/ya/d1ya00052g

Lead acid batteries

Lead-acid batteries are a well-established and widely used technology for energy storage, particularly in automobile starting, lighting, and ignition (SLI) batteries and industrial applications. This battery technology does not use PFAS. However, lead has been recommended by ECHA for inclusion in REACH Authorisation Annex XIV. Once included in Annex REACH Annex XIV, the use of lead will be subject to a ban unless company-specific and use-specific authorisation is granted. The authorisation is, however, time-limited and puts pressure on substitution. Further, **lead-acid batteries are not considered as viable alternatives to Lithium-ion batteries due to several factors such as their lower energy density, shorter cycle life, and slower charge and discharge rates.** Additionally, lead acid batteries are more prone to sulfation, which can significantly reduce their performance and lifespan. A study published in the Journal of Energy Storage compared the performance of lead acid batteries and Lithium-ion batteries for energy storage applications. The study found that Lithium-ion batteries had higher energy density, longer cycle life, and faster charge and discharge rates compared to lead acid batteries. Additionally, the study found that the cost per cycle for Lithium-ion batteries was lower than that of lead acid batteries.[59] Lead acid batteries cannot be used for powertrain systems in mobility solutions such as electric vehicles, fork-lift trucks, e-bikes, and e-scooters.[60]

Hydrogen fuel cells

PFAS, foremost fluoropolymers are used in the hydrogen sector, including hydrogen fuel cells.[61] Hydrogen fuel cells convert the chemical energy stored in hydrogen into electrical energy without combustion, producing only water vapor as a by-product. Further, they have higher energy density, faster refuelling times, and potentially lower environmental impact. Nevertheless, hydrogen fuel cells also require a dedicated infrastructure for efficient hydrogen production, storage, and distribution, which can be costly and challenging to implement.[62]

3.4. Redesign process and timing

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[59] Chandra, A., Pathak, M. J., & Kollimalla, V. R., 2018. Performance comparison of lead-acid and lithium-ion batteries for stand-alone renewable energy systems: A review. Journal of Energy Storage, 20, 142-154.

[60] RECHARGE, 2023. Application for derogations from PFAS REACH restriction for specific uses in batteries – First submission. Submission number: cb6a7d0a-caa1-42fa-a806-f7410538f8b9.

[61] Hydrogen Europe, 2023. Hydrogen Europe Position Paper on PFAS. Available at: Hydrogen-Europe-position-paper-on-PFAS-ban_v12_FINAL.pdf (hydrogeneurope.eu) (Assessed in May 2023).

[62] Jiang, B., Li, J., & Song, X. (2021). Hydrogen fuel cell vehicles versus lithium-ion battery electric vehicles: A review on technologies, development and challenges. Renewable and Sustainable Energy Reviews, 150, 111473.

(A) [CONF.]

[CONF.]

(B) [CONF.]

[CONF.]:

- [CONF.]
- [CONF.]

(C) [CONF.]

[CONF.]:

- [CONF.]
- [CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

[CONF.]

3.5. Safety considerations

The PFAS restriction proposal contains certain derogations (proposed or for reconsideration) that would need to consider the critical PFAS applications used by Northvolt. For example, given the sufficiently strong evidence that alternatives for the full range of applications in the transport sector are not available at entry into force (EiF), the following potential derogation is marked for reconsideration after the Annex XV report consultation: **"[Applications affecting the proper functioning related to the safety of vehicles, and affecting the safety of operators, passengers or goods]"** to the extent not addressed under other parts of the restriction proposal. As stated by Northvolt in this report:

- PVDF as a binder is critical to secure cell performance and safety;
- PFAS ([CONF.]) remains indispensable for meeting the safety requirements of the automotive industry;
- the replacement of PTFE for the larger part of the equipment used at the facilities today could lead to safety concerns;
- [CONF.]
- [CONF.]

The critical PFAS applications discussed in this report are therefore often indispensable for the safety of the final Lithium-ion battery cells and scalable battery systems. As stated in this report, **the applications of the Lithium-ion battery cells and scalable battery systems produced by Northvolt are not exclusive to vehicles**. The products produced and placed on the market by Northvolt are also used in numerous other applications, for example, in mining machines, tools, and energy storage, among others.

3.6. Overall conclusion on suitability and availability of alternatives

The applications discussed above highlight the function and technical performance of the relevant PFAS in Lithium-ion batteries and scalable battery systems, as well as the PFAS used in the manufacturing process. The availability of alternatives and their performance is also considered for the respective application. This section (3.6) provides a brief summary of the 'analysis of alternatives' section (3).

There are no alternatives to PVDF in NMP wet solvent-based cathode manufacturing, which is the current industry standard utilized by Lithium-ion battery producers, available today. As it stands, if PVDF was completely banned, it would not be possible to manufacture a high-performance Lithium-ion battery for a number of years until alternatives are found and validated. It is currently not feasible to reduce the concentration of PVDF in the cathode active material of Lithium-ion cells, as it is a crucial component in the manufacturing process. PVDF is essential to the dispersion of cathode active material into a homogeneous and stable slurry, using NMP as a solvent. Additionally, PVDF provides critical electrochemical stability and mechanical integrity to the electrode, ensuring the performance and safety of the battery cell.

PFAS ([CONF.]) is used in several applications of the cell, such as gaskets, seal gaskets, and seal balls, due to its good mechanical properties, high resistance to chemical reactions, high thermal resistance, low friction, and non-stick properties. While there are ongoing investigations into alternative options for non-automotive industry applications, PFAS ([CONF.]) remains indispensable for meeting the safety requirements of the automotive industry.

There are also no alternatives to PTFE for the larger part of the equipment used at Northvolt's facilities today. Replacement could lead to safety concerns, as described above. For the manufacturing parts where it may be possible to change from PTFE [CONF.], extensive checks still need to be carried out and confirmed by the supplier.

[CONF.]

[CONF.]

[CONF.]

[CONF.]

In addition, most alternative battery technologies are still in development and are not commercially available yet. As discussed above, alternative technologies may also rely on PFAS for their functioning or may not have the required performance standards.

4. ANALYSIS OF IMPACTS

4.1. Economic impacts

The sections below provide a general overview of the social and economic impacts, considering business impacts (i.e., at different stages of the value chain), market impacts (i.e., on the product market), substitution costs, and broader macroeconomic consequences resulting from a potential restriction of the PFAS used in Lithium-ion battery cells and systems.

4.1.1. Business impacts on manufacturers of Lithium-ion battery cells and systems

A detailed questionnaire has been used to gather SEA data and information from Northvolt, a manufacturer of PFAS-based Lithium-ion battery cells and systems. The long-term market share covered by this questionnaire is approximated in the range between 10 to 20% of the whole EEA Lithium-ion battery market.

Therefore, if PFAS used in Lithium-ion battery cells and systems would be restricted,[63] it is estimated that **Northvolt would face a net EBIT loss of approximately [CONF.] EUR/year. Over four years**, the total impact for Northvolt is expected to be approximately **[CONF.] EUR** (NPV, 3% d.r.).[64]

PFAS quantities used in production

[CONF.]. The cell manufacturing technique Northvolt is using and plans to use in future manufacturing plants is based on using PVDF in the cathode binder. The equipment needed for this type of production is specially designed for that technique. [CONF.].

Within the Lithium-ion battery manufacturing industry, a normal amount of PVDF in a battery cell is in the range of 0.5 to 3 wt%, per electrode loading for a battery cell used by vehicle industry. In 2022, Northvolt [CONF.] for the production of the abovementioned cathode slurry to produce Lithium-ion batteries to reach a total cell production of 60 GWh/year (production is about to start). The quantities of [CONF.] ([CONF.] PVDF) used is expected to grow [CONF.], as total cell production is expected to reach 150 GWh/year[65] through three production sites in Europe in 2030. 150 GWh/year will represent approximately 20% of European capacity; it is worth noting that this outlook fluctuates.

Northvolt also receives PFAS ([CONF.]) for parts used in production (seal ball, lid gasket, terminal gasket, seal gasket, seal gasket cathode, seal plug) The concentration of PFAS in parts used in production is illustrated in Table 2 below.

Table 2: Volume of PFAS used in production parts.

Production part	Gross Weight (GW) in g
[CONF.]	[CONF.]
[CONF.]	[CONF.]
[CONF.]	[CONF.]
[CONF.]	[CONF.]
[CONF.]	[CONF.]
[CONF.]	[CONF.]

[CONF.]

[CONF.]

Product supply and demand

The Northvolt Ett gigafactory will start its series production of rechargeable Lithium-ion battery cells during 2023 (first sample cell was produced in 2021). [CONF.].

The output from Northvolt Systems (Poland) assembly facility (for manufacturing larger battery units from battery cells) [CONF.] is expected to rapidly increase over the coming years, [CONF.].

[63] The company was asked to consider how the revenues (and EBIT) for the year 2027 were impacted under the assumption that a REACH restriction on PFAS used in the production Li-ion battery cells and systems was to be fully adopted in the near future.

[64] Using the Excel function =PV(3%,4,-[CONF.],0,0)

[65] 150 GWh/year is the sum of Northvolt's gigafactories Northvolt Ett (Sweden), Drei (Germany), and NOVO (Sweden).

The manufacturing plant NOVO is in the phase of applying for permits to start construction during 2023/2024. There are also discussions to expand into Germany. Cells manufactured at these facilities will predominantly be sold to larger companies, namely automotive manufacturers.

Business impacts

PFAS-containing products are very important for Northvolt: PVDF, [CONF.], and PTFE materials or equipment made using these materials. The PVDF, as previously described, is used in the actual production of the cell and serves an important part in the cathode slurry and cathode electrode as a binder. PVDF therefore has a very significant role in the Lithium-ion battery production and guarantees their stable performance.

According to Recharge,[66] all players in the industry using NMC cathode material are using PVDF as cathode binder. [CONF.].

Concerning the suppliers, they are actively researching alternative solutions to PFAS as long as they are technologically feasible and applicable. This process requires significant time and effort, as companies are just beginning to evaluate their compliance with PFAS regulations. Most suppliers closely monitor new regulations with the goal of meeting any restrictions that may be imposed on the type of parts/components they place on the market within the EEA.

Market impacts

If Northvolt were unable to continue using necessary fluoropolymers, such as PVDF, [CONF.], and PTFE, which are essential for their current cell manufacturing technique, Lithium-ion batteries could not be produced until alternatives are found. Northvolt has further indicated that it is not feasible to switch to a different technique within a short period of time, as the facilities are specifically designed for the current process and may not be compatible with other techniques. Additionally, the proposed restriction on PFAS substances in articles would effectively prohibit the import and placement of Lithium-ion batteries in the EEA market. This would have a significant impact on the automotive industry, particularly those based in the EEA, as they rely on a steady supply of Lithium-ion batteries for EVs to shift away from combustible engines. It is important to note that many other industries also depend on Lithium-ion batteries from the EEA or other parts of the world.

4.2. Wider economic impacts

It is also important to consider the wider macroeconomic impacts and consequences on the EU society at large, by focusing on the expected consequences for the EEA market.

Impacts on the market – Quality and costs

If PFAS were no longer available in Lithium-ion battery cells and systems, sectors relying on these substances would be particularly affected. The development of new molecules with the same technical function as the one currently available today is not technically possible. Indeed, a restriction of a crucial category of chemicals would **require a completely new redesign across the battery and automotive industry and would lead to a loss of functionality and technical performance of Lithium-ion battery**

[66] RECHARGE, 2023. Application for derogations from PFAS REACH restriction for specific uses in batteries – First submission. Submission number: cb6a7d0a-caa1-42fa-a806-f7410538f8b9.

cells and systems. This would have an adverse impact on the availability, quality and costs of products in the EEA.

[CONF.].

<u>Impacts on the market – Competitiveness</u>

A broad restriction of PFAS used in the production of Lithium-ion battery cells and systems in the EEA would disadvantage European markets in their competition with the rest of the world, that would have access to a wider portfolio of products.

This restriction will affect all manufacturers of Lithium-ion battery cells producing for the industry in the EEA, including automotive industry. No cells can be manufactured without PVDF as the cathode binder and without using PFAS ([CONF.]) in the seal gaskets, as sealants are needed to close the cell. **The major risk is that non-EEA manufacturers would have a considerable advantage as compared to EEA manufacturers in international markets.** Indeed, non-EEA manufacturers would not be subject to a restriction of PFAS used for the production of Lithium-ion battery cells and systems and would be able to supply and place on the non-EEA market a wider range of products, without bearing any redesign cost.

As a result, some producers of finished products could decide to **move outside of the EU** in case of a negative regulatory decision and to focus on other regional markets completely. [CONF.]. Should the industry move out of Europe to service the rest of the world, it would result in a **significant downsize for innovation and manufacturing in Europe, with no alternatives for applications such as EVs in the short/medium term**.

[CONF.].

[CONF.].

The phase-out of diesel and petrol cars and vans in the EU is expected to accelerate the demand for and growth of lithium batteries over the next decade. This means that at least 59% of all cars sold in 2030 will have to be electric, rising to 100% by 2035. Europe has already secured large investments in EVs and batteries to scale manufacturing. In terms of public funding, more than 20 billion EUR has been devoted to the battery value chain at the EU level via the IPCEI framework, the EIB, and research funding in the past few years. Billions EUR more are available via the InvestEU and the EU Recovery and Resilience Facility, and more will become available through state aid under the revised March 2023 Temporary Crisis and Transition Framework. Over half of all lithium batteries on the EU market in 2022 were produced in Europe, with the continent projected to become the world's second- largest battery cell manufacturer by the end of the decade.[67] In addition, Europe is on track to produce 6.7 M battery electric cars (BEV) by 2032 (or just over half of all the cars produced), which is in line with the recently agreed 55% CO_2 reduction target for carmakers for 2030, that is expected to result in a 50-60% share of BEV sales.[68] **The proposed ban of PFAS, which is included in all such batteries, threatens to wipe out the entire EU automotive sector which in recent years accounts for 14 M jobs and revenues of**

[67] Transport & Environment, 2023. A European Response to US IRA How Europe can use its soft and financial powers to build a successful electric vehicle value chain. Available at: https://www.transportenvironment.org/wp-content/uploads/2023/01/2023_01_TE_Raw_materials_IRA_report-1.pdf (Accessed in April 2023).

[68] Transport & Environment, 2021. Promises, but no plans: How the EU can make or break the transition to zero emission cars. Available at: https://www.transportenvironment.org/wp-content/uploads/2021/08/202106_EV_Report-Final-1.pdf (Accessed in April 2023).

about 940 billion EUR,[69] **thus representing 7% of the EU GDP**.[70] In addition, the automotive sector is responsible for about 25% of the annual EU emissions and thus **the PFAS ban would also severely hinder EU ambitions to drive these emissions to zero through electrification, risking the EU target of net-zero greenhouse gas emissions by 2050**.[71]

Impacts on the market – Innovation and R&D

If this ban were to be immediately enforced in the European battery manufacturing landscape, Northvolt projects that European battery manufacturers would fail to reach short-term profitability. These emerging European manufacturers will suffer a severe loss of revenue, and lost profits will be diverted to non-EEA companies. As a result, **R&D funding and innovation are also expected to migrate to non-EEA companies, which would make it even harder for the European industry to catch up with their competitors.** Innovation will be critical in the success of European battery manufacturers, who are unfortunately lagging behind their competitors in terms of intellectual property (IP). In today's battery IP landscape, major incumbent non-EU players, which are often older and better-established, are currently patenting at a rate of more than 1,000 inventions per year, thus securing their freedom to operate for the coming years and severely limiting that of EU players.

Unlike most competitors, Northvolt strives at mass producing batteries with a minimal carbon footprint and environmental impact. While a PFAS regulation is a step forward in terms of sustainability, there are numerous ongoing developments needed to achieve Northvolt's sustainability goals. **[CONF.].**

The restriction still allows the use of PFAS for R&D purpose. However, such R&D will most likely only be used for comparison reasons for new developments, new chemistry, and/or material development.

[CONF.].

[CONF.]

[CONF.]

Impacts on the market – Trade

A broad restriction of PFAS used in the production of Lithium-ion battery cells and systems in the EEA would disadvantage European companies in their trade with the rest of the world. The exports from the EEA would be particularly hard hit by a potential restriction. Thus, the restriction of PFAS used in the production of Lithium-ion battery cells and systems produced in the EEA would reduce the exports of these products to non-EEA markets.

---

[69] European Commission. Internal Market, Industry, Entrepreneurship and SMEs: Automotive Industry https://single-market-economy.ec.europa.eu/sectors/automotive-industry_en (Accessed in April 2023).

[70] Policy Department for Economic, Scientific and Quality of Life Policies, 2021. The Future of the EU Automotive Sector. Available at: https://www.europarl.europa.eu/RegData/etudes/STUD/2021/695457/IPOL_STU(2021)695457_EN.pdf (Accessed in April 2023).

[71] McKinsey Center for Future Mobility, 2019. Race 2050 – A Vision for the European Automotive Industry. Available at: https://www.mckinsey.com/~/media/mckinsey/industries/automotive%20and%20assembly/our%20insights/a%20long%20term%20vision%20for%20the%20european%20automotive%20industry/race-2050-a-vision-for-the-european-automotive-industry.pdf (Accessed in April 2023).

Many automotive manufacturers are currently increasing their EV-fleet due to the EU regulation that ensures that placing vehicles with combustion engines will reach an end in 2035. Cells are needed for the EVs as these are a huge part of the final vehicle. As mentioned above, the majority of the cells manufactured by Northvolt in the EEA will go to automotive manufacturers. For these manufacturers to be able to claim that the car is manufactured in EEA, the country-of-origin rules says that a minimum of 60% of all parts used in the car must be manufactured within the EEA. **This percentage will be very difficult, if not impossible, for the car manufactures to fulfil if the cells are not manufactured in the EEA**. Car manufacturers will most likely not obtain cells from outside the EEA either. **An adverse impact on EEA car production will affect the trade balance of the region.**

Impacts on the Lithium-ion recycling market

The changing landscape from oil-dependency to electrification across all sectors results in a dependency on critical metals that are contained in high quantities in Lithium-ion batteries, such as nickel, cobalt, and lithium. Recycling of Lithium-ion batteries is fundamental to alleviating geo-political dependencies on critical raw materials, as laid out by the EU Critical Raw Materials Act (European Commission proposal). Under the proposed PFAS restriction, the long-term business case for recycling of Lithium-ion batteries in the EU would be compromised.

Under a PFAS restriction, the manufacturing of Lithium-ion batteries in the EU may decrease. Since the feed material for the recycling industry is made up of market volumes as well as battery manufacturing waste, decreasing EU-based production will decrease EU-based recyclable volumes. Since recycling capacity in the EU is currently growing, the EU market may end up in a situation with over-capacity of recycling facilities whilst recyclable volumes decrease. As supply decreases, it will be difficult to operate recycling at competitive levels, whilst the recycling product will need to be exported (as production shifts out of the EU). **Therefore, the PFAS restriction may shift market dynamics to such an extent that recycling in the EU becomes uncompetitive.**

4.3. Social impacts: unemployment

In general, it is difficult to estimate the unemployment because this depends on numerous factors such as whether the completely different PFAS-free Lithium-ion battery cells and systems can be developed and accepted by the market. Moreover, the scale of impact on employment is expected to be lower than the impact on EBIT. [CONF.]. Here, the monetization of the likely social costs of unemployment for these workers is reported.

The average annual salaries across these European workers (including the employer's social security contributions) are reported below.

A well-known guideline in monetizing the social impact of unemployment has been developed by the European Chemicals Agency (ECHA) for evaluating such impact in different regulatory processes. Estimates have been made in accordance with the ECHA document on the evaluation of unemployment (SEAC/32/2016/04)[72] and the paper of Dubourg (2016)[73] endorsed by ECHA. Therefore:

[72] ECHA, 2016. The Social Cost of Unemployment. Available at: https://echa.europa.eu/documents/10162/13555/seac_unemployment_evaluation_en.pdf/af3a487e-65e5-49bb-84a3-2c1bcbc35d25

[73] Richard Dubourg, 2016. Valuing the Social Costs of Job Losses in Applications for Authorization. The Economics Interface Limited.

- Using Table A7 (column G, considering the gross wages including the employer's social security contributions) in Dubourg's paper, the total social cost of unemployment in Sweden is equal to 1.69 times the annual gross salary, 2.18 in Germany, and 1.95 in Poland. [74]
- Tables 3, 4, and 5 present the statistics from Eurostat (data for 2022-Q4) on the average duration of unemployment for both men and women in the age of 15-64 years in EU-27.[75]
- Only 75% of the average duration of employment is considered, to reflect the fact that some affected workers are highly skilled and could find employment sooner.

Table 3: Duration of unemployment in Sweden.

Duration Grouping	Thousand units	Proportion (A)	Assumed duration (B)	Weighted average (A*B)
Less than 1 month	83.4	0.237742303	0.5	0.118871152
From 1 to 2 months	69.3	0.197548461	1.5	0.296322691
From 3 to 5 months	58.6	0.16704675	4.5	0.751710376
From 6 to 11 months	43.4	0.123717218	8.5	1.051596351
From 12 to 17 months	35.9	0.102337514	14.5	1.483893957
From 18 to 23 months	21.4	0.061003421	20.5	1.250570125
From 24 to 47 months	30.9	0.088084379	35.5	3.126995439
48 months or over	7.9	0.022519954	48	1.080957811
Total	350.8	1		**9.160917902**

The social costs of unemployment for workers employed in Sweden would therefore be equal to: [CONF.] EUR x [CONF.] people x [CONF.] x [CONF.]/12 x 75% = [CONF.] EUR.

Table 4: Duration of unemployment in Germany.

Duration Grouping	Thousand units	Proportion (A)	Assumed duration (B)	Weighted average (A*B)
Less than 1 month	243.4	0.18696614	0.5	0.09348307
From 1 to 2 months	279.1	0.214419591	1.5	0.321629386
From 3 to 5 months	185.8	0.142721072	4.5	0.642244823
From 6 to 11 months	195.5	0.150172064	8.5	1.276462545
From 12 to 17 months	97.6	0.074970811	14.5	1.087076753
From 18 to 23 months	68.7	0.052771462	20.5	1.08181497
From 24 to 47 months	113.4	0.087107479	35.5	3.092315492
48 months or over	118.3	0.090871382	48	4.361826338

[74] These values are greater than 1 because they take into account the following components: lost wage, costs of job searching, recruitment costs, the impact of unemployment status on future wages (scarring effect) and employment possibilities, and leisure time (which is a benefit and therefore subtracted from the previous components).

[75] Data extracted from: https://ec.europa.eu/eurostat/databrowser/view/LFSQ_UGAD__custom_5694655/default/table?lang=en

Total	1301.8	1		**11.95685338**

The social costs of unemployment for workers employed in Germany would therefore be equal to:

[CONF.] EUR x [CONF.] people x [CONF.] x [CONF.]/12 x 75% = [CONF.] EUR.]

Table 5: Duration of unemployment in Poland

Duration Grouping	Thousand units	Proportion (A)	Assumed duration (B)	Weighted average (A*B)
Less than 1 month	14.0	0.028220117	0.5	0.014110058
From 1 to 2 months	137.3	0.276758718	1.5	0.415138077
From 3 to 5 months	120.0	0.241886716	4.5	1.088490224
From 6 to 11 months	81.0	0.163273534	8.5	1.387825035
From 12 to 17 months	62.5	0.125982665	14.5	1.826748639
From 18 to 23 months	16.6	0.033460996	20.5	0.685950413
From 24 to 47 months	50.6	0.101995565	35.5	3.620842572
48 months or over	14.1	0.028421689	48	1.36424108
Total	496.1	1		**10.4033461**

The social costs of unemployment for workers employed in Poland would therefore be equal to:

[CONF.] EUR x [CONF.] people x [CONF.] x [CONF.]/12 x 75% = [CONF.] EUR.

[CONF.].

[CONF.]

5. CONCLUSION

This SEA and AoA identify the main potential impact of the proposed REACH restriction of PFAS on Northvolt's Lithium-ion battery manufacturing and recycling. It also identifies the potential impact on the EEA society at large given Northvolt's projected 10-20% European market share. The assessment has been performed in line with existing ECHA guidance under REACH. The results are based on a detailed questionnaire focused on Northvolt as a representative of the EEA battery and battery recycling industry.

Based on the evidence-based considerations, the SEA and AoA performed conclude that a broad restriction without a long-term derogation for the use of PFAS in the manufacturing of Lithium-ion battery cells and scalable battery packs and systems will have disproportionate negative impacts on the European economy and society. The analysis presented reasonably justifies the request for a time-limited derogation of [CONF.] years for the use of critical fluoropolymers, such as PVDF, [CONF.], and PTFE and other specified PFAS in Lithium-ion battery cell and scalable battery system production, the use of batteries containing PFAS, and the recycling of batteries containing PFAS.

The above statement is founded on the following:

- **Lithium-ion batteries, as well as Northvolt's manufacturing process, heavily depend on several PFAS chemicals. [CONF.].**
- **There is no evidence of technically suitable alternatives** readily available which can substitute PFAS chemicals across their uses and in the manufacturing process. Namely, there are no alternatives available today for PVDF in NMP wet solvent-based cathode manufacturing, which is the current industry standard, as well as for [CONF.], PTFE, and other PFAS chemicals used. In addition, most of the alternative battery technologies are still in development and are not commercially available yet. As discussed above, alternative technologies may also rely on PFAS for their functioning or may not have the required performance standards. **There are therefore also no alternatives available today at scale for Lithium-ion batteries used in the applications of Northvolt's customers**.
- **The total impact of a PFAS restriction is monetised as more than [CONF.] EUR**, including [CONF.] EUR of social impacts from unemployment in the EEA and [CONF.] EUR of economic impacts (EBIT loss) for Northvolt. **This is a conservative estimate (lower boundary), based on the understanding that this is not the sole injury likely to be suffered in the EU.** Moreover, the total impact for the whole EEA is unknown. As the expected long-term market share of Northvolt has been estimated in the range of 10 to 20%, no extrapolation to cover the EEA market is made based on such a low percentage.
- A thorough risk assessment (jointly submitted to the authorities with this SEA) has been conducted by Royal HaskoningDHV at the request of Northvolt. **This risk assessment demonstrates that all possible technical means, supported by risk management measures and, where indicated, personal protection equipment, are employed to minimise exposure to workers and emissions to the environment.**
- Since many PFAS substances are non-classified according to CLP, the information about the potential PFAS content in many cases is not declared for chemical mixtures or articles. As demonstrated, **information collection has been done for the battery cell and partly for manufacturing equipment** to Northvolt's best ability in the timeframe provided but collecting that information for thousands of purchased components and equipment takes a very long time and is not possible during the timeframe of this PFAS public consultation ending in September 2023. **[CONF.].**

- Communication within the supply chain to identify PFAS content and criticality is further complicated by potentially different PFAS definitions within the EEA and the UK and, identification numbers such as CAS-numbers lacking in the PFAS restriction proposal. **As many PFAS uses have not been identified on time for this public consultation, there is very high potential that there will be critical applications that have not been mentioned in the material sent into the public consultation. Considerably more time than 6 months would be required to collect the requested information.**

Non-EEA manufacturers would have a considerable competitive advantage on non-EEA markets compared to EEA manufacturers. Hence, a PFAS restriction in the EEA will have impacts on the competitiveness of the EEA markets, on competition in the EEA, and on innovation. Downstream sectors in the EEA that rely on Lithium-ion battery cells and systems, such as the automotive industry, would face large-scale negative consequences. An adverse impact on EEA battery and car production will adversely affect the trade balance of the region.

To conclude, the PFAS applications discussed above highlight that alternatives do not currently exist. Alternative substances to PFAS, if they do exist, do not match the required performance characteristics and safety properties.

eppa
SINCE 1987
interfacing government & business society

2 Place du Luxembourg | be-1050 Brussels
+32 2 735 82 30

[redacted]@eppa.com
www.eppa.com