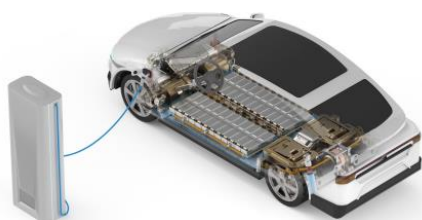


RECHARGE's technical contribution for the ECHA PFAS Restriction Consultation



September 2023

Second submission

By RECHARGE

Background Information

This document is a technical report by members of RECHARGE. It is based on non-confidential information provided by our members and may not fully capture the specific circumstances of each individual member. We acknowledge that some members have submitted confidential information to support their requests for longer transition periods and derogations. Please note, this confidential information was unable to be shared with RECHARGE.

RECHARGE's submission is on a sector level¹ where we have gathered and presented all relevant information on PFAS across the entire battery value chain. It is important to note that, for particular battery components some members have transitioned or are transitioning to non-PFAS alternatives and other members have specific technology which relies on the continued use of PFAS. As a result, the transition periods and derogations and requirements for each company vary significantly based on each company's unique product portfolio.

To address these variations, RECHARGE have closely followed the proposal guidelines and basis for transition periods and derogations as outlined on slide 41 from the 5 April 2023 ECHA webinar². **This document does not aim to contradict or undermine individual members' submissions.** We respect the confidential nature of company sensitive data and understand requests for longer transition periods and derogations are based on each company's product portfolio.

We hope ECHA, the Commission, Member States and the REACH Committee understand this document serves as a collective effort to provide information on PFAS across the battery value chain – **from an association level perspective**. We have worked within the guidelines and the proposed basis for transition periods and derogations considering the diverse needs and challenges faced by our members.

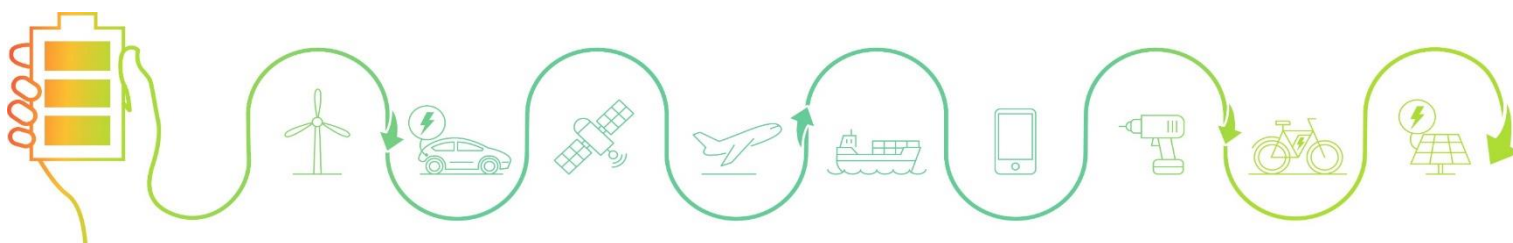
Please note, **although we have provided feedback to the consultation within the guidelines, RECHARGE and its members do not believe that the basis for transition periods and derogations proposed by the Dossier Submitters (even with review clauses) provides sufficient certainty for companies to invest in Europe** because there is risk that transition periods and derogations may not be renewed. **This uncertainty is already diverting some new investments from Europe and putting a high risk on the current investments in Europe, which could jeopardise the future European batteries value chain.**

For this reason and in the need of predictability and certainty required for industry, RECHARGE requires the Commission for a swift public statement after the ECHA opinion, that its decision would not undermine in any way future investments in the EU battery industry which is highly needed for reaching the ambitious Green Deal targets.

This document is an answer to the ECHA public consultation and does not represent an endorsement by RECHARGE of the derogation process proposed by the Dossier submitters.

¹ 'Joint submissions encouraged – e.g. per sector', Slide 49, Restriction of PFAS under REACH, ECHA Webinar 5 April 2023, <https://echa.europa.eu/-/restriction-of-per-and-polyfluoroalkyl-substances-pfass-under-reach>

² 'Basis for derogations', Slide 41, Restriction of PFAS under REACH, ECHA Webinar 5 April 2023, <https://echa.europa.eu/-/restriction-of-per-and-polyfluoroalkyl-substances-pfass-under-reach>

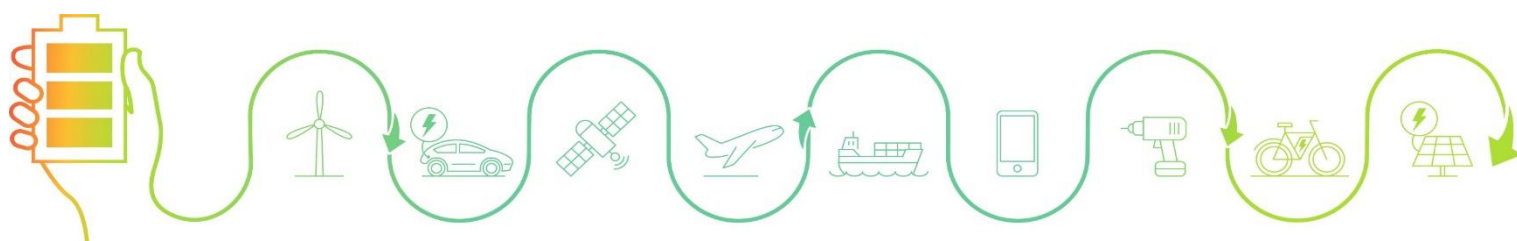


Executive Summary

This document provides RECHARGE's technical contribution for the ECHA PFAS Restriction consultation and the latest proposal of 22 March. It builds upon RECHARGE's first submission (Reference 3925) and serves as a collective effort of members to provide information on PFAS across the entire battery value chain.

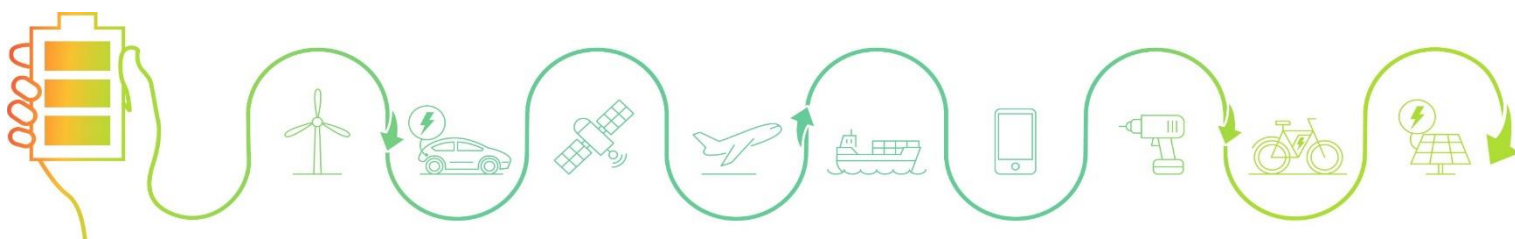
This document is comprised of five sections:

- An introduction to the battery industry and the scope of batteries included in this document (Section 1). It also includes the errors that were identified in Annex E of the PFAS restriction proposal.
- Why are PFAS used in batteries – what are their unique properties and where within batteries are PFAS used (Section 2)? During this process, PFAS identified in key battery components are mainly those substances of low concern according to the OECD definition.
- An analysis of PFAS alternatives (Section 3). A summary of the availability of alternatives and corresponding derogation/transition periods in line with the dossier submitters' proposal for PFAS identified in key battery components is outlined. This section then explains the need for periodic review of (i) derogations for uses where alternatives are not yet available (section 3.2) and (ii) where substitution is technically feasible but more time is required (section 3.4).
- Section 4 outlines PFAS consumption in tonnes (section 4.1) and details emissions during the battery life cycle (section 4.2). Members emphasised the limitations of no standardised methods to perform PFAS emission data measurements. Despite this:
 - wastewater samples analysed during battery manufacturing confirm there is no detectable emission of PFAS to the environment (Section 4.2.2).
 - There are no PFAS emissions from any type of battery during normal use (Section 4.2.3).
 - During battery recycling, there are no PFAS emissions from the pyrometallurgical process and no uncontrolled or unintended PFAS emissions from the hydrometallurgical process (Section 4.2.4.2).
- The socio economic impact assessment of a PFAS restriction on the battery value chain (section 5). This section details the reliance of the Green Deal on batteries as a strategic value chain to achieve objectives for low-emission mobility, decarbonised energy generation and digitalisation. It also outlines forecasted electric vehicle growth in order for Europe to be a global competitor in this field, and includes the amount of investment at risk for battery cell production and the battery recycling industry (Section 5.4). The ECHA PFAS restriction proposal is creating high uncertainty for the battery value chain industry and diverting forecasted growth and investment away from the EU.

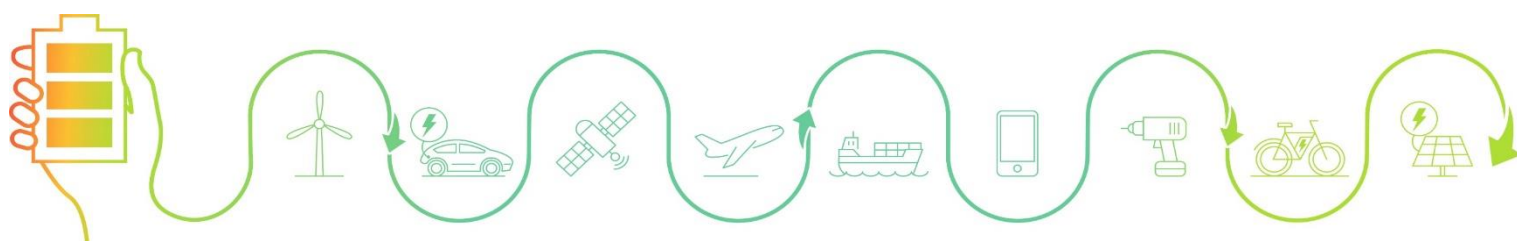


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1 Introduction and scope

RECHARGE represents over 60 organisations spanning all aspects of the battery value chain including:

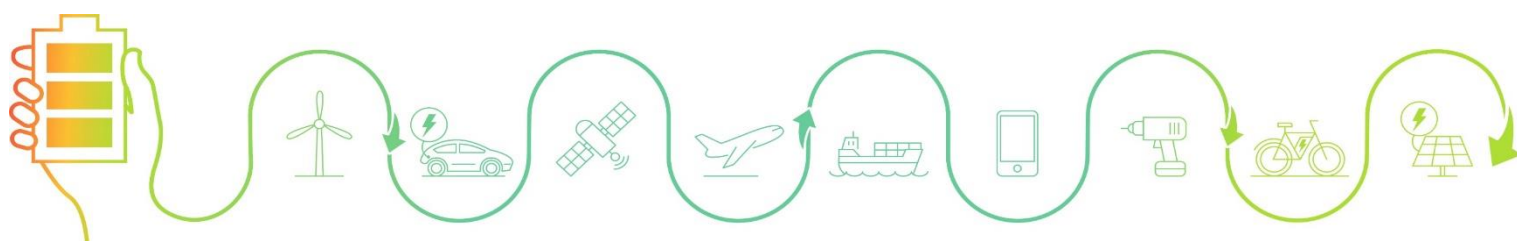
- raw materials suppliers
- manufacturing equipment producers
- cell and battery manufacturers
- original equipment manufacturers
- logistic partners, and
- battery recyclers

In addition to consulting 60 RECHARGE members, we solicited feedback from

- European Portable Battery Association (EPBA)
- Association of European Automotive and Industrial Battery Manufacturers (EUROBAT)
- National Electrical Manufacturers Association (NEMA)
- European Automobile Manufacturers' Association (ACEA)
- European Power Tools Association (EPTA)
- EGMF (European Garden Machinery Federation EGMF)

The scope of this document as feedback to the ECHA consultation includes the following types of high performance, advanced rechargeable and lithium batteries:

- Lithium-ion rechargeable batteries (also known as Li-ion batteries)
- Lithium (Li) primary batteries (also known as primary Lithium batteries)
- Nickel-based rechargeable batteries (Ni-Cd and Ni-MH)
- Metal air batteries
- Zinc oxide batteries
- Silver oxide batteries
- Sodium-ion (Na-ion) rechargeable batteries
- Zinc-ion (Zn-ion) rechargeable batteries
- Solid-state batteries



- Lithium metal rechargeable batteries
- Other battery technologies currently under research

RECHARGE and its members understand the concern behind the regulatory action and support efforts to restrict PFAS which are widely used across the EU and pose unacceptable risk to human health or the environment such as perfluorooctanoic acid (PFOA). **The energy sector represents between 0 and 1% of the total emissions of PFAS³** of which a small part of this can be attributed to batteries.

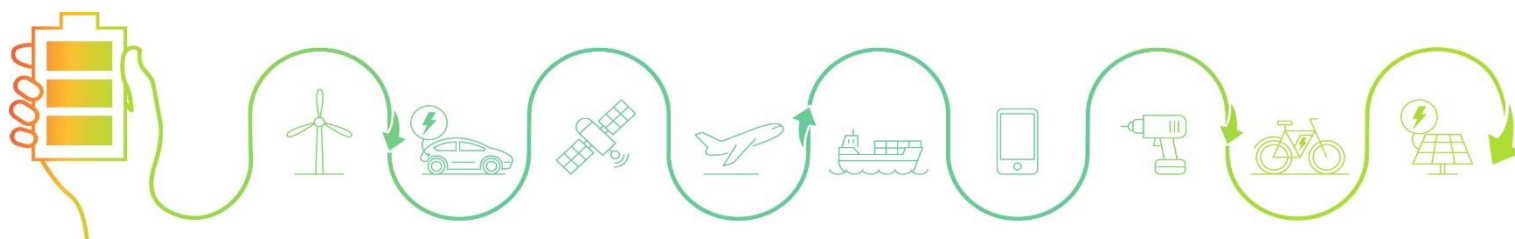
Batteries have been identified by the European Commission as a strategic value chain. Batteries are a main enabler for the transition towards low-emission mobility, decarbonised energy generation and digitalisation. Batteries power a wide range of **general public** applications such as smartphones, tablets, power tools, hearing aids, defibrillators, safety lighting in public buildings, and provide many services to **industry** such as back-up power for mission critical industrial assets such as nuclear power plants and internet data centers. Battery storage helps renewable generators reliably integrate with existing grids by storing the excess generation and by smoothing the energy distribution. Batteries also provide power to an increasing number of **mobility** solutions such as electric vehicles, forklift trucks, e-bikes and e-scooters. They generate significant economic growth and provide jobs for millions of people. Batteries are essential to ensure the sustainable development of society and provide critical environmental and social benefits.

This document has been produced using information provided by our members, company reports, governmental publications, patent reviews and academic articles. All uses of PFAS described in this document have been researched in detail to determine whether non-PFAS alternatives are available on the EU market. All statements provided in this document are supported by scientific evidence (with more than 70 references to scientific publications and websites).

This is a second submission⁴.

³ Slide 24, Restriction of PFAS under REACH, ECHA Webinar 5 April 2023, <https://echa.europa.eu/-/restriction-of-per-and-polyfluoroalkyl-substances-pfass-under-reach>

⁴ The reference number for the first submission is 3925.



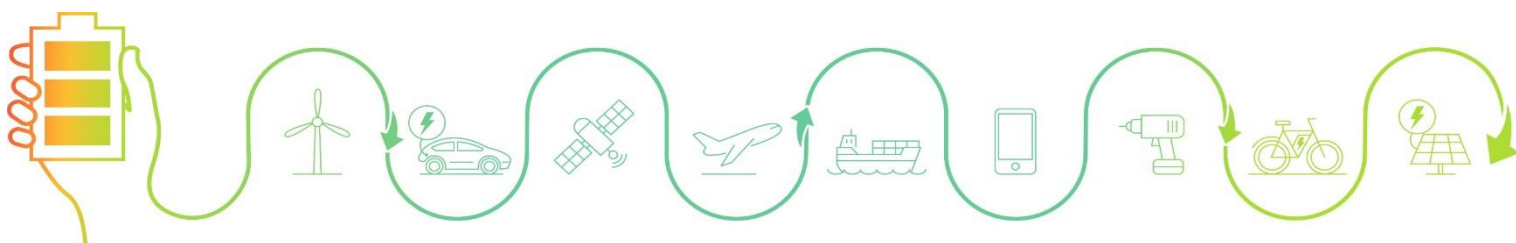
1.1 Errors in the PFAS Restriction Proposal

Contrary to what is stated in Annex E (page 416), solid state batteries and lead acid batteries **are not potential** non-PFAS alternatives to Lithium-ion batteries. This is because:

- Solid state batteries use PFAS, specifically PVDF (Polyvinylidene difluoride) and PTFE (Polytetrafluoroethylene):
 - in the binder within the active material
 - in solid electrolytes and
 - in gel polymer electrolytes.
- Although lead acid batteries do not use PFAS, they have a low energy density and cannot be used in applications which require high energy, high power, very long life, superior reliability, and the ability to withstand extreme temperatures. In addition, lead compounds used for battery manufacturing and lead metal are on the REACH Candidate List and have been recommended by ECHA for authorization under REACH Annex XIV. Lead acid batteries cannot be used for technologies such as smartphones, tablets, power tools, hearing aids, defibrillators, and many other portable applications used by EU citizens today. Lead acid batteries cannot be used for powertrain systems in mobility solutions such as electric vehicles, fork-lift trucks, e-bikes and e-scooters.

2 Why are PFAS used in batteries and where?

Batteries are comprised of two electrodes, a separator and an electrolyte, as schematized in Figure 1. Each electrode consists of an active material mass which is coated onto a current collector.



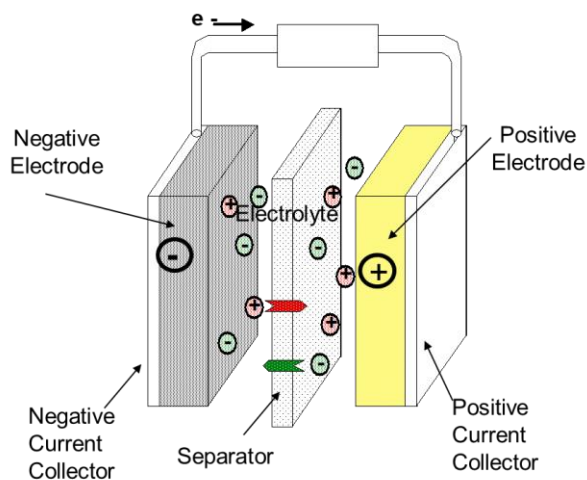


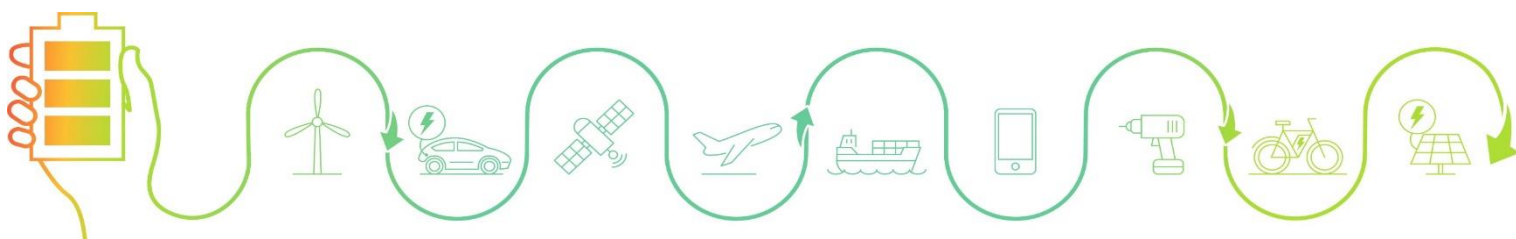
Figure 1. Components of a battery

PFAS have very unique properties:

- Water, oil and dirt repellent
- Durable under extreme conditions (high temperature, pressure, and aggressive chemicals)
- Electrical and thermal insulation.

As chemical resistance and tolerance to a high range of working temperatures are crucial for batteries, PFAS, mainly those substances of low concern according to the OECD definition, are used in key components for all high performance and lithium battery technologies. As depicted in Figure 2, PFAS are used in key components in:

- Cathode
- Anode
- Separator
- Gasket
- Electrolyte
- Insulating washer



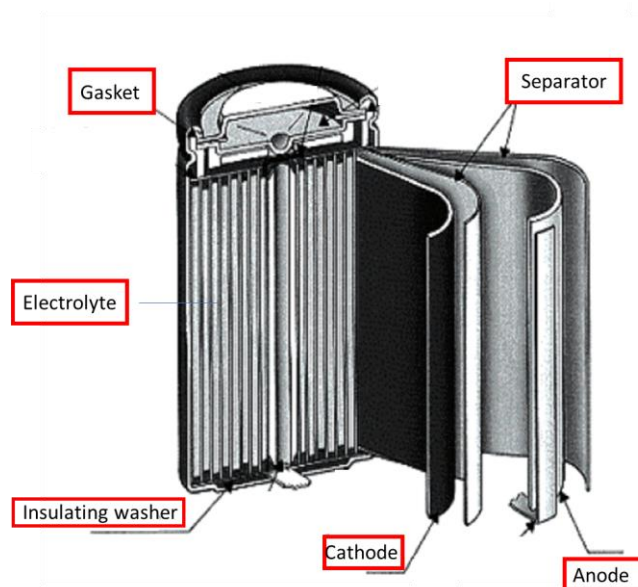
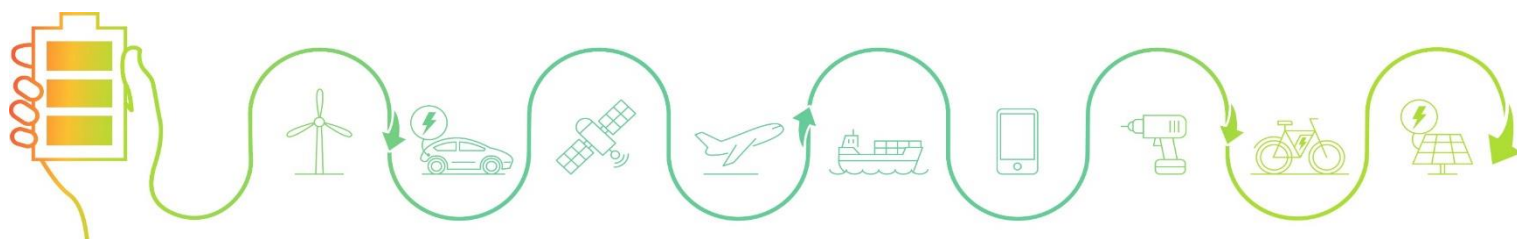


Figure 2. Where PFAS are used in a battery⁵

2.1 PFAS used in active material mass of electrodes

Each electrode is a composite which is manufactured by coating an active material mass onto a current collector (as shown in Figure 3). The active material mass comprises an active material, conductive additives (when needed) and a binder material.

⁵ Original figure from Figure 1(c) of Arora, P., & Zhang, Z. (John). (2004). Battery Separators. *Chemical Reviews*, 104(10), 4419–4462. <https://doi.org/10.1021/cr020738u>



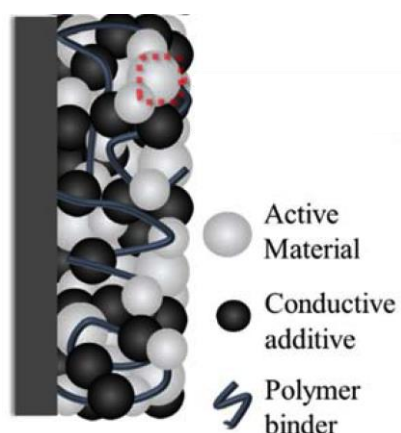


Figure 3. Composite electrode materials⁶

Binder material is used to hold the active material particles together within the composite electrode and to provide a strong connection between the electrode and the current collector. The binder material plays an important role in the manufacturability of the battery and in the battery performance.

Due to their unique properties, both Polytetrafluoroethylene (PTFE) and Polyvinylidene difluoride (PVDF – both homopolymer and copolymer) are used as binder materials in the active material masses in electrodes in a wide range of battery technologies, as detailed in Table 1.

⁶ 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; <https://doi.org/10.3390/polym13040631>

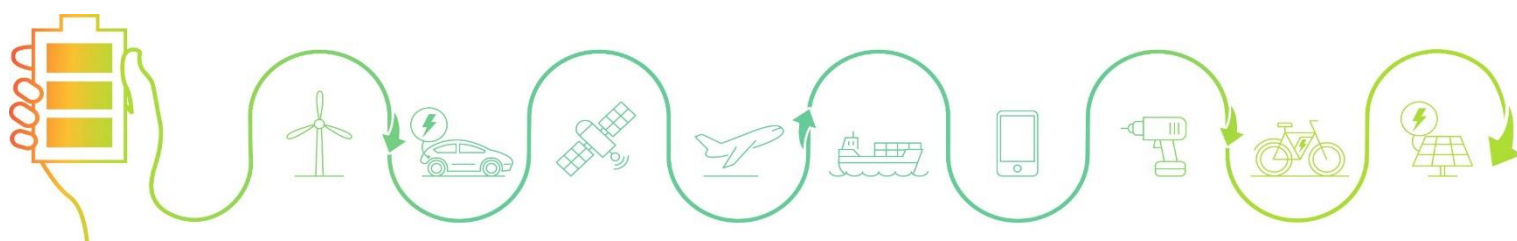


Table 1. Binders used in active material masses for different battery technologies

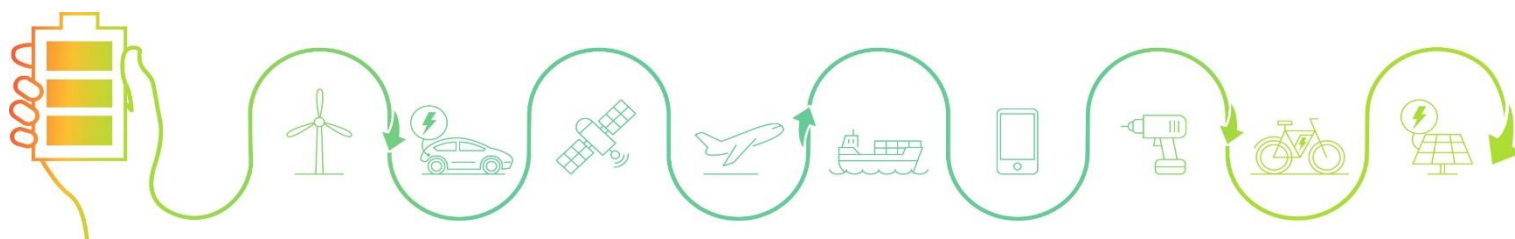
Battery technology	Positive electrode	Negative electrode	Electrolyte
Li-ion (wet-process)	PVDF with NMC, NCA, LCO, LMO, LFP active masses	1. SBR/CMC with graphite anode 2. PVDF with LTO anode	Liquid organic electrolyte
Li-ion (dry process)	PTFE with NMC, NCA, LMO and LFP active masses	1. SBR/CMC with graphite anode 2. PTFE with graphite anode.	Liquid organic electrolyte
Na-ion	PVDF with PBA, Na-NFM and phosphate based active masses	PVDF with hard carbon anodes	Liquid organic electrolyte
Solid-state LMP	PEO with LFP active mass	No binder required for metallic lithium anode	Polymeric layer including PEO and PVDF
Ni-based rechargeable batteries	PTFE with Ni(OH) ₂ foam active mass	PTFE with Cd or MH electrode	Liquid alkaline electrolyte
Primary Li-SOCl ₂	PTFE with carbon anode	No binder required for metallic lithium	SOCl ₂ electrolyte
Primary Li-SO ₂	PTFE with carbon anode	No binder required for metallic lithium	SO ₂ electrolyte
Primary Li-MnO ₂	PTFE with MnO ₂ active mass	No binder required for metallic lithium	Liquid organic electrolyte
Primary Zn-Air	PTFE with MnO ₂ active mass	PTFE -membrane	Liquid alkaline electrolyte
Primary Silver oxide	PTFE binder with Silver oxide	Zinc	Liquid alkaline electrolyte
Lithium metal rechargeable	PVDF (and PTFE), with with NMC, NCA, LCO, LMO, LFP	No binder required for metallic lithium	Liquid organic electrolyte, PE/PP or cellulose separator

2.1.1 PVDF used in active material mass of electrode

Although the PVDF binder comprises only a small portion of the composite electrode (typically 2–5% of the mass of the electrode⁷), the binder plays four important roles in battery performance. The PVDF binder:

- helps to disperse the active material and the conductive additive in the solvent during the fabrication process, enabling a homogeneous distribution of the slurry,

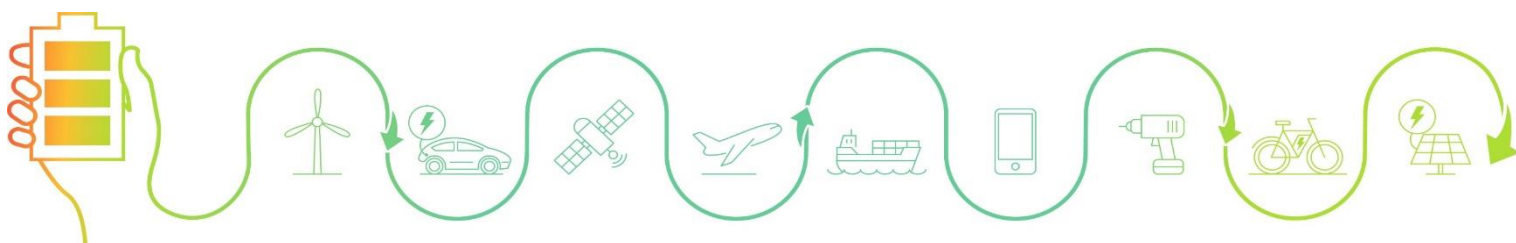
⁷ Cholewinski, A., Si, P., Uceda, M., Pope, M., & Zhao, B. (2021). Polymer Binders: Characterization and Development toward Aqueous Electrode Fabrication for Sustainability. *Polymers*, 13(4), 631–. <https://doi.org/10.3390/polym13040631>



- holds the active material and the conductive additive together and connects them to the current collector, ensuring the mechanical integrity of the solid electrode without significantly impacting electronic or ionic conductivity (see Figure 2),
- acts as an interface between the composite electrode and the electrolyte. In this role, the PVDF binder protects the composite electrode from corrosion and the electrolyte from depletion while facilitating ion transport across this interface,
- tailors the viscosity of the slurry to allow a smooth coating onto the current collector during electrode manufacturing.

PVDF has several unique properties that enable it to fulfil these critical roles:

- **Mechanical properties**, including stiffness, toughness and hardness as well as good adhesion to the active material, the conductive additive, and the current collector. PVDF ensures the flexibility of electrode for cylindrical designs. The positive electrode binder must be able to withstand the forces that result from the expansion and contraction of active materials during charge/discharge cycles,
- **Thermal properties**, particularly thermal stability, are also important, both for the high temperatures commonly used for curing and drying during electrode fabrication and also for operation of the battery at various temperatures,
- **Good dispersive capabilities** are important to help distribute the slurry evenly over the current collector during fabrication,
- **Chemical and electrochemical stability** are essential properties to enable the binder to function for long periods and over numerous cycles without degradation of the battery. The positive electrode binder must not react with any other components or intermediates formed during operation. In particular, the positive electrode 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 cell⁸) and high-capacity cells. This stability guarantees its safe use in the electrochemical environment of the lithium cell.

All Lithium-ion battery manufacturing processes use PVDF as the binder material for all types of positive electrodes. Many other binder materials have been evaluated as replacements for PVDF, however all other materials have been found to oxidise at the high voltage at the positive electrode.

PVDF was previously also used as the binder material for all negative electrodes, however companies using graphite negative electrodes have successfully substituted PVDF with water-based CMC/SBR binder materials. For other types of negative electrodes using higher voltage materials such as lithium titanate oxide (LTO), NTO (Niobium Titanate Oxide)⁹ the use of PVDF binder material is required because no research on alternative non-PFAS binders has proved sufficiently conclusive for transfer to industrialization to date.

For Sodium-ion rechargeable batteries, some research is ongoing regarding non-PFAS SBR/CMC binder materials for some hard carbon/PBA cells but this research work has not yet been scaled up. PVDF is preferred with some other PBA materials¹⁰ and with hard carbon.¹¹

Next generation Lithium-ion battery developments are focussed on producing cathodes using a dry process which avoids the need for NMP solvent. This dry process will significantly reduce energy consumption and lower environmental footprint. However, the dry process requires the use of PTFE or PVDF as the cathode binder material^{12,13}.

⁸ These different cell formats (cylindrical, prismatic and pouch cell) are required for optimisation of performance at battery system level.

⁹ Next-Generation SCiB™ supporting smart mobility in the age of MaaS, Using Niobium Titanium Oxide (NTO) as a next-generation anode material. (n.d.). <https://www.global.toshiba/www/products-solutions/battery/scib/next/nto.html>

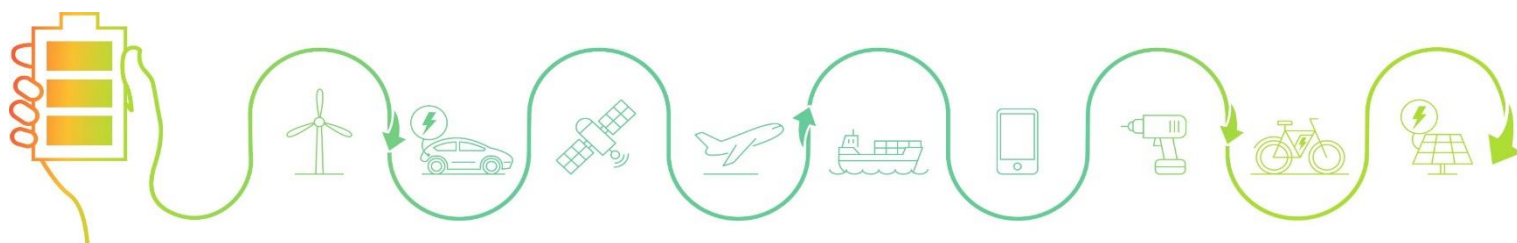
¹⁰ Wessels, C., D., Motallebi, S., (2020). Electrolyte Additives for Electrochemical Devices. Patent No.: US 10 862 168 B2. <https://app.dimensions.ai/downloads/patents?ucid=US-10862168-B2>

¹¹ Barker, J. & Heap, R., (2020). Metallate Electrodes. United States Patent. Patent No.: US 10 756 341 B2. <https://patentimages.storage.googleapis.com/4e/07/f0/c9dd46a4691e63/US10756341.pdf>

¹² Xi, X., Mitchell, P., Zhong, L. & Zou, B., (2009). Dry particles based adhesive and dry film and methods. Unites States Patent Application Publication. Publication No.: US 2009/0239127 A1 <http://pdfs.oppedahl.com/US/20090239127.pdf>

¹³ BMW Poster at IBA 2022,

Degen, F., & Kratzig, O. (2022). Future in Battery Production: An Extensive Benchmarking of Novel Production Technologies as Guidance for Decision Making in Engineering. IEEE Transactions on Engineering Management, 1–19. <https://doi.org/10.1109/TEM.2022.3144882>;



2.1.2 PTFE used in active material masses of electrode

Industry outreach has confirmed that all leading manufacturers of primary batteries based on the technologies listed in Table 1 use PTFE, or another fluoropolymer, as the binder material for the positive electrode. PTFE is used as the binder material for the positive electrode in Lithium primary batteries, it is used in 2-10% of the mass of the electrode and applied by a 'dry process', which does not require the use of solvent or water. The PTFE as a binder provide three main functions:

1. Mechanical cohesion between the positive electrode particles to enable electrode integrity during cell assembly and throughout the lifecycle of the battery storage and use,
2. Lubricant to allow the electrode particles to slide over each other during electrode formation (compression) giving uniform electrode density that is important to consistent battery performance and longevity,
3. Lower water absorption during mixing (PTFE is a hydrophobic material) and more complete drying during electrode baking - low moisture content is critical in Lithium chemistry.

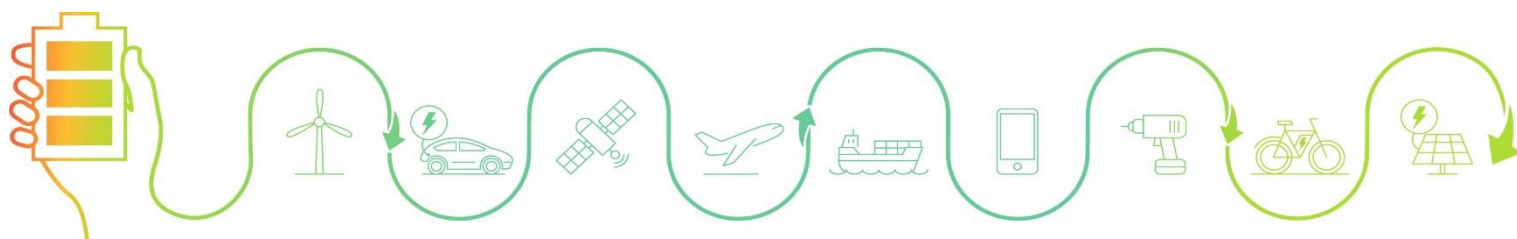
PTFE provides a unique combination of properties that are essential for the performance and durability of Lithium primary batteries.

The main PTFE properties are:

- **High chemical stability** against the solvents used in Lithium primary batteries (such as thionyl chloride, sulphur dioxide and organic solvents),
- **High electrochemical stability**, which is necessary due to the high voltages (up to 3.9V),
- **High temperature stability** to withstand the temperature necessary for drying the electrodes and provide stability in high temperature applications,
- **Good adhesion properties** to hold the active mass together in the electrode,
- **Good dispersion properties** to ensure the uniformity during the manufacturing of the electrodes,

Li, Y., Wu, Y., Wang, Z., Xu, J., Ma, T., Chen, L., Li, H., & Wu, F. (2022). Progress in solvent-free dry-film technology for batteries and supercapacitors. *Materials Today (Kidlington, England)*, 55, 92–109. <https://doi.org/10.1016/j.mattod.2022.04.008>;

Lu, Y., Zhao, C.-Z., Yuan, H., Hu, J.-K., Huang, J.-Q., & Zhang, Q. (2022). Dry electrode technology, the rising star in solid-state battery industrialization. *Matter*, 5(3), 876–898. <https://doi.org/10.1016/j.matt.2022.01.011>



- **Unique fibrillation properties**, very low concentrations are needed to hold the active mass in place without covering the active mass surface, this provides excellent porosity, which is needed for good penetration of the electrolyte,
- **Mechanical flexibility** to allow the winding of the electrode during cell assembly.

Polyvinyl alcohol (PVA, CAS 9002-89-5) or Poly(acrylic acid) (PAA, CAS 9003-01-4) may be added to the positive electrode binder material to create void volume after baking, this helps with electrolyte absorption.

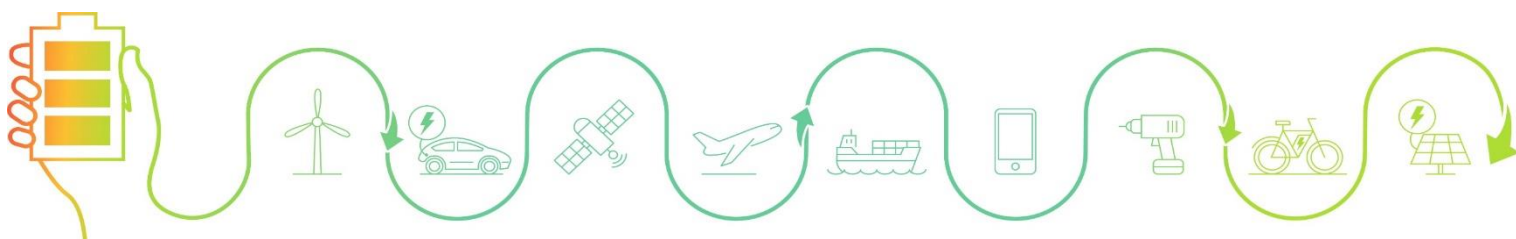
As explained in (2.1.1), PTFE is also used for Li-ion rechargeable batteries (dry process). Outside of Europe, this technology is already being commercialised. The technology holds promise to increase battery performance and durability, reduce manufacturing costs and improve the environmental footprint of cell manufacturing.

PTFE is also used as the binder material for the positive and negative electrodes in industrial stationary Ni-Cd and Ni-MH rechargeable batteries.

2.2 PFAS used in electrolytes

Different PFAS are used in the electrolytes for Lithium-ion rechargeable, Lithium primary, Lithium metal rechargeable, and Sodium-ion rechargeable batteries.

In rechargeable batteries, LiPF₆ (which is not a PFAS) has been widely used as lithium salt in standard Lithium-ion battery technologies for many years and is still dominant on the market. However, recent advances in battery technology have established the use of PFAS substances as a promising solution today, including as additives and as Lithium salt with PFAS anion. These include Lithium salts of PFAS monomers such as Li-Triflate (CAS 33454-82-9), LiTFSI (CAS 90076-65-6), LiBETI (CAS 132843-44-8), LiFAP (LiPF₃(CF₂CF₃)₃n and LiTDI (CAS 761441-54-7). Examples of PFAS additives include Tris(2,2,2-trifluoroethyl)borate (TFEB CAS 659-18-7) and Trifluorotoluene (TFT CAS No. 98-08-8). PFAS substances are also used as gelifiers for Lithium-ion polymer batteries. Sodium bis(trifluoromethylsulfonyl)imide (NaTFSI CAS 91742-21-1) may be used for Na-ion batteries.



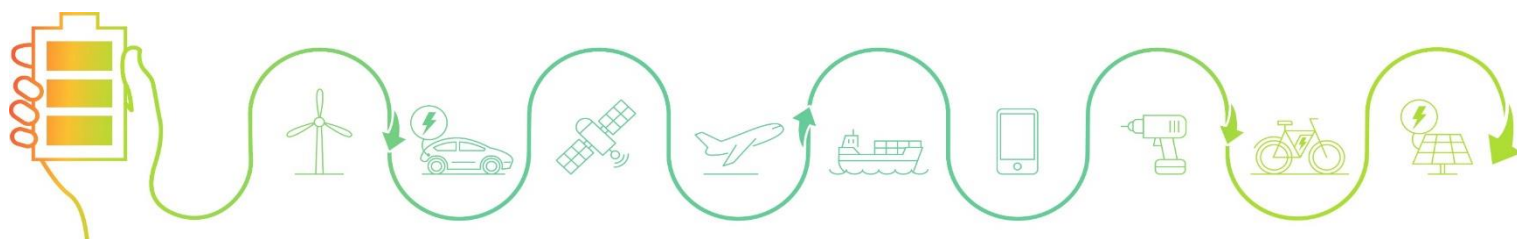
These advanced PFAS substances have properties which increase the electrolyte stability through chemical mechanisms such as capturing water and avoiding hydrogen fluoride emissions. The increased stability of the electrolyte provides significant increases in lifetime duration of the battery and battery operating temperature range. The PFAS substances will be widely used in next generation Lithium rechargeable batteries and particularly in the case of solid-state batteries.

For Lithium metal rechargeable batteries, polyfluorinated ether solvents, such as 1,1,2,2-Tetrafluoroethyl 2,2,3,3-tetrafluoropropyl ether, are essential to ensure adequate battery cycling lifetimes. This chemically inert solvent (in particular to Li metal) has unique properties that can reduce the viscosity of the cell and therefore the conductivity of the Lithium metal rechargeable batteries.

For Lithium primary batteries, the lithium manganese dioxide (Li-MnO₂) electrochemical system is widely used in coin cells and cylindrical consumer cells such as CR2 and CR123A (one of the main electrochemical systems used for Lithium primary batteries), as well as in many cylindrical Lithium primary cell types for industrial applications. Li-MnO₂ cells contain an electrolyte composed of organic solvents and a lithium salt. Lithium perchlorate (CAS 7601-90-3) has traditionally been used as the lithium salt, however lithium perchlorate has been found to act as an endocrine disruptor. Lithium perchlorate is the subject of ongoing regulatory management options analysis (RMOA) and is expected to become restricted. As a result, many manufacturers of Lithium primary batteries have already transitioned to using Li-Triflate (CAS 33454-82-9) and LiTFSI (CAS 90076-65-6) for cylindrical Li-MnO₂ cells in general, and LiBETI (CAS 132843-44-8), LiFAP (LiPF₃(CF₂CF₃)₃n and LiTDI (CAS 761441-54-7) especially for high power Lithium primary cells (similar to the substitution observed in in rechargeable Lithium-ion cells). The use of the PFAS salts instead of lithium perchlorate also provides increased stability and performance. Most importantly, it provides higher safety levels. Perchlorates in dry form are explosive materials which can explode in case of a thermal runaway of the battery or a fire.

2.3 PFAS used in valves, gaskets, washers, permeable membranes

PFAS is used in valves, gaskets, washers, and permeable membranes for Lithium-ion rechargeable, Lithium primary, solid-state batteries, Lithium metal rechargeable and Zinc air batteries.



Gasket sealings and washers, shown in Figure 4 for cylindrical cells and Figure 5 for prismatic cells¹⁴, are critical components in batteries to prevent leakage of the electrolyte from the inside and penetration of moisture from the outside. Electrolyte leakages can cause short circuits and severe safety issues.

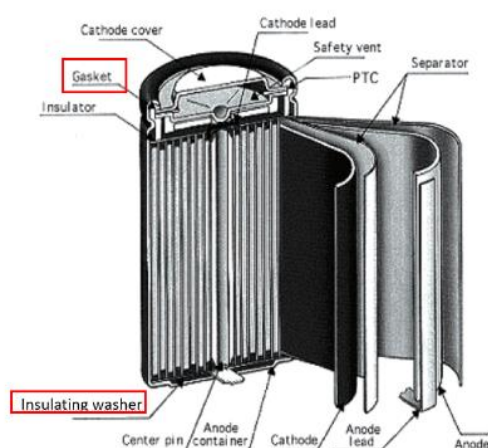


Figure 4. Gasket and washer in a cylindrical cell

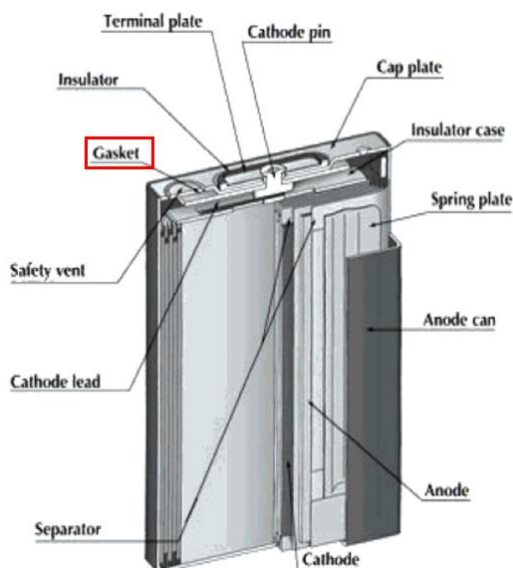
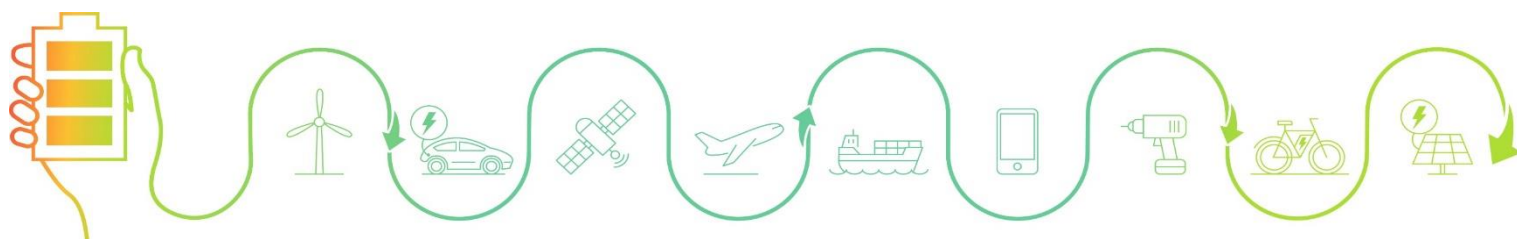


Figure 5. Gasket in a prismatic cell

¹⁴From Figures 1(c) and (d) from Arora, P., & Zhang, Z. (John). (2004). Battery Separators. *Chemical Reviews*, 104(10), 4419–4462. <https://doi.org/10.1021/cr020738u>



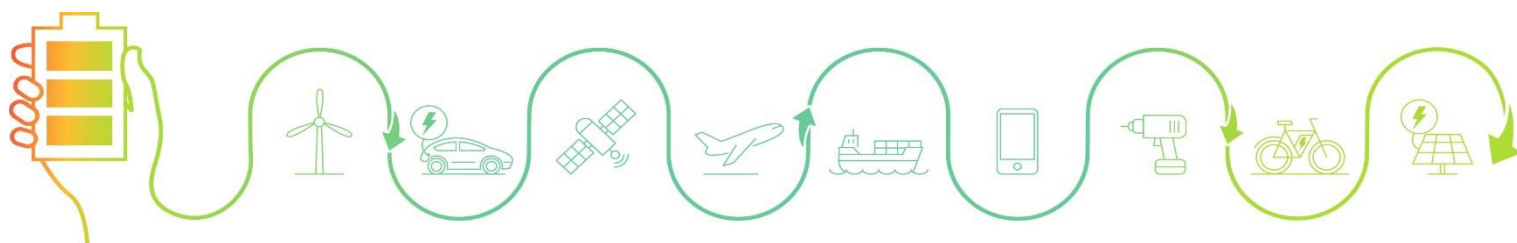
For some applications used in mild temperature ranges, non-PFAS gasket sealing materials like PBT or PEI provide an adequate sealing performance. However, in high energy density Lithium-ion rechargeable and Lithium metal rechargeable batteries (e.g., high power batteries for automotive, industrial applications and power tools) it is crucial to employ very thin high-performance gaskets with high chemical and thermal stability, and high permeation resistance. This stability for high power and high temperature cells can only be provided by PFAS-based materials such as PTFE, PFA, FEP, VDF-HFP and FKM.

A very thin permeable membrane of PTFE is used in venting valves for cell, module or battery system casing. The purpose of these venting valves is to evacuate pressure and gases associated with potential thermal runaway of a single cell or module. At the same time, due to the unique properties of PTFE, these valves prevent ingress of moisture, water, dirt and dust into the batteries which is particularly important for batteries that operate outdoors in harsh environmental conditions.

PTFE is not used for sealing gaskets in Li-MnO₂ primary Lithium batteries. However, some industrial primary Lithium batteries use Li-SOCl₂ and Li-SO₂ electrolytes which are much more aggressive materials. SOCl₂ is highly reactive and can violently release hydrochloric acid upon contact with water and alcohols. Sealing gaskets and washers for these much more aggressive materials require the use of PFAS-based materials such as FEP, PTFE, glass fiber with PTFE coating. These PFAS-based materials are critical to ensure the long lifetime of the battery, typically around 20 years. FEP is the preferred material for use in internal washers of high-power spiral primary Lithium Li-SOCl₂ batteries because it provides excellent insulating properties and prevents internal shorts, thereby ensuring safe design and operation.

PTFE glass fiber washers are also used in Li-MnO₂ and Li-SO₂ industrial batteries to increase safety, especially in high temperature applications and safety-sensitive applications such as aviation. However, it is unclear at present if it will be possible to replace PTFE with another high-temperature non-PFAS polymer in these applications.

Zinc air batteries have the highest energy density of any practical battery system and operate by allowing oxygen to access the battery and react with the zinc. The oxygen is reacted on a catalytic surface inside the cell. Air permeable PTFE membranes are necessary to allow air to enter the battery



whilst also preventing the release of the alkaline electrolyte from the battery. PTFE has unique hydrophobic properties and air permeability properties to achieve this critical function.

2.4 PFAS used in separator coatings

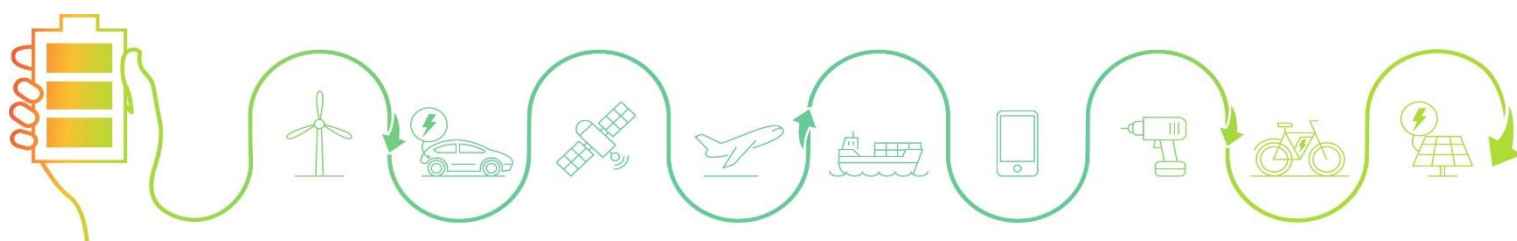
The separator is an indispensable part of batteries which separates the negative electrode from the positive electrode to prevent internal short circuits, whilst not participating in electrochemical reactions. At present, the most commonly used commercial separators are polyolefin separators, such as polypropylene (PP), polyethylene (PE) and multi-layer composite separators (PP-PE-PP)¹⁵. The layer materials are processed to make them porous by including tiny pores or voids at 35-45% porosity. The typical pore size is 200 nm - 1 μ m which is large enough for the lithium ions to move smoothly through the separator.

Commercial tri-layer PP/PE/PP separators take advantage of the difference in the melting point of PP (165°C) and PE (135°C), using PE as the shutdown layer and PP to protect structural integrity. When the cell temperature rises near the melting point of the PE layer, the PE layer will melt at a temperature of 135°C and close the pores in the separator to stop the current flow while the PP layer, which has a higher melting temperature than PE, remains solid. However, such protection is only effective below the melting point of PP.

To provide better thermal and mechanical stability, commercially available ceramic coated separators have been developed. Ceramic particles, such as alumina, silica, or zirconia can be mixed with polymeric binders and slurry-coated onto the polyolefin separators. In comparison to PP layers, ceramic coatings offer a better electrolyte wettability, which translates into better Li-ion transport through the separator and therefore a better performance of the battery. Although ceramic coatings have proven effective in improving the thermal stability of separators, the effectiveness of the protection is still limited by the thermal stability of the polymeric binder used.

Some companies use PVDF as the binder material for the ceramic coating to provide good adhesion to the electrolyte/composite electrode, as well as providing good adhesion of the ceramic coating to

¹⁵ Costa, C. M., Lee, Y. H., Kim, J. H., Lee, S. Y., & Lanceros-Méndez, S. (2019). Recent advances on separator membranes for Lithium-ion battery applications: From porous membranes to solid electrolytes. *Energy Storage Materials*, 22, 346-375. <https://doi.org/10.1016/j.ensm.2019.07.024>



the separator. The adhesion strength level to the electrolyte/composite electrode required at this time varies depending on the battery manufacturing method and application. Other companies have developed non-PFAS binders which are suitable for their own manufacturing processes. Although it may provide good level of adhesion to the separator and the electrolyte/composite electrode under the higher temperature condition they used, if the battery manufacturing process is performed at high temperature, lifespan and safety may be affected, so it cannot be considered a replacement for all applications. Whether non-PFAS materials can be used to substitute the existing PFAS materials depends on the battery production method and application.

In search of the next-generation separator technologies, some academic organisations are researching the 'new concept' of binder-free, thin-film ceramic-coated separators which aims to provide improved safety for Lithium-ion batteries. However, this technology is irrelevant to the current use of the separator binder which aims to provide adhesion to separator and electrode, as it is simply the new concept separator which does not exist today. Thus, this technology cannot be the replacement of the current use of PFAS for separator binder¹⁶.

2.5 PFAS used in solid-state batteries

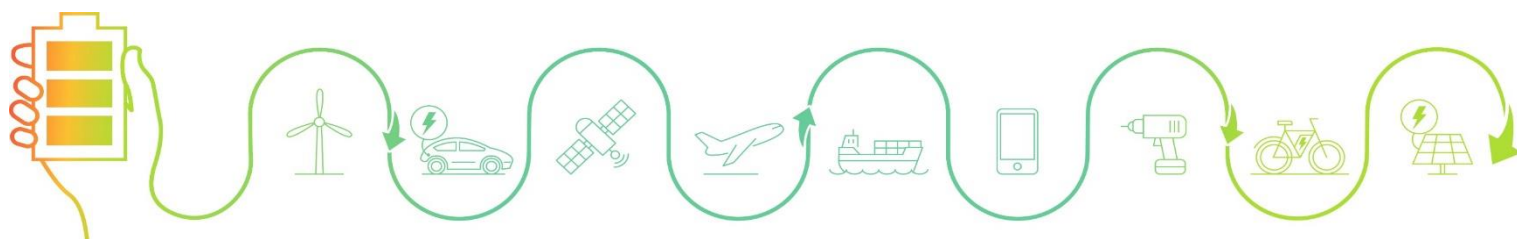
Several technical solutions are considered as fundamental to solid-state batteries, particularly for the development of solid-state electrolytes:

- a. Polymer
- b. Ceramic Sulfide
- c. Ceramic Oxide

Polymer electrolyte is used for instance in Lithium-metal-polymer (LMP) solid-state batteries and is already in production. Another solid electrolyte is based on ceramic sulfide. A third category of solid-state batteries are based on ceramic oxides. The last two are still under development at present.

As an example, the architecture of LMP batteries is illustrated in Figure 6 and is based on using

¹⁶ Gogia, A., Wang, Y., Rai, A. K., Bhattacharya, R., Subramanyam, G., & Kumar, J. (2021). Binder-Free, Thin-Film Ceramic-Coated Separators for Improved Safety of Lithium-ion Batteries. *ACS Omega*, 6(6), 4204–4211. <https://doi.org/10.1021/acsomega.0c05037>



polymers as electrolytes and managing their chemical interfaces.

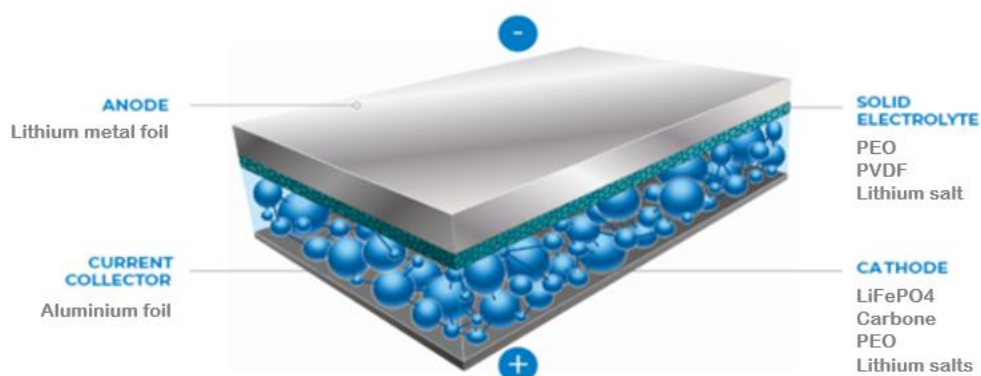


Figure 6. Schematic diagram of an LMP solid-state battery

The Lithium salt LiTFSI is used for the electrolyte and the cathode because it:

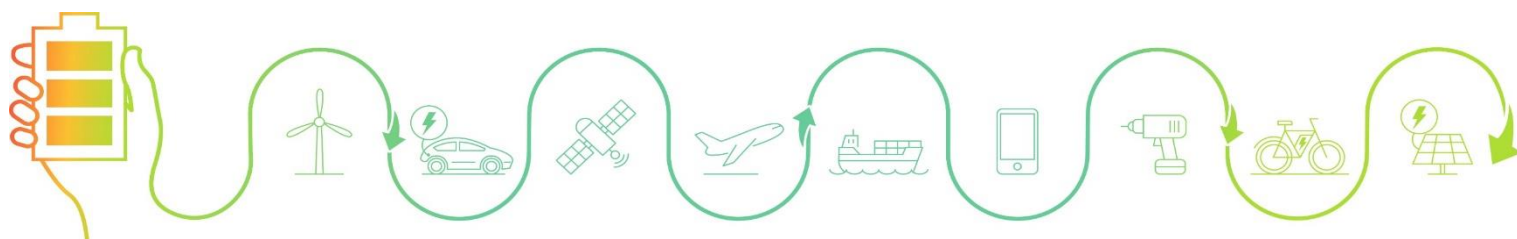
- has good conductivity allowing high power performance,
- is compatible with water (it does not hydrolyze and since there is water within the process, a salt that is stable in water is needed)
- is compatible with Lithium (also needed given the anode is Li-Metal)

PVDF and PTFE are used as a binder in the electrolyte to provide mechanical strength and to act as an interface between the electrolyte and the electrodes.

These PFAS represent less than 5% of the cell's weight, but their role is crucial for the battery. PFAS are foreseen as even more important for the next generation of solid-state batteries. TFSI will be part of the cell recipe for its superior conductivity performances. PVDF is also expected to be a key component to ensure good adhesion between the cathode and the current collector.

2.6 PFAS used in electronical/electrotechnical articles at battery system level

At battery system level, some critical components like connectors, contactors, relays, self-welder sleeves, LHD (Linear Heat Detection) cables, cable ties and vents are using PFAS (mainly PTFE, PVDF, ETFE and fluorosilicone).



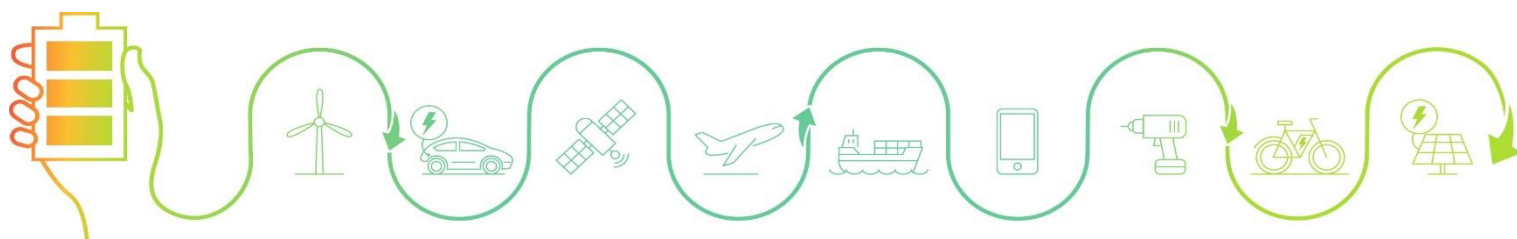
For all these components widely used in different industrial sectors, RECHARGE supports the derogation requests made by other industry sectors.

3 Missing uses – analysis of alternatives

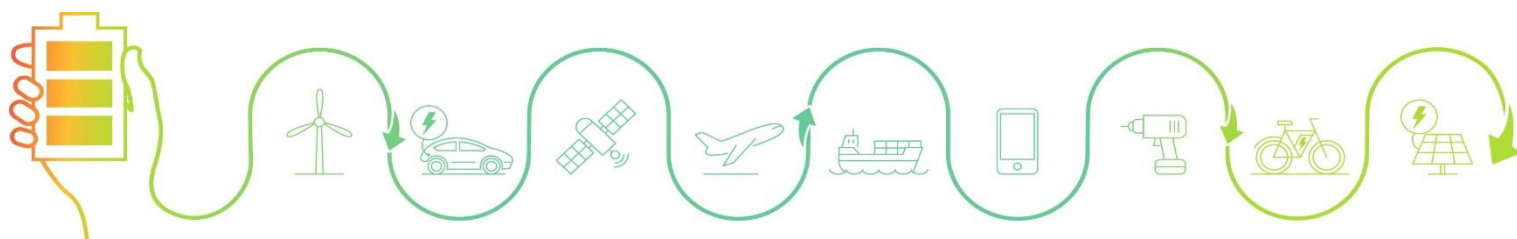
The below Table 2 summarises the availability of alternatives for various PFAS types and follows the general time periods proposed by the 5 Member State dossier submitters of 6.5 years transition period and 13.5 years derogation period for these applications. However, this does not mean that we believe the time periods proposed by the 5 Member States are sufficient.

Table 2. Summary of availability of alternatives and derogation/transition period in line with dossier submitters' proposal for various PFAS types.

PFAS type	Where used in the battery	Type of battery	Alternatives available today?	Alternatives in development?	Derogation / transition period in line with dossier submitters' proposal
PVDF	Binder in active material mass	Li-ion wet process (except for the graphite anode), Na-ion, Lithium metal rechargeable, solid-state	No	Preliminary research programmes funded by EU and Germany Govt	13.5 years with review*
PTFE	Binder in active material mass	Li-ion dry process and semi-dry process, Lithium primary, Ni-Cd, Ni-MH, Zinc oxide, Metal air, Silver oxide, Zinc-ion rechargeable, Lithium metal rechargeable, solid-state	No	No	13.5 years with review*



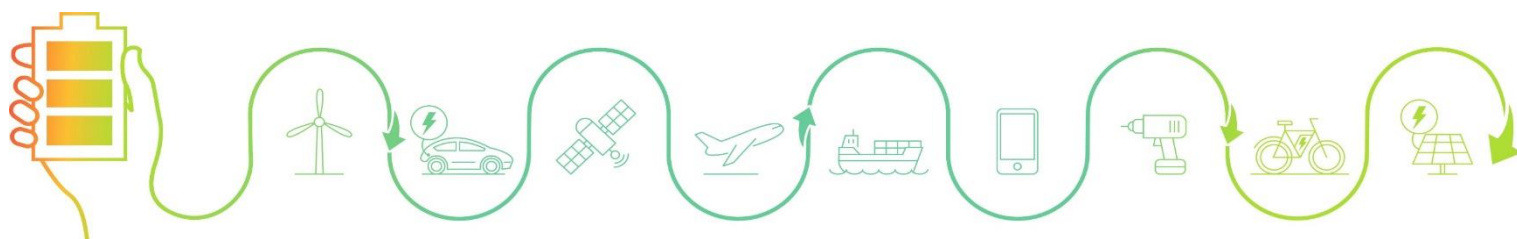
PFAS type	Where used in the battery	Type of battery	Alternatives available today?	Alternatives in development?	Derogation / transition period in line with dossier submitters' proposal
Various PFAS including LiTFSI, LiCF ₃ SO ₃ (triflate)	In electrolytes	Li-ion rechargeable, Lithium primary, Lithium metal rechargeable, Na-ion rechargeable batteries	Not for high performance/ next generation batteries	No - PFAS additives are better for safety	13.5 years with review*
PTFE, FEP	Gaskets, washers	Chemically aggressive environments where PFAS is needed for electrochemical stability such as Lithium primary batteries using Li-SO ₂ and Li-SOCl ₂	No	No	13.5 years with review*
PFA, VDF-HFP, FKM	Gaskets	High performance batteries which require very thin gaskets such as Lithium-ion rechargeable batteries, Lithium metal rechargeable batteries	No other polymers have required mechanical properties and electrical insulation properties.	No	13.5 years with review*
PTFE	Oxygen permeable membrane	PFAS hydrophobic properties are needed to facilitate air permeation and prevent alkaline electrolyte leakage in Zinc air batteries	No	No	13.5 years with review*



PFAS type	Where used in the battery	Type of battery	Alternatives available today?	Alternatives in development?	Derogation / transition period in line with dossier submitters' proposal
PVDF, PTFE	Solid electrolyte/ gel polymer electrolyte	Solid-state batteries	No	No	13.5 years with review*
PTFE, PVDF	In coatings on the separator	Li-ion rechargeable, Lithium primary	Yes	Yes	Transition period of 6.5 years with review**
PTFE, FEP, PFA, VDF-HFP, FKM	In valves, gaskets, washers	Li-ion rechargeable, Lithium primary, solid- state batteries where specific PFAS properties identified in section 3.1.4, 3.1.5 are not required	Yes	Yes	Transition period of 6.5 years with review**

***At the end of the 13.5 years derogation it may be possible that some uses could be identified for which alternatives will still not be available, or where the alternatives would be regrettable substitutions. We therefore request the European Commission should review the derogations for specific uses in the battery industry by 3 years before their expiry to assess whether alternatives are now available or whether further renewals of selected derogations for specific uses are needed and to publish amendments to the Regulation.**

****At the end of the 6.5 years transition period there may be some specific types of subcomponents where industry experience finds that it is not possible to achieve substitution within the 6.5 years and so the battery industry may need to apply for an extension to this transition period. We therefore request the European Commission should review the transition period by 3 years before its expiry to assess whether industry is on track to achieve substitution within 6.5 years or whether a further renewal of the transition period for specific types of subcomponents is needed and to publish amendments to the Regulation.**



3.1 Uses where alternatives are not available today

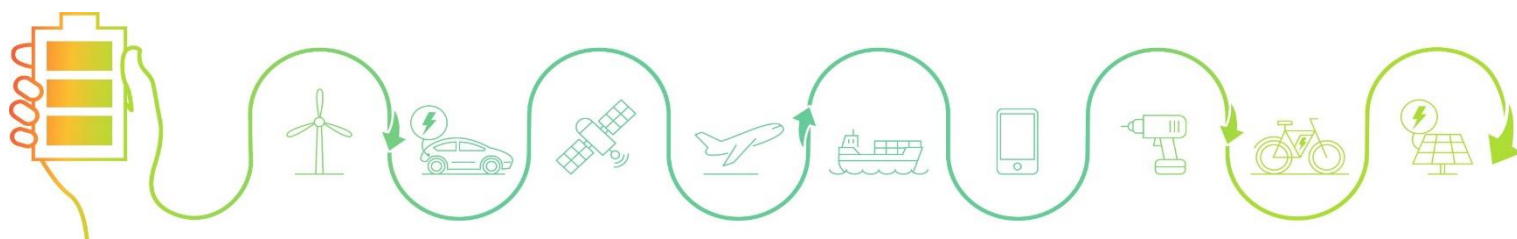
For the below uses where there are no alternatives available today, the chemicals industry will need to invest in research and development to build up the capacity and value chain for new innovative chemistries. The chemicals industry will need to make significant changes to existing research and development roadmaps which will be driven by industry demand for these new chemistries in Europe. In addition to research and development efforts, there is an immediate need for industrial investments to secure the manufacturing and the supply of chemicals to sustain the battery value chain in Europe. There is considerable uncertainty about the future of industry demand in Europe and therefore the timelines for these investments by the chemicals industry are not known.

We have followed the time periods proposed by the 5 Member States of 6.5 years transition period and 13.5 years derogation period, however this does not mean that we believe these time periods are sufficient. To align with the dossier submitters' basis for derogations, the battery industry is applying for derogation periods of at least 13.5 years for each of the below applications. **If after the end of 13.5 years there are still no alternatives for specific applications, then the battery industry will need to apply to renew the derogation period for these specific applications.**

3.1.1 Use of PVDF as the binder of the active material masses

PVDF is used as the binder material in the active masses for electrodes for Li-ion wet process (except for the graphite anode), Na-ion, Lithium metal rechargeable, and solid-state batteries. For the positive electrode, all attempts to replace PVDF binder materials with other polymers have caused cell performance and manufacturability issues. For the positive electrode, the degradation of alternative binder systems in the electrolyte has been demonstrated.

PVDF binder material is expensive (about 8-10 Euro/kg) and wet processes require the use of n-methyl-pyrrolidone (NMP) solvent (which is also expensive at about 2-6 Euro/kg) to dissolve the PVDF so that the slurry containing the binder material, active material and conductive additive can be dispersed evenly across the metal current collectors. NMP is classified in the EU as toxic to reproduction and its use is restricted under entry 71 of REACH Annex XVII. As a result, the use of NMP



requires expensive solvent extraction and recovery systems. NMP also has a high boiling point of 204°C and so the curing and drying process has a high carbon footprint.

In view of the costs of PVDF and the health and safety concerns around the use of NMP solvent, many organisations have carried out research to try to find alternatives to PVDF as a binder material and/or NMP as the solvent. New research papers and grant applications are regularly being proposed to develop alternatives to PVDF as the cathode binder and/or NMP as the solvent. We investigated all these research papers in detail and include comments on all research papers published up to August 2023 in this dossier. However, some research papers may be published after the public consultation closes in September 2023 and where we are not able to comment on them in this dossier.

The ÖkoMatBatt project¹⁷ funded under the German Federal Ministry of Education and Research is investigating possible alternatives to toxic solvents such as NMP and fluorinated binder materials in the context of battery cell production. Here, fluorine-free elastomers as well as reactive resins are analysed and further developed as new binders. These will be investigated in terms of their physical, chemical and electrochemical requirement profile. Within the project, other research topics related to binder substitution will also be explored. These include the structure-property relationship between binder and active material, wetting behaviour of the new component, processing of the reactive resins compared to commercial binders using scalable processes, and the life cycle assessment of these substitutes.

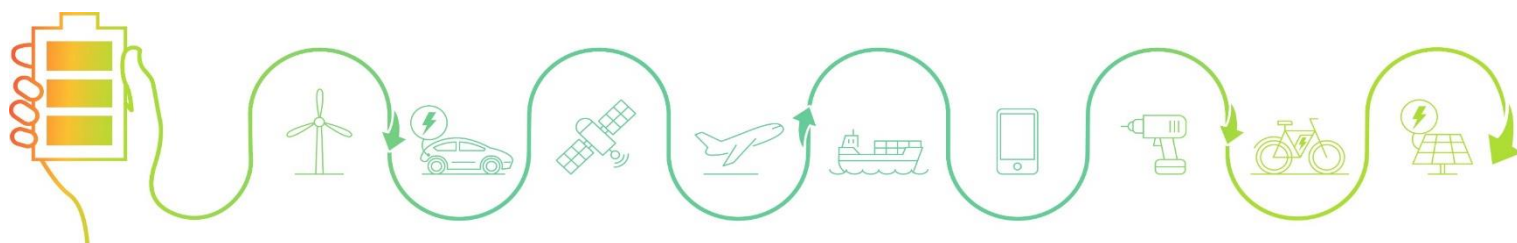
In only a few research papers^{18,19&20} as well as in ÖkoMatBatt, possible binder variations, but also binder-solvent variations are investigated as substitutes for fluorinated and toxic materials. Positive

¹⁷ The ÖkoMatBatt project is a three year project funded under the German Federal Ministry of Education and 'is concerned with the development of ecologically and economically sustainable materials for the lithium-ion battery', <https://www.tu-braunschweig.de/en/blb/research/projects/oekomatbatt>

¹⁸ Park, G., Park, Y., Park, J., & Lee, J. (2017). Flexible and wrinkle-free electrode fabricated with polyurethane binder for lithium-ion batteries. *RSC Advances*, 7(26), 16244–16252. <https://doi.org/10.1039/c7ra00800g>

¹⁹ Zhu, Z., Lu, Z., Ding, J., Yang, G., Li, W., & Ji, H. (2017). A Novel Blending Adhesive in the Fabrication of the Composite Cathode for Lithium-Ion Batteries. *ChemElectroChem*, 4(10), 2709–2716. <https://doi.org/10.1002/celec.201700283>

²⁰ Zhang, Z., Zeng, T., Lai, Y., Jia, M., & Li, J. (2014). A comparative study of different binders and their effects on electrochemical properties of LiMn2O4 cathode in lithium ion batteries. *Journal of Power Sources*, 247, 1–8. <https://doi.org/10.1016/j.jpowsour.2013.08.051>



results were only achieved with very high binder volumes^{21,22}. In other cases, only individual properties of the binders form a benefit compared to PVDF^{23,24} and often fail in adhesion, specific capacity or C-rate stability. In ÖkoMatBatt's investigations, it is evident that it is not possible to replace all the properties of PVDF right away, especially if nickel-rich cathodes are involved (such as NMC 811). A step-by-step approach to new materials is the goal. Furthermore, the process-related properties are also a very important point, which makes a short-term material change from PVDF to an alternative binder system impossible. The simple factor of slurry pH stability, for example, makes a direct implementation into the process very challenging²⁵. However, the temperature-side requirements, the drying properties of the new materials, the compatibility with different active materials, as is possible with PVDF, have not been investigated in most cases. However, ÖkoMatBatt have been able to establish, these are the properties that make a decisive difference to implementation in the industrial process.

Correspondence with the project participants show that while alternative materials might have a future in this regard, they are still at an early stage of development (with a technical readiness level (TRL) 4 (as defined by the European Commission²⁶)), as evidenced by most publications, so still require significant further research to safely establish them in the industrial process. In addition, a significant time component is required before substitute materials are validated and qualified for each application-specific battery format, as well as in the use of the corresponding application for performance, lifetime and safety. Another issue that has also not yet been clarified for alternative

²¹ Zhang, Z., Zeng, T., Qu, C., Lu, H., Jia, M., Lai, Y., & Li, J. (2012). Cycle performance improvement of LiFePO₄ cathode with polyacrylic acid as binder. *Electrochimica Acta*, 80, 440–444. <https://doi.org/10.1016/j.electacta.2012.07.054>

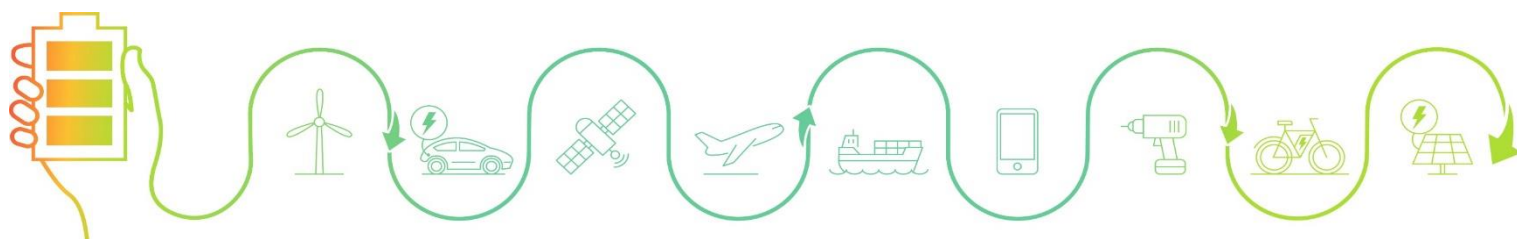
²² Chong, J., Xun, S., Zheng, H., Song, X., Liu, G., Ridgeway, P., Qiang Wang, J. & Battalia, V. S. (2001). A comparative study of polyacrylic acid and poly(vinylidene difluoride) binders for spherical natural graphite/LiFePO₄ electrodes and cells. *Journal of Power Sources*, 196(18), 7707–7714. <https://doi.org/10.1016/j.jpowsour.2011.04.043>

²³ Trivedi, S., Pamidi, V., Fichtner, M., & Anji Reddy, M. (2022). Ionically conducting inorganic binders: a paradigm shift in electrochemical energy storage. *Green Chemistry : an International Journal and Green Chemistry Resource : GC*, 24(14), 5620–5631. <https://doi.org/10.1039/d2gc01389d>

²⁴ Radloff, S., Scurtu, R.-G., Hölzle, M., & Wohlfahrt-Mehrens, M. (2022). Water-Based LiNi_{0.83}Co_{0.12}Mn_{0.05}O₂ Electrodes with Excellent Cycling Stability Fabricated Using Unconventional Binders. *Journal of the Electrochemical Society*, 169(4). <https://doi.org/10.1149/1945-7111/ac6324>

²⁵ Radloff, S., Scurtu, R.-G., Hölzle, M., & Wohlfahrt-Mehrens, M. (2021). Applying Established Water-Based Binders to Aqueous Processing of LiNi_{0.83}Co_{0.12}Mn_{0.05}O₂ Positive Electrodes. *Journal of the Electrochemical Society*, 168(10). <https://doi.org/10.1149/1945-7111/ac2861>

²⁶ https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf



materials is the accessibility and securing of the alternative raw materials that will be used as an alternative to PVDF.

Li et al (2020)²⁷ indicate that PVDF as a latex can be used as the binder for the positive electrode with water as the solvent instead of NMP. Next generation Lithium-ion battery developments are focussed on producing positive electrodes using a dry process which avoids the need for NMP solvent. This dry process will significantly reduce energy consumption and lower the environmental footprint. However, the dry process still requires the use of PTFE or PVDF as the binder material for the positive electrode.

For Lithium-ion rechargeable batteries, PVDF was previously also used as the binder material for the negative electrode as well as for the positive electrode. For graphite negative electrodes, companies have successfully substituted PVDF with water-based CMC/SBR binder materials. CMC/SBR is now the most common commercially used binder material for the graphite negative electrodes due to its good cell performance, lower cost and reduced environmental impact²⁸. For other types of negative electrodes using higher voltage materials such as Lithium titanate oxide (LTO), NTO (Niobium Titanate Oxide)²⁹ the use of PVDF binder material is required because no research on alternative non-PFAS binders has proved sufficiently conclusive for transfer to industrialization to date.

For Sodium-ion rechargeable batteries, some research is ongoing regarding non-PFAS SBR/CMC binder materials for some hard carbon/PBA cells but this research work has not yet been scaled up. PVDF is preferred with some other PBA materials³⁰ and with hard carbon³¹.

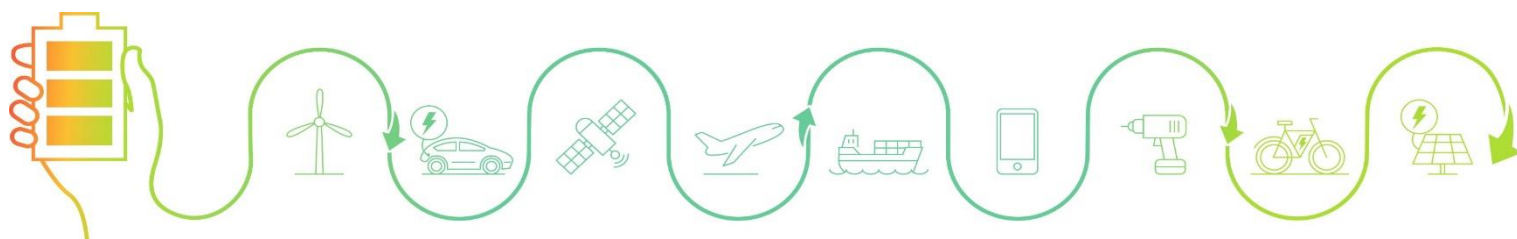
²⁷ Li, J., Lu, Y., Yang, T., Ge, D., Wood, D. L., & Li, Z. (2020). Water-Based Electrode Manufacturing and Direct Recycling of Lithium-ion Battery Electrodes—A Green and Sustainable Manufacturing System. *iScience*, 23(5), 101081–101081. <https://doi.org/10.1016/j.isci.2020.101081>

²⁸ Hawley, W. B., & Li, J. (2019). Electrode manufacturing for Lithium-ion batteries—Analysis of current and next generation processing. *Journal of Energy Storage*, 25(C), 100862–. <https://doi.org/10.1016/j.est.2019.100862>

²⁹ Next-Generation SCiB™ supporting smart mobility in the age of MaaS, Using Niobium Titanium Oxide (NTO) as a next-generation anode material. (n.d.). <https://www.global.toshiba/ww/products-solutions/battery/scib/next/nto.html>

³⁰ Wessels, C., D., Motallebi, S., (2020). Electrolyte Additives for Electrochemical Devices. Patent No.: US 10 862 168 B2. <https://app.dimensions.ai/downloads/patents?ucid=US-10862168-B2>

³¹ Barker, J. & Heap, R., (2020). Metallate Electrodes. United States Patent. Patent No.: US 10 756 341 B2. <https://patentimages.storage.googleapis.com/4e/07/f0/c9dd46a4691e63/US10756341.pdf>



The European Commission has recently funded the GIGAGREEN research project on dry alternatives and water-based binder systems for the positive electrode which propose to utilise a range of polymers including CMC/SBR, poly(acrylic acid), sodium alginate, polyurethanes and catechol-bearing polymers³². Whilst these initial research studies have indicated that these aqueous binder systems may have good adhesion properties, further research and development is required to investigate whether these alternatives have adequate chemical, mechanical, and electrical properties³³. There are significant concerns about whether water-based CMC/SBR technology will have the necessary rheology and stability to match with today's positive electrode active materials such as LCO, NMC, NCA, LNMO, LFP. There are specific concerns about the use of water in the slurry production and the electrode coating, drying and calendaring processes, particularly if the water is not completely removed before the battery is assembled.

The Germany Government has funded the DigiBatt Pro 4.0³⁴ research project which also includes development of water-based binder systems for positive electrodes. As part of this research project, positive electrodes of around 100 metres in a lab scale with roughly 1/100 to 1/50 the scale of mass production have been produced using a nickel rich NCM cathode active material, $\text{LiNi}_{0.83}\text{Co}_{0.12}\text{Mn}_{0.05}\text{O}_2$. The cells could be successfully charged and discharged 1,000 times at 25°C before they fall below 80% of initial capacity³⁵. Whilst this research project appears to show promising results for very high nickel content batteries, correspondence with the project partners highlights that:

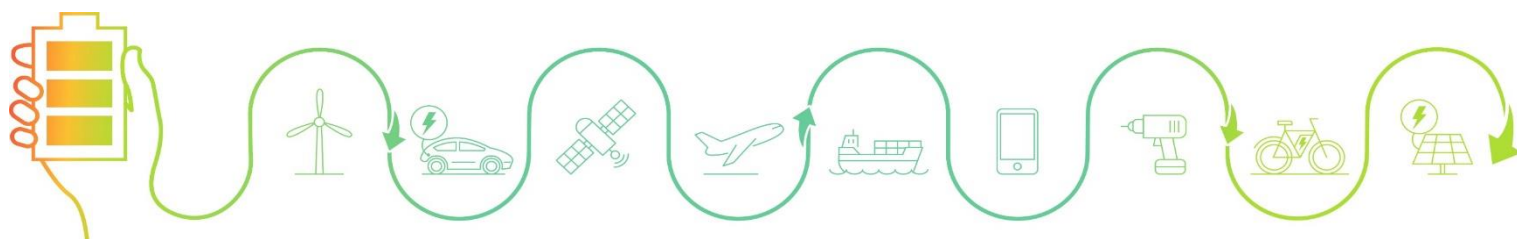
- Positive electrodes manufactured using water-based binder materials show increasing impedance/resistance with increasing numbers of charging and discharging cycles,

³² Funding & tenders, Towards the sustainable giga-factory: developing green cell manufacturing processes (GIGAGREEN). (n.d.). <https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/how-to-participate/org-details/999999999/project/101069707/program/43108390/details>

³³ 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–. <https://doi.org/10.3390/polym13040631>

³⁴ “DigiBattPro 4.0 - BW” - Digitized Battery Production 4.0 - Fraunhofer IPA. (n.d.). Fraunhofer Institute for Manufacturing Engineering and Automation IPA. https://www.ipa.fraunhofer.de/en/reference_projects/digibattpro.html

³⁵ Radloff, S., Scurtu, R.-G., Hölzle, M., & Wohlfahrt-Mehrens, M. (2021). Applying Established Water-Based Binders to Aqueous Processing of $\text{LiNi}_{0.83}\text{Co}_{0.12}\text{Mn}_{0.05}\text{O}_2$ Positive Electrodes. *Journal of the Electrochemical Society*, 168(10). <https://doi.org/10.1149/1945-7111/ac2861>



- The stability of the charging and discharging cycles is substantially lower than state-of-the-art positive electrodes using PVDF binder materials,
- The rapid increase in pH alkalinity of the water-based binder materials results in a very short shelf life for the mixed slurries, this would be very challenging for an industrial process as the mixture would go out of specification very quickly.

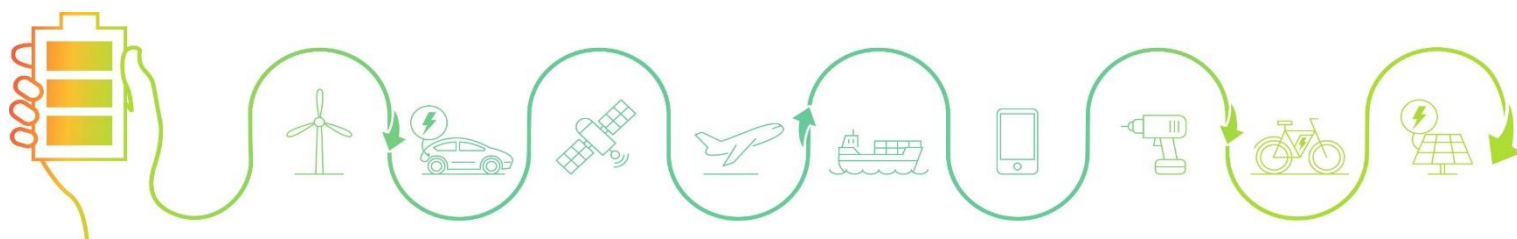
Further investigation of this research project confirms it focussed on a very specific high nickel NCM cathode active material at a moderate cell voltage of 4.2V. There is no evidence that this water-based binder material could be developed to meet the performance targets for positive electrodes with LCO chemistries operated at higher voltages, which is what many electronic devices use today.

It is also important to note that this research project focussed on a very specific cylindrical 21700 cell form factor used in certain automotive and power tool applications³⁶. Performance in this specific form factor is not directly transferrable to other cell form factors used in other applications. There are many unknowns which would need to be investigated before this technology could be adopted in other chemistries and other form factors, including:

- cycle life and calendar life and impedance growth under wide range of temperatures
- swelling, fast charge cycling is unknown,
- electrode processibility for multilayer pouch cells and uniformity of coating is unknown,
- correspondence with the project partners highlighted that the positive electrodes manufactured using water-based binder materials show higher cell resistance and faster growth in resistance with increasing numbers of charging and discharging cycles with the high nickel NCM cathode active material. This trend is anticipated to become worse when industry moves to cathode active material operating at higher voltage, higher energy and higher power.

Several other research laboratories have reported developments in water-based binder systems for positive electrodes using other polymer materials in limited applications on the lab scale with simple coin cell batteries, but none of these efforts have successfully been scaled up to perform for industry

³⁶ Radloff, S., Carbonari, G., Scurtu, R.-G., Hölzle, M., & Wohlfahrt-Mehrens, M. (2023). Fluorine-free water-based Ni-rich positive electrodes and their performance in pouch- and 21700-type cells. *Journal of Power Sources*, 553, 232253–. <https://doi.org/10.1016/j.jpowsour.2022.232253>



relevant chemistries, cell configurations and production volumes. For example, Lawrence Berkeley National Laboratory reports they have tested polyacrylic acid (PAA) with the cross-linking agent polyethylenimine (PEI) as the binder for sulphur cathodes for Lithium Sulphur coin cells operating between 1.5V and 2.8V for 100-200 cycles³⁷. In contrast, Lithium-ion batteries have a cathode voltage of 4.2V or more, and so these PAA/PEI based batteries would have very limited applications in commercial usage.

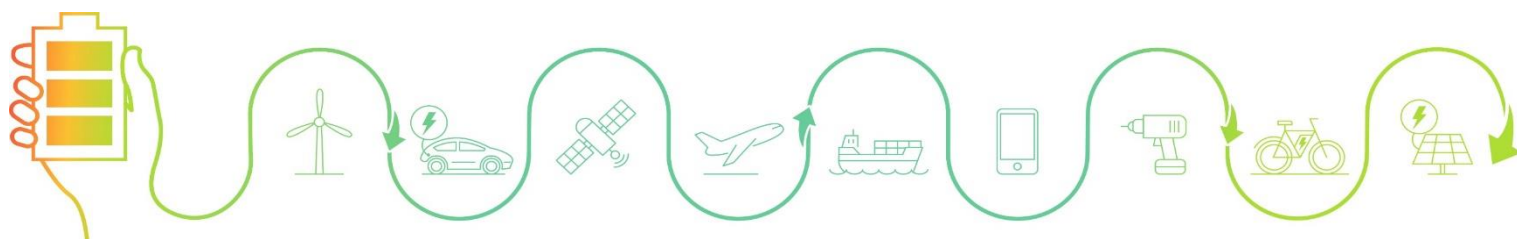
No information is provided on performance in larger cells or industry scale applications. Furthermore, industry relevant chemistries such as LCO and NMC have high pH when dispersing in water and this may not be compatible with the binding function of this PAA/PEI binder.

Furthermore, replacing the PVDF cathode binder likely requires the development of new cathode active material and Aluminium current collectors that are compatible with a new binder and solvent system. Water is known to cause poor cycle life and increased impedance growth in Lithium-ion cells. A new grade of active cathode powder may need to be developed to increase particle surface protection against water.

Replacing the PVDF cathode binder with new binder and solvent also requires development of a compatible electrode and cell manufacturing process and equipment. The necessary process and equipment change at mass production scale is unknown at this point and will be different for different companies depending on which alternative technology they pursue. The performance of mass production line produced PVDF free battery may have significant performance gaps compared with current batteries. Addressing these performance gaps may require a significant number of iterations of materials improvement, production process change and cell performance testing.

Given the above, we estimate that efforts to develop and commercialise high performance non-PFAS cathode binder, Al foil, active materials and corresponding cell manufacturing processes would take longer than the dossier submitters' proposed basis for derogations.

³⁷ Liu, Z., He, X., Fang, C., Camacho-Forero, L. E., Zhao, Y., Fu, Y., Feng, J., Kostecki, R., Balbuena, P. B., Zhang, J., Lei, J., & Liu, G. (2020). Reversible Crosslinked Polymer Binder for Recyclable Lithium Sulfur Batteries with High Performance. *Advanced Functional Materials*, 30(36), 2003605–n/a. <https://doi.org/10.1002/adfm.202003605>



3.1.2 Use of PTFE as the binder of the active material masses

PTFE is used as the binder material in the active masses for electrodes for Li-ion dry process and semi-dry process, Li primary, Ni-Cd, Ni-MH, Zinc oxide, metal air, Silver oxide, Zinc-ion rechargeable, Lithium metal rechargeable and solid-state batteries.

There are currently no alternatives to PTFE due its unique combination of properties that are essential for the performance and durability of these batteries, especially for the:

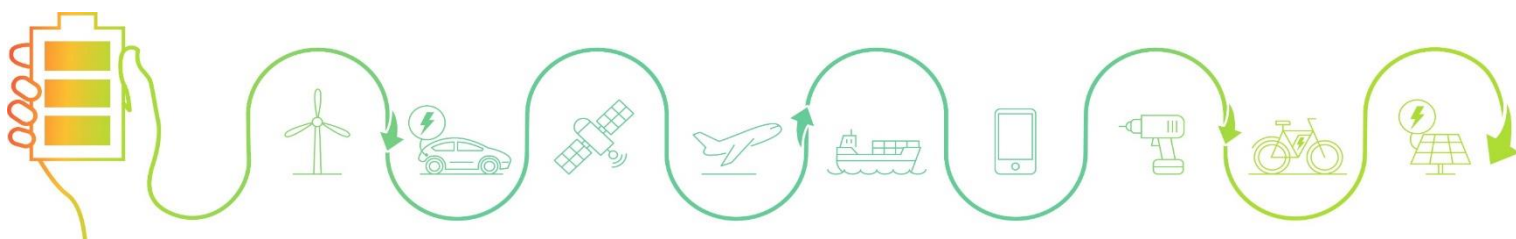
- **fibrillation properties**, which produce an excellent mechanical electrode surface without covering the surface of the active material,
- **chemical properties**, including chemical stability in very aggressive environments,
- **hydrophobic properties**.

Alternative non-PFAS materials such as Polyvinyl alcohol (PVA, CAS 9002-89-5) and Poly(acrylic acid) (PAA, CAS 9003-01-4) have been tested as potential binder materials for the positive electrode and have been found to fail due to performance and manufacturability issues. The degradation of these alternative binder systems in the electrolyte has been demonstrated.

No research has been concluded on whether some of non-PFAS alternatives that are being investigated as potential replacements for PVDF as binders in Lithium-ion rechargeable batteries (see 3.1.1) may also be applicable to Lithium primary batteries. As a consequence, the timescale needed to investigate, develop and qualify alternatives for PTFE binder of the active material mass for Lithium primary batteries would be even longer than in the case of Lithium-ion rechargeable batteries.

3.1.3 Use of PFAS in electrolytes

Various PFAS substances are used in electrolytes for both established and new battery technologies under development in areas such as Lithium-ion rechargeable, Lithium primary, secondary Lithium metal, and Sodium-ion rechargeable batteries. PFAS substances are utilised as salts (either as a major



component or as an additive), electrolytes solvents or as electrolyte additives. These substances improve the performance, efficiency, safety and lifetime of a battery³⁸.

LiPF₆ (which is not a PFAS) has been widely used as a major salt in standard Li-ion battery technologies for many years and is still dominant on the market. However, LiPF₆ has been found to cause degradation in Li-ion cells, primarily from its thermal decomposition or hydrolysis to form acidic species^{39,40}. This breakdown of the LiPF₆ salt has been attributed as the cause of capacity fade in Lithium-ion cells, to address this manufacturers impose voltage and state of charge (SOC) limits that compromise capacity. This means more cells are required for a given device performance. Recent advances in battery technology have shown that PFAS based lithium salts such LiTFSI (CAS 90076-65-6), can provide greater thermal and chemical stability and increased performance compared to LiPF₆ based electrolytes⁴¹. Additionally, the inclusion of a small amount of a PFAS based lithium salt as an additive can significantly improve the performance of LiPF₆ systems. Lithium salts of PFAS anions such as LiTFSI, and LiTDI (CAS 761441-54-7)⁴² can be used as additives to significantly improve the performance and stability of LiPF₆ based electrolytes. In one specific study LiPF₆ was tested with 2wt% LiTFSI additive, a capacity fade of only 2% was observed after 600 cycles, compared to 20% capacity loss for the analogue without the PFAS salt⁴³. The addition of fluorinated PFAS additives and solvents has also been shown to introduce flame-retardancy to the combustible electrolyte, making Lithium-

³⁸ Xu, N., Shi, J., Liu, G., Yang, X., Zheng, J., Zhang, Z., & Yang, Y. (2021). Research progress of fluorine-containing electrolyte additives for lithium ion batteries. *Journal of Power Sources Advances*, 7, 100043–. <https://doi.org/10.1016/j.powera.2020.100043>

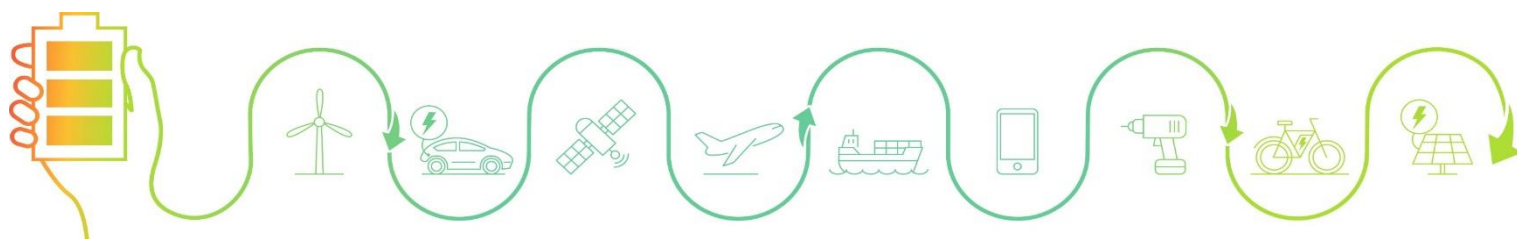
³⁹ Dahbi, M., Violleau, D., Ghamouss, F., Jacquemin, J., Tran-Van, F., Lemordant, D., & Anouti, M. (2012). Interfacial Properties of LiTFSI and LiPF₆-Based Electrolytes in Binary and Ternary Mixtures of Alkylcarbonates on Graphite Electrodes and Celgard Separator. *Industrial & Engineering Chemistry Research*, 51(14), 5240–5245. <https://doi.org/10.1021/ie203066x>

⁴⁰ Zinigrad, E., Larush-Asraf, L., Gnanaraj, J. S., Sprecher, M., & Aurbach, D. (2005). On the thermal stability of LiPF₆. *Thermochimica Acta*, 438(1-2), 184–191. <https://doi.org/10.1016/j.tca.2005.09.006>

⁴¹ Dahbi, M., Ghamouss, F., Tran-Van, F., Lemordant, D., & Anouti, M. (2011). Comparative study of EC/DMC LiTFSI and LiPF₆ electrolytes for electrochemical storage. *Journal of Power Sources*, 196(22), 9743–9750. <https://doi.org/10.1016/j.jpowsour.2011.07.071>

⁴² Xu, C., Hernández, G., Abbrent, S., Kobera, L., Konefal, R., Brus, J., Edström, K., Brandell, D., & Mindemark, J. (2019). Unraveling and Mitigating the Storage Instability of Fluoroethylene Carbonate-Containing LiPF₆ Electrolytes To Stabilize Lithium Metal Anodes for High-Temperature Rechargeable Batteries. *ACS Applied Energy Materials*, 2(7), 4925–4935. <https://doi.org/10.1021/acsaem.9b00607>

⁴³ Sharova, V., Moretti, A., Diemant, T., Varzi, A., Behm, R. J., & Passerini, S. (2018). Comparative study of imide-based Li salts as electrolyte additives for Li-ion batteries. *Journal of Power Sources*, 375, 43–52. <https://doi.org/10.1016/j.jpowsour.2017.11.045>



ion batteries safer and enabling the safer use of high voltage Lithium batteries⁴⁴. This stability is provided by the high strength of the carbon-fluorine bond in the PFAS which is not present in the non-PFAS electrolytes. This is a critical factor when considering the blanket banning of PFAS materials – fundamental stability is an attractive attribute when considering safety and lifetime of batteries. The inclusion of PFAS substances results in the socio-economic benefits of improved battery safety and prolonged battery life and therefore a reduction in waste and a reduction in the demand for critical raw materials.

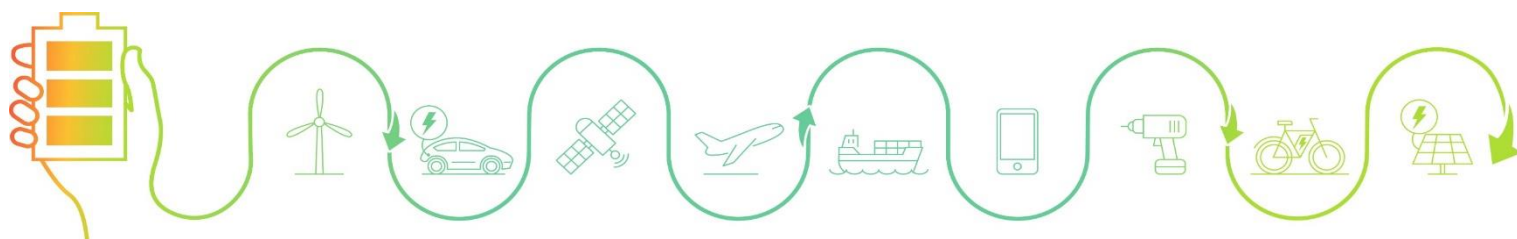
In Li-ion and Na-ion rechargeable batteries, Lithium salts of PFAS monomers such as LiTFSI (CAS 90076-65-6), NaTFSI (CAS 91742-21-1), LiBETI (CAS 132843-44-8) and LiFAP (LiPF₃(CF₂CF₃)₃n) may be used to provide stability, performance and higher safety levels. There are no non-PFAS alternatives available today which provide similar stability, performance and safety levels. We estimate that research and development efforts to identify non-PFAS alternatives would take longer than the dossier submitters' proposed basis for derogations.

PFAS compounds will likely play an important role in enabling next generation battery technologies such as lithium metal and high voltage batteries that will drive improvements in cell efficiency, energy density and sustainability⁴⁵. Polyfluorinated ether, ester and carbonate solvents, such as 1,1,2,2-tetrafluoroethyl 2,2,3,3-tetrafluoropropyl ether or 3,3,3-trifluoropropylene carbonate, are essential to ensure adequate battery cycling rates and lifetimes. These chemically inert solvents (in particular, inert to Li metal) have unique properties that can reduce the viscosity of the cell and therefore improve the conductivity of the rechargeable batteries. They are also able to form stable interfaces against negative electrodes, whilst withstanding oxidation at high voltages⁴⁶. PFAS solvents significantly improve battery safety by reducing the electrolyte flammability and by acting as flame-

⁴⁴ Dagger, T., Rad, B. R., Schappacher, F. M., & Winter, M. (2018). Comparative Performance Evaluation of Flame Retardant Additives for Lithium Ion Batteries – I. Safety, Chemical and Electrochemical Stabilities. *Energy Technology (Weinheim, Germany)*, 6(10), 2011–2022. <https://doi.org/10.1002/ente.201800132>

⁴⁵ Fan, X., Ji, X., Chen, L., Chen, J., Deng, T., Han, F., Yue, J., Piao, N., Wang, R., Zhou, X., Xiao, X., Chen, L., & Wang, C. (2019). All-temperature batteries enabled by fluorinated electrolytes with non-polar solvents. *Nature Energy*, 4(10), 882–890. <https://doi.org/10.1038/s41560-019-0474-3>

⁴⁶ Yang, J., Liu, Q., Pupek, K. Z., Dzwiniel, T. L., Dietz Rago, N. L., Cao, J., Dandu, N., Curtiss, L., Liu, K., Liao, C., & Zhang, Z. (2021). Molecular Engineering to Enable High-Voltage Lithium-Ion Battery: From Propylene Carbonate to Trifluoropropylene Carbonate. *ACS Energy Letters*, 6(2), 371–378. <https://doi.org/10.1021/acsenenergylett.0c02400>



retardants. Improving battery safety protects personal users and property and is of great importance to the industry⁴⁷. Non-fluorinated solvents can be used in combination with fluorinated ones, but not as a complete replacement primarily due to their lower chemical stability in conjunction with a metal Lithium electrode or a high voltage cathode⁴⁸. There are no non-PFAS alternatives available for the promising family of lithium metal with polymer electrolytes today.

Cathode active materials with reduced Co and Ni have been shown to operate at higher voltages, therefore requiring increased levels of chemical stability. PFAS materials provide this stability in the electrolyte, thus enabling these active materials⁴⁹. If these PFAS electrolyte components are banned this may have the unforeseen consequence of prolonging use of Cobalt and Nickel in the battery market.

In the field of Lithium primary batteries, lithium triflate (lithium trifluoromethanesulfonate, CAS 33454-82-9) is a PFAS substance that has become the industry standard as lithium salt in the electrolyte of lithium manganese dioxide (Li-MnO₂) batteries, which are widely used in industrial applications as well as consumer products. It replaces lithium perchlorate, which has traditionally been used in Li-MnO₂ batteries, but is considered to be less safe especially in large Li-MnO₂ batteries, because it behaves as an explosive when heated as a solid⁵⁰. The replacement of lithium perchlorate by lithium triflate was further promoted since perchlorates were found to act as endocrine disruptor in the environment⁵¹. Non-PFAS alternatives for lithium perchlorate are currently not known (the use of LiBF₄ was evaluated but found non-conclusive due to lithium metal passivation issues) and have to be newly developed and qualified.

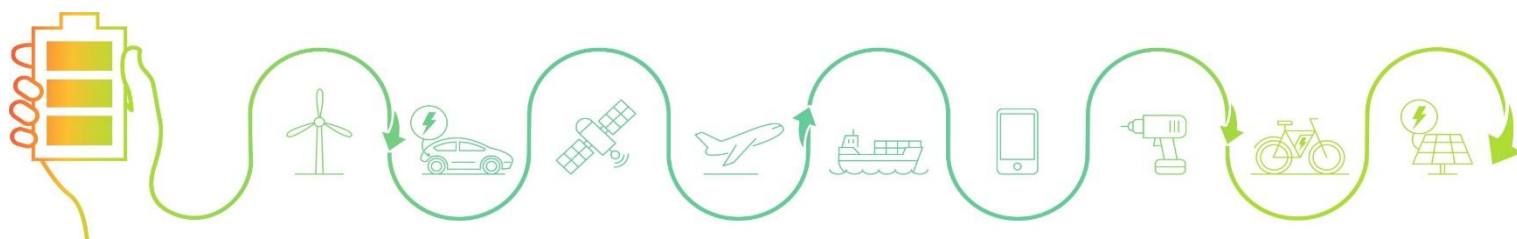
⁴⁷ Xu, N., Shi, J., Liu, G., Yang, X., Zheng, J., Zhang, Z., & Yang, Y. (2021). Research progress of fluorine-containing electrolyte additives for lithium ion batteries. *Journal of Power Sources Advances*, 7, 100043–. <https://doi.org/10.1016/j.powera.2020.100043>

⁴⁸ Huang, W., Xing, L., Wang, Y., Xu, M., Li, W., Xie, F., & Xia, S. (2014). 4-(Trifluoromethyl)-benzonitrile: A novel electrolyte additive for lithium nickel manganese oxide cathode of high voltage lithium ion battery. *Journal of Power Sources*, 267, 560–565. <https://doi.org/10.1016/j.jpowsour.2014.05.124>

⁴⁹ Fan, X., Chen, L., Borodin, O., Ji, X., Chen, J., Hou, S., Deng, T., Zheng, J., Yang, C., Liou, S.-C., Amine, K., Xu, K., & Wang, C. (2018). Non-flammable electrolyte enables Li-metal batteries with aggressive cathode chemistries. *Nature Nanotechnology*, 13(8), 715–722. <https://doi.org/10.1038/s41565-018-0183-2>

⁵⁰ Sedlářiková, M., Vondrák, J., Musil, M., Mathieisová, H., & Libich, J. (2013). Explosivity of lithium perchlorate in gel polymer electrolytes. *Polymer Composites*, 34(11), 1970–1974. <https://doi.org/10.1002/pc.22604>

⁵¹ RMOA on perchloric acid and its salts, first published 15 October 2018. <https://echa.europa.eu/assessment-regulatory-needs/-/dislist/details/0b0236e180c691ac>



We estimate that research and development efforts to identify non-PFAS alternatives for electrolytes would take longer than the dossier submitters' proposed basis for derogations.

3.1.4 Use of PTFE & FEP in gaskets & washers (and in battery equipment) in chemically aggressive environments

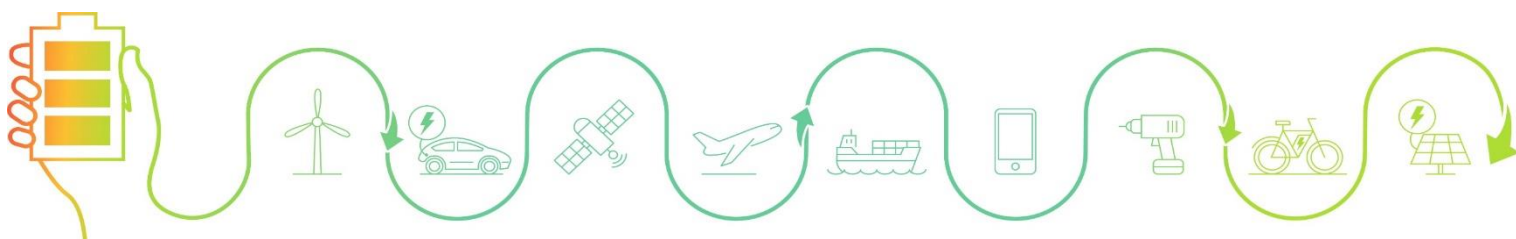
There are no alternatives to use of PTFE and FEP in gaskets and washers used in chemically aggressive environments such as the SO₂ and SOCl₂ substances used in electrolytes in primary Lithium batteries. SO₂ and SOCl₂ are very powerful oxidising agents which degrade almost all polymer types except PFAS materials. Degradation of the gasket and washer would result loss of battery component properties and release of the electrolyte. These primary industrial batteries using these electrolytes are required to operate for 20 years, significant research and development efforts will be needed to identify suitable alternatives which can provide the needed safety and long-term performance.

Polyimidazoles and fully chlorinated PVC may be some potential non-PFAS alternatives which may provide sufficient chemical stability against thionyl chloride in some applications. Thick bound fiberglass materials may also provide possible solutions. However, for chemically aggressive environments, more research on alternative materials is needed before the testing and final qualification can start. To align with the dossier submitters' basis for derogations, the battery industry is applying for at least a 13.5 year derogation with a review clause if no alternatives are available after 13.5 years.

In addition, some battery manufacturing equipment like mixers, pipes, coaters are also exposed to extreme conditions (high or low temperatures, high frictional resistance, aggressive/corrosive/toxic chemical conditions or a combination of these). The use of PFAS containing gaskets, hoses, wires, valves and coatings is of high relevance for these battery manufacturing equipment industry.

RECHARGE supports the contribution submitted by the VDMA⁵² to the ECHA PFAS restriction proposal consultation. The VDMA is the largest network organisation and an important voice for the machinery

⁵² VDMA ECHA Consultation feedback reference number 4471 (doc 20).
<https://echa.europa.eu/documents/10162/f4521406-a1ef-d406-3834-42af5b6d5f5c>



and equipment manufacturing industry in Germany and Europe. RECHARGE supports also the contribution of one of its members regarding the need of PFAS for battery manufacturing equipment⁵³.

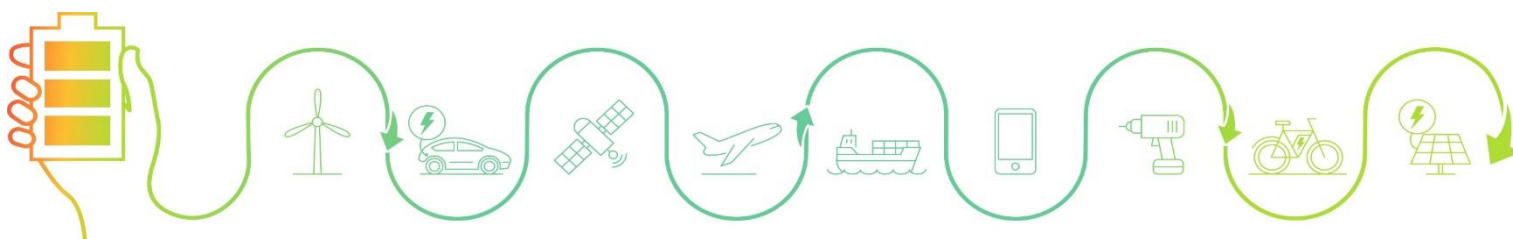
3.1.5 Use of PFA, VDF-HFP, FKM in gaskets in high performance batteries which require very thin high performance gaskets

There are no alternatives to use of PFA, VDF-HFP, FKM in gaskets in high performance Lithium-ion rechargeable and Lithium metal rechargeable batteries (e.g., high power batteries for automotive, industrial applications and power tools) which require very thin and thermally robust gaskets for safety reasons. These gaskets are critical to the functioning of current interrupt devices which are essential to ensure the safe use of high performance batteries. Attempting to use non-PFAS materials available today to manufacture these gaskets will result in the battery failing safety testing standards and risking that the battery catches fire or explodes during use.

Rechargeable high performance batteries are characterized by a high energy density in combination with low internal resistance and minimised diffusion path lengths for ion transfer. This design allows to draw high power up to 1.8kW. For example, such batteries are essential for the construction industry to run demanding applications like saws and impact drills in places where there is no electricity available. To ensure that high performance batteries can be handled by users safely and to meet the requirements set by European legislation like the Machinery Directive the batteries are undergoing extensive safety testing and certification for use, as well as for transport. Industry standards like the “Manual of Tests and Criteria” of the United Nations or the IEC 62841 standard describe clear testing procedures comprising short-circuit tests, over charging and over discharging tests and many more. Responsible manufacturers also use the internationally recognized testing procedures according to IEC 62133 standard to ensure the battery safety itself. Such safety requirements are specified both for product (battery) and component (cell) level.

During every current driven safety related event, such as short circuit or over charging, both the temperature and cell internal pressure are increased at the same time causing in worst case a fire or

⁵³ Northvolt ECHA Consultation feedback reference number 6133 (doc 30).



explosion of the battery. To prevent such safety issues cylindrical cells are equipped with a special current interrupt device [CID]. Here, the top cap is designed in a way that in case of overpressure the electrical connection inside the cell to the cell chemistry is mechanically and irreversibly disconnected. The cell remains intact and does not release any liquids, gases or eject any solid material. By interrupting the current flow, a further temperature increase can be prevented. An essential part of every CID is the so called “CID gasket” (see Figure 7). A melting of the CID gasket during any safety related event would lead to an electrical bypass and in consequence to a malfunction of the CID. Therefore, it is critical to ensure the usage of thermally robust CID gasket materials. The only gasket materials proven to provide adequate thermal stability for reliable operation of the CID are PFA, VDF-HFP, FKM. Other materials like PBT or PEI have shown decomposition, shrinkage or other loss of sealing performance when being subjected to such harsh testing conditions.

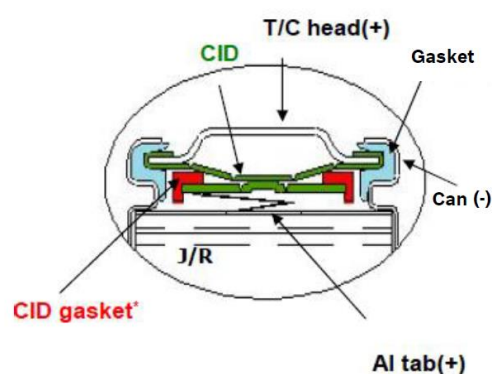
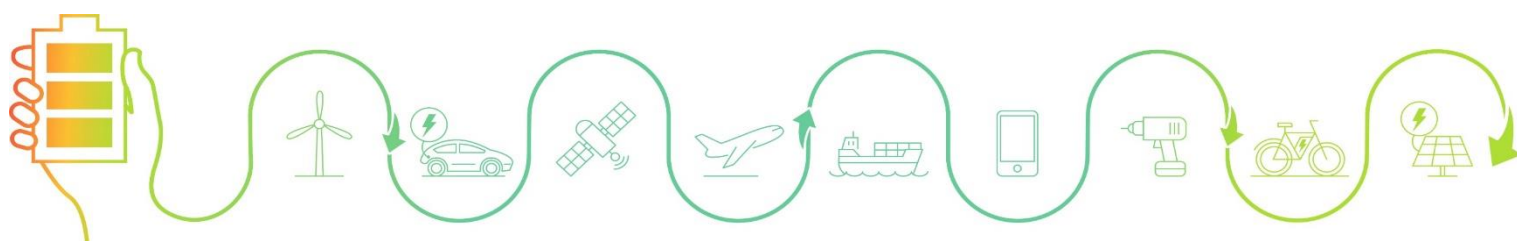


Figure 7. Schematic assembly of the current interrupt device for cylindrical battery cells⁵⁴

For a deeper insight into the sealing application described, please refer to Figure 8. In cases where internal heating due to high current or temporary short circuit occurs in the cells, materials like PFA, VDF-HFP, FKM still provide sufficient compression set to seal the cavity⁵⁵.

⁵⁴ Li, W., Crompton, K. R., Hacker, C., & Ostaneck, J. K. (2020). Comparison of Current Interrupt Device and Vent Design for 18650 Format Lithium-ion Battery Caps. *Journal of Energy Storage*, 32, 101890–. <https://doi.org/10.1016/j.est.2020.101890>

⁵⁵ Liu, J., Aoyama, T., Tsuda, H. & Sukegawa, M. (2019). Long-term Reliability Evaluation of Fluororesin Gasket for Electrode of Automotive Lithium-ion Battery Using Simulation, *VIII International Conference on Computational Methods for Coupled Problems in Science and Engineering*. https://upcommons.upc.edu/bitstream/handle/2117/190005/Coupled_2019-24-Long-term%20reliability%20evaluation.pdf



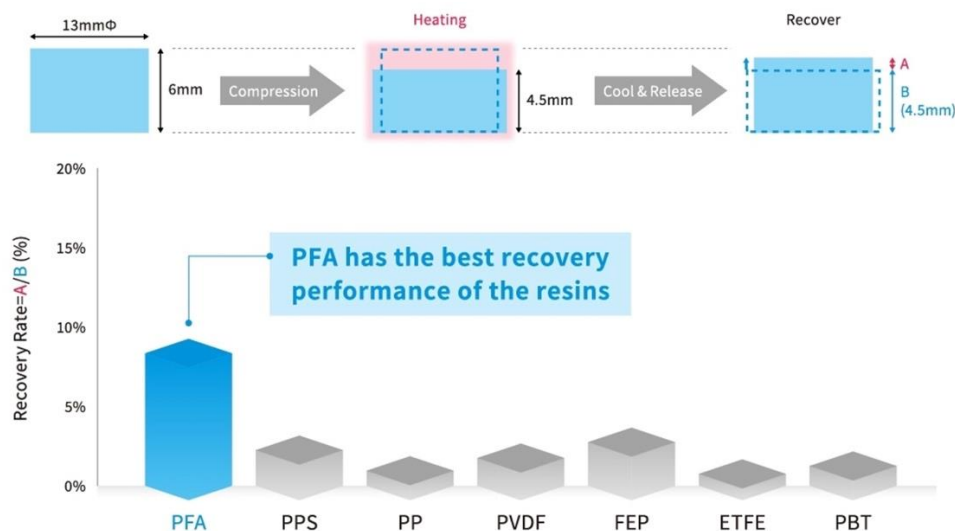


Figure 8. Compressive properties of polymer resins⁵⁶

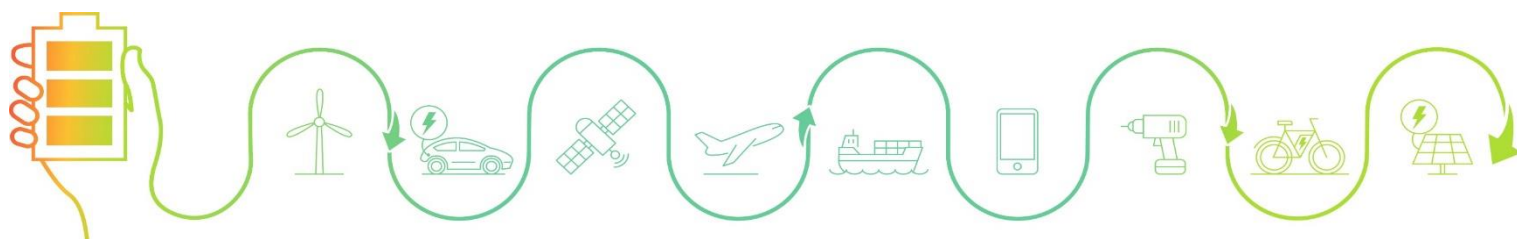
It will take significant time and effort for industry to carry out the necessary research and development to identify potential alternative materials that may be able to be developed to meet these demanding safety requirements. Extensive safety testing of the potential new gasket material at the component (cell) and product (battery) level will be needed to investigate whether it can be used instead of PFAS in manufacture these safety-critical gaskets. We estimate that research and development efforts to identify non-PFAS alternatives would take longer than the dossier submitters' proposed basis for derogations.

3.1.6 Use of PTFE in oxygen permeable membranes in Zinc air batteries

There are no known alternatives for use of PTFE in oxygen permeable membranes in Zinc air batteries or other types of alkaline metal-air batteries.

Zinc air batteries operate by allowing oxygen to access the battery and react with the zinc. The oxygen is reacted on a catalytic surface inside the cell. Air permeable PTFE membranes are necessary to allow air to enter the battery whilst also preventing the release of the alkaline electrolyte from the battery.

⁵⁶ Gasket Materials – Fluoropolymer NEOFLON PFA, Battery Materials (n.d.). Daikin Global. <https://www.daikinchemicals.com/solutions/products/battery-materials.html#anchor04>



PTFE has unique hydrophobic properties and air permeability properties which allow gas molecules to pass through the membrane whilst at the same time preventing the release of the alkaline electrolyte. Extensive research would be needed to find alternatives. To align with the dossier submitters' basis for derogations, the battery industry is applying for at least a 13.5 year derogation for this application with a review clause if alternatives are not available when this derogation approaches expiry.

3.1.7 Use of PTFE / PVDF in solid electrolyte / gel polymer electrolytes in solid-state batteries and future cell technology

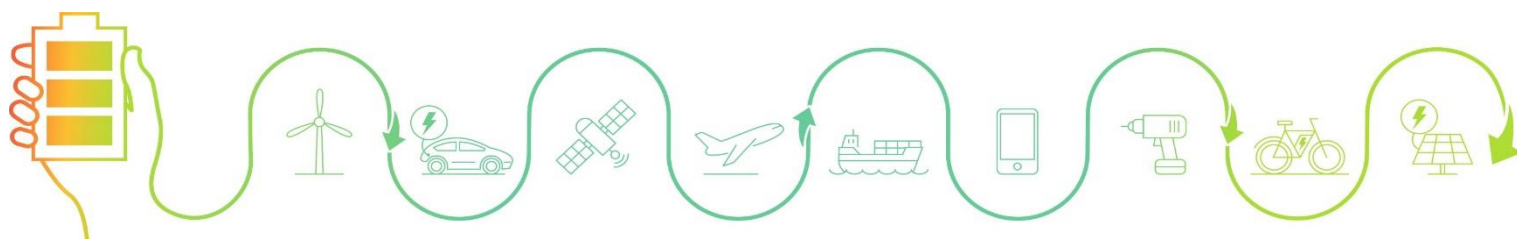
Fluorinated polymers, specifically PTFE and PVDF are important components in future cells, including polymer gel and solid state cells. The intrinsic stability of PTFE and PVDF within electrochemical systems, combined with their affinity for electrolyte and their processability means that these materials will play a critical role in future cell technologies. The advantages of these systems have not yet been fully realised; however, they may include reduced environmental impact through elimination of toxic solvents (NMP, classified in the EU as toxic to reproduction and its use is restricted under entry 71 of REACH Annex XVII), reduced energy required for electrode processing⁵⁷ and enhanced cell safety.

Cells with gel polymer electrolytes provide an opportunity to address many of the safety concerns associated with liquid electrolytes. Issues of flammability and leakage may be mitigated by incorporating the electrolyte into a polymer gel⁵⁸. In addition, the inert and inherent flame retardancy of PVDF and its copolymers offers further advantages compared to other non-fluorinated alternative polymers⁵⁹.

⁵⁷ Lu, Y., Zhao, C.-Z., Yuan, H., Hu, J.-K., Huang, J.-Q., & Zhang, Q. (2022). Dry electrode technology, the rising star in solid-state battery industrialization. *Matter*, 5(3), 876–898. <https://doi.org/10.1016/j.matt.2022.01.011>

⁵⁸ Long, L., Wang, S., Xiao, M., & Meng, Y. (2016). Polymer electrolytes for lithium polymer batteries. *Journal of Materials Chemistry. A, Materials for Energy and Sustainability*, 4(26), 138–169. <https://doi.org/10.1039/c6ta02621d>

⁵⁹ Wei, C., Zhao, J., Wang, G., Chai, J., Shi, Z., Zhao, P., & Wang, Y. (2022). Strong and flame-retardant thermally insulating poly(vinylidene fluoride) foams fabricated by microcellular foaming. *Materials & Design*, 221, 110932–. <https://doi.org/10.1016/j.matdes.2022.110932>



Polymers utilised in gel polymer electrolytes must meet several key property requirements: good mechanical strength when gelled, good compatibility with liquid electrolytes, wide electrochemical stability window, processability, thermal stability, chemical stability, ability to uptake electrolyte and good ionic conductivity⁶⁰. PVDF and co-polymers of PVDF are uniquely placed to meet these requirements due to their presence of strong electron-withdrawing functional group ($-C-F$) and high dielectric constant ($\epsilon=8.4$)⁶¹. Key advantages of PVDF based polymers include high polarity, excellent thermal and mechanical strength, compatibility with organic solvents and chemical stability⁶².

Established non-fluorinated alternative polymers fail to meet the performance shown by PVDF and its copolymers when utilised in gel systems⁶³. Alternative polymers such as poly(methyl methacrylate) (PMMA), polyethylene oxide (PEO) and polyacrylonitrile (PAN) have been studied in gel polymer electrolyte systems but present significant challenges. PEO based systems often suffer from low conductivities due to high crystallinity, resulting in poor cell performance. PAN examples give good mechanical strength but have poor long-term stability exhibiting solvent loss. PMMA based gels have good electrolyte affinity but exhibit poor mechanical properties⁶⁴.

The processability of the polymer is a key property to enable production of viable gel polymer cells. Thanks to the semicrystalline nature of PVDF and its copolymers it is possible to generate conductive, stable and mechanically robust films. This is not the case with many of the established alternatives to PVDF. A study was undertaken looking at forming gels with cyclic organic carbonate solvents, lithium salt and various polymers including PMMA, polystyrene, polyvinyl chloride, polyvinyl acetate, PAN,

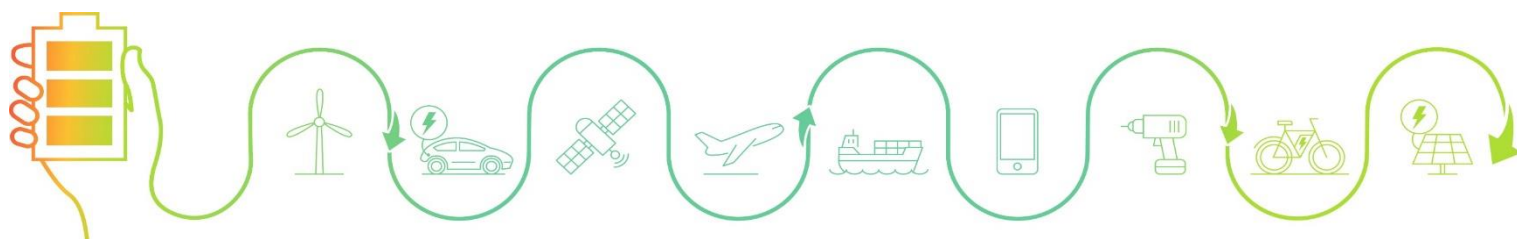
⁶⁰ Li, G., Li, Z., Zhang, P., Zhang, H., & Wu, Y. (2008). Research on a gel polymer electrolyte for Li-ion batteries. *Pure and Applied Chemistry*, 80(11), 2553-2563. doi:10.1351/pac200880112553

⁶¹ Manuel Stephan, A. (2006). Review on gel polymer electrolytes for lithium batteries. *European Polymer Journal*, 42(1), 21-42. <https://doi.org/10.1016/j.eurpolymj.2005.09.017>

⁶² Barbosa, J. C., Dias, J. P., Lanceros-Méndez, S., & Costa, C. M. (2018). Recent Advances in Poly(vinylidene fluoride) and Its Copolymers for Lithium-Ion Battery Separators. *Membranes (Basel)*, 8(3), 45-. <https://doi.org/10.3390/membranes8030045>

⁶³ Liu, W., Zhang, X. K., Wu, F., & Xiang, Y. (2017). A study on PVDF-HFP gel polymer electrolyte for lithium-ion batteries. *IOP Conference Series. Materials Science and Engineering*, 213(1), 12036-. <https://doi.org/10.1088/1757-899X/213/1/012036>

⁶⁴ Song, J. Y., Wang, Y. Y., & Wan, C. C. (1999). Review of gel-type polymer electrolytes for lithium-ion batteries. *Journal of Power Sources*, 77(2), 183-197. [https://doi.org/10.1016/S0378-7753\(98\)00193-1](https://doi.org/10.1016/S0378-7753(98)00193-1)



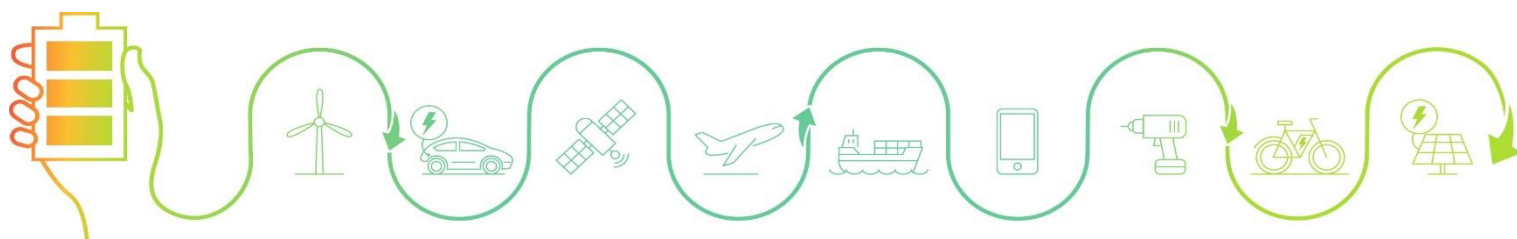
and PVDF. Of these polymers only PAN and PVDF allowed for the formation of homogeneous, well dispersed films⁶⁵.

Tests were performed by a RECHARGE member⁶⁶ to replace LiTFSI in solid electrolyte/gel polymer electrolytes with the following salts - LiPF_6 ; LiBF_4 ; LiClO_4 ; $\text{LiN}(\text{SO}_2\text{F})_2$ (LiFSI); LiAsF_6 and LiNO_3 . In summary:

- LiPF_6 and LiBF_4 are salts that hydrolyze in the presence of water. They are not compatible with the cathode preparation process, which uses water as a process solvent. Tests were carried out using organic solvents. Despite the use of organic solvents, traces of water remained. This water will hydrolyze the salt, producing and generating strong acids (HF). These acids will degrade and depolymerize the POE, leading to a limited cycle life for batteries incorporating these salts. The main drawback of these salt is related to the formation of HF in presence of water.
- LiClO_4 was evaluated despite its explosive nature. Power responses are significantly poorer due to the salt's lower conductivity. The cycle life obtained with this salt is also extremely limited. This is probably due to poorer dissociation of the salt. The main drawback of this salt is related to its low dissociation leading to low power and cyclability.
- LiFSI has also been studied as a possible replacement. The first problem is the thermal instability of this salt, which degrades at temperatures below those used in processes. By using a new process, Blue Solutions were able to evaluate it in the battery however, encountered another problem. Its stability during reduction is not good which lead to a consumption and a strong decrease of its concentration in the electrolyte during the battery forming stages. This consumption leads to poor performances. The main drawback of this salt is related to its low dissociation leading to low power and cyclability.
- LiAsF_6 was not tested due to its toxicity. The main drawback of this salt is related to its toxicity.
- LiNO_3 was evaluated as replacement of LiTFSI. The conductivity of this salt was too low to allow its use in LMP battery. The main drawback of this salt is related to its low conductivity.

⁶⁵ Ibid

⁶⁶ Private communications from Blue Solutions to RECHARGE

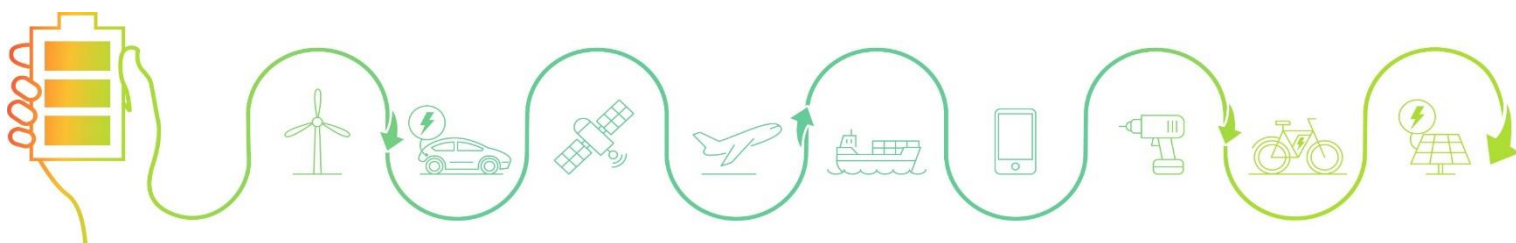


Despite the evaluation of numerous alternatives, **none have demonstrated sufficient performance to replace LiTFSI** in solid electrolyte/ gel polymer electrolytes. Extensive research would be required to find alternatives to PVDF and its copolymers for use in gel polymer electrolyte systems. To align with the dossier submitters basis for derogations the battery industry is applying for a 13.5 years derogation for this application, with a review clause to potentially renew this derogation if alternatives are not available when it approaches expiry.

3.2 Periodic review of derogations for uses where alternatives are not yet available

For the uses listed in section 3.1 where alternatives are not available today and therefore, to align with the dossier submitters basis, this document calls for 13.5 years derogation periods. At the end of this derogation period, it may be possible that some uses could be identified for which alternatives will still not be available, or where the alternatives would be regrettable substitutions. In these cases, a mechanism to renew the derogation would be essential to avoid the substantial socio-economic impacts to the Green Deal which are detailed in section 5. However, such a renewal mechanism is currently missing from the proposed PFAS restriction. Therefore, we have drafted a review clause which should be included in the final restriction to provide 3 years to evaluate derogations before their expiry, to assess whether alternatives are now available or whether a further renewal of the derogation is needed.

“The European Commission shall review the derogations for specific uses in the battery industry by 3 years before their expiry to assess whether alternatives are now available or whether further renewals of selected derogations for specific uses are needed and to publish amendments to the Regulation.”



Including this review clause in the final restriction would align with similar periodic reviews of derogations which have been recommended by Dossier Submitters and SEAC in the proposed REACH restriction of microplastics⁶⁷ and the proposed REACH restriction of PFAS in firefighting foams⁶⁸.

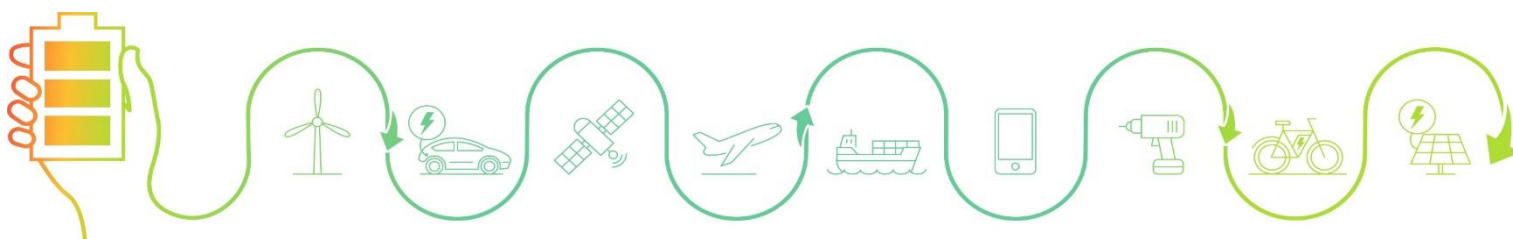
3.3 Uses where substitution is technically feasible but more time is required

As highlighted below, where substitution is technically feasible, the steps involved in substituting new materials into several subcomponents in a company's battery manufacturing process are considerably more complicated than in other industry sectors. To align with the dossier submitters' basis for derogations, this document calls for a transition period of 6.5 years in these cases. The difference is that in a battery cell each component has to interact successfully with every other component in a closed system. As a result, each new subcomponent needs to be developed and tested separately, and then the combination of the new subcomponents needs to be tested in the new battery and the product applications. In addition, each company's battery manufacturing equipment and process lines also have unique aspects which are specific to that company's products and applications. Some companies may need to make significant changes to their manufacturing equipment and process lines to accommodate the new subcomponents.

The below consecutive steps 1 to 4 in Figure 9 are representative of the actual best practice processes which have been used for over 20 years in the battery industry to introduce innovation in battery design. This represents an optimistic scenario where no complications arise such as additional certification requirements or unforeseen customer validation requirements. For example, a significant amount of R&D resource will be needed to carry out the development of new subcomponents and the battery industry may face a shortage of qualified technical staff to carry out this work. In addition, a large amount of battery models and finished products containing batteries which are on the market

⁶⁷ See Section A2 of the Compiled RAC and SEAC Opinion (and minority positions) at <https://echa.europa.eu/documents/10162/a513b793-dd84-d83a-9c06-e7a11580f366> and Section 2.6.2 of the Final Background Document at <https://echa.europa.eu/documents/10162/b56c6c7e-02fb-68a4-da69-0bcdb504212b>

⁶⁸ See Section 1.2 of the SEAC Draft Opinion at <https://echa.europa.eu/documents/10162/b06cc564-858e-daa8-845e-ed8e11194b59>



today will need to be recertified and there may not be sufficient third-party certification companies available in the market today to provide these needed recertification services.

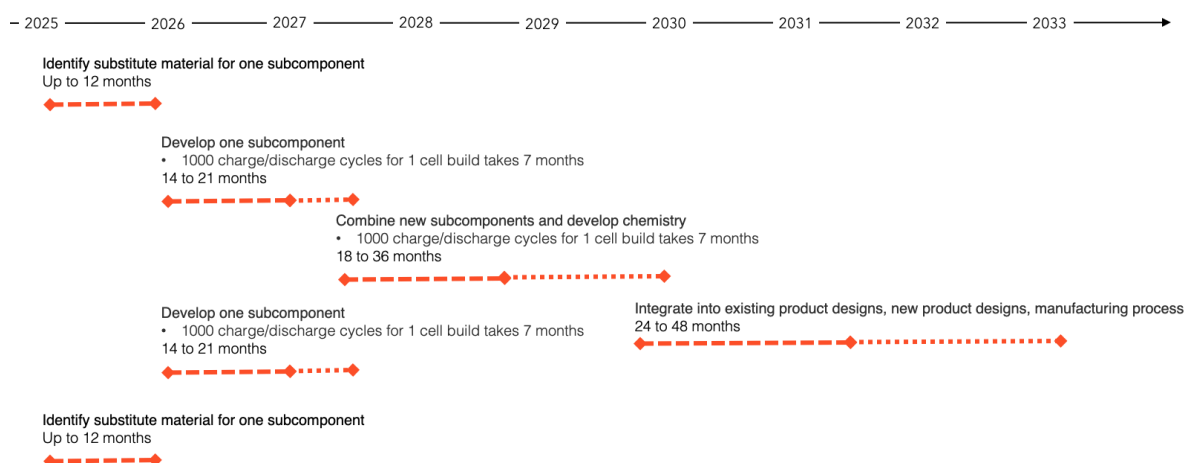
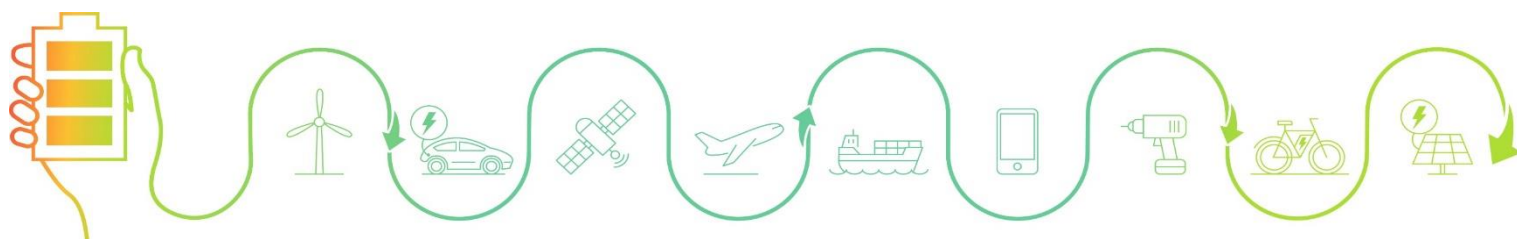


Figure 9. Best practice processes for introducing new design components in the battery industry

The battery industry will make every effort to work within a 6.5 years transition time. **However, there may be some types of subcomponents where industry experience finds that it is not possible to achieve substitution within the 6.5 years and so the battery industry may need to apply for an extension to this transition period.**

Step 1: Identify substitute material for one subcomponent: up to 12 months

Each company's battery manufacturing process is customised to meet the needs of that company's products. In many cases there are a range of chemistries that could be considered as alternatives for a specific subcomponent. The first step is assessment and laboratory verification to identify which target substitute material is likely to provide the best combination of properties for the specific subcomponent in the company's products. The identification of a target substitute material for one subcomponent alone can take up to 12 months. For example, in the case of the binder for the ceramic coating on the separator, companies which are currently using PVDF will need to evaluate several different alternatives to identify the best material for their application. There are several alternatives in use today which will need to be considered.



Step 2: Separate development of one subcomponent: 14 - 21 months

In this step, the target substitute material is developed into the new subcomponent and tested in a cell with an existing, already proven chemistry. This step is necessary to isolate the new subcomponent as the only variable that has changed in the cell. Once the cells are built, the testing of the cell cycling process can begin. It takes about 7 months to carry out 1000 charging and discharging test cycles of the cell build containing the new subcomponent, to check that it can meet swelling, impedance, capacity retention and other technical requirements after 1000 cycles. Some companies also need to carry out environmental testing of the subcomponent such as long-term storage at elevated temperatures. A cell build can fail the cycles tests, therefore most companies assume at least one additional iteration of the cell build will be required to refine the specific chemistry of the target substitute material. Therefore, this stage can take several multiples of 7 months, at least 14 to 21 months.

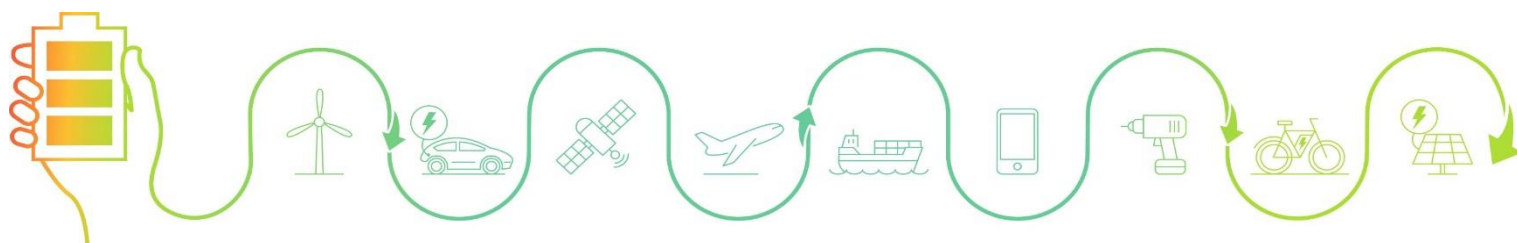
Step 3: Combine all the new subcomponents and develop new chemistry package: 18 - 36 months

In this step, new subcomponents are integrated and developed into a next generation cell chemistry package. Each new subcomponent needs to be qualified as part of this larger chemistry package.

The integration and development process requires several cell builds to find a combination of components and process conditions that meets all electrochemical and safety requirements. Depending on the testing capacities at the company, some companies may need to carry out between 3 and 6 cell builds, as some cell builds may fail testing. It takes about five months to develop each cell build and carry out tests of the initial 250 cycles so that sufficient data can be collected to accurately inform the development of the next cell build. The final cell chemistry needs to be tested at 1000 cycles which takes 7 months. Therefore, it may take around 18 - 36 months to arrive at a validated battery chemistry which is ready to be integrated into a new product.

Step 4: Integrate into existing product designs, new product designs, and manufacturing processes: 24 - 48 months

The final step is to integrate the new validated battery chemistry into existing product designs and new product designs, and to carry out testing on finished assembled products to ensure they meet all electrochemical, process, safety and reliability requirements and certifications. This requires



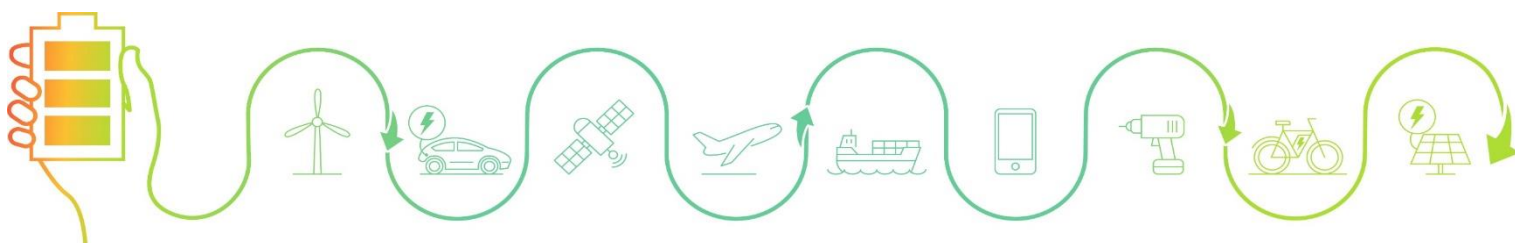
requalification of the new battery in all existing products which are already in production in Europe. Companies will need to make changes to their manufacturing equipment and process lines to qualify the manufacturing of the new subcomponents, the integration of the new subcomponents into the cell and the integration of the new battery into existing and new products. These changes to manufacturing equipment and process lines may be significant and require extensive time and capital investment.

Product requalification is a very time-consuming exercise which will require extensive resources over many years. The completion of this task will require sufficient test house capacity and transition time to requalify all battery-powered products which are used in Europe for safety, performance and lifetime. Additionally, the process of re-certifying batteries for existing product designs may trigger other regulatory updates unrelated to the new subcomponents that could otherwise have been avoided. For a company with a wide range of existing product designs, this can take around 24 - 48 months.

For example, in order to apply a new binder, it is necessary to develop a new process rather than the existing process to achieve acceptable quality. The following are the essential stages which will ensure such quality; 1) equipment developing for each process, 2) process recipe development, and 3) semi-product verification. And it take at least 7 to 8 years for verification of each process stage of binder dissolution, main-mixing, coating, pressing, notching. In addition, it may take at least 9 to 10 years as an additional 2 years are required for yield, equipment efficiency, and quality stabilisation.

3.4 Periodic review of transition period for uses where substitution is technically feasible but more time is required

For the uses where substitution is technically feasible but more time is required and therefore, to align with the dossier submitters basis for transition periods, the battery industry is applying for 6.5 years transition period. **At the end of this transition period there may be some specific types of subcomponents where industry experience finds that it is not possible to achieve substitution within the 6.5 years and so the battery industry may need to apply for an extension to this transition period.** In these cases, a mechanism to renew the transition period for specific types of subcomponents would be essential to avoid the substantial socio-economic impacts to the Green Deal



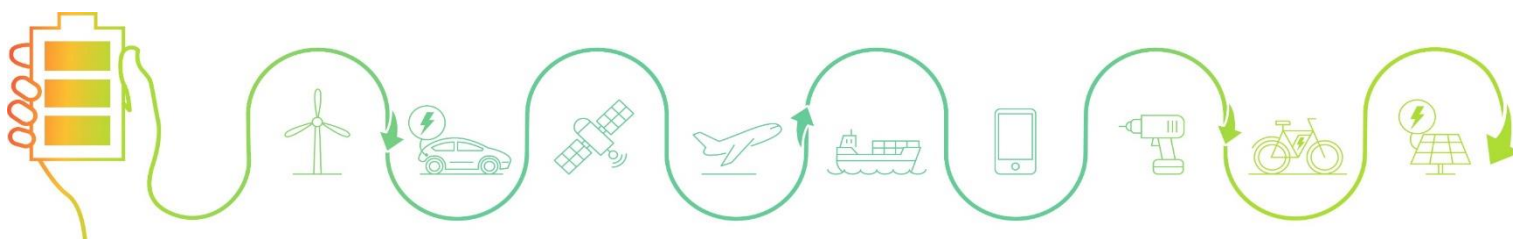
which are detailed in section 5. However, such a renewal mechanism is currently missing from the proposed PFAS restriction. Therefore, we have drafted a review clause which should be included in the final restriction to provide 3 years to review the transition period before expiry, to assess whether the industry is on track to achieve substitution within 6.5 years or whether a further renewal of the transition period for specific types of subcomponents is needed.

“The European Commission shall review the transition period for uses in the battery industry where substitution is technically feasible by 3 years before its expiry to assess whether industry is on track to achieve substitution within 6.5 years or whether a further renewal of the transition period for specific types of subcomponents is needed and to publish amendments to the Regulation.”

Including this review clause in the final restriction would align with similar periodic reviews of derogations which have been recommended by Dossier Submitters and SEAC in the proposed REACH restriction of microplastics⁶⁹ and the proposed REACH restriction of PFAS in firefighting foams⁷⁰.

⁶⁹ See Section A2 of the Compiled RAC and SEAC Opinion (and minority positions) at <https://echa.europa.eu/documents/10162/a513b793-dd84-d83a-9c06-e7a11580f366> and Section 2.6.2 of the Final Background Document at <https://echa.europa.eu/documents/10162/b56c6c7e-02fb-68a4-da69-0bcdb504212b>

⁷⁰ See Section 1.2 of the SEAC Draft Opinion at <https://echa.europa.eu/documents/10162/b06cc564-858e-daa8-845e-ed8e11194b59>

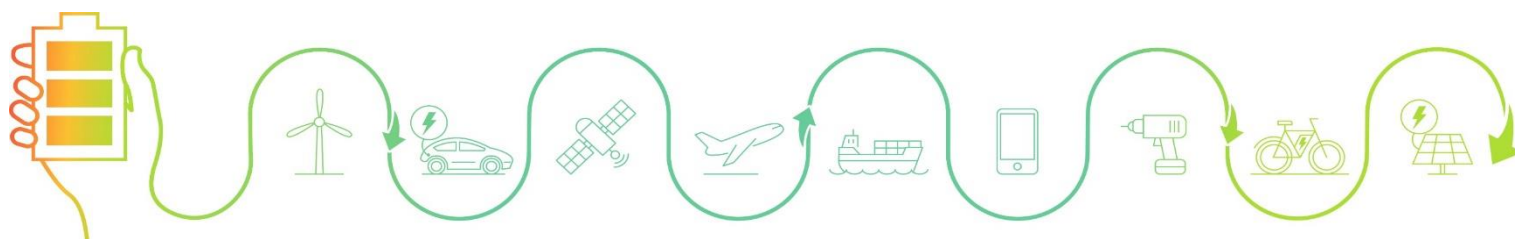


4 PFAS consumption in tonnes and emissions during battery life cycle

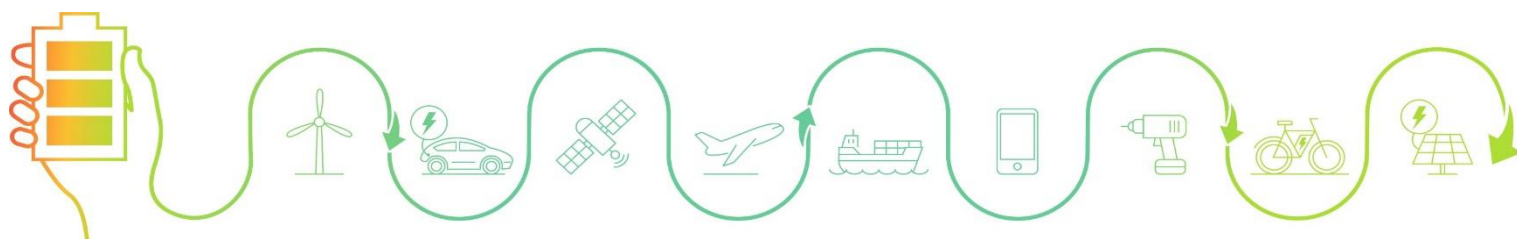
4.1 PFAS consumption in tonnes

Table 3. PFAS consumption in tonnes

PFAS type	Where used in the battery	Type of battery	Estimated PFAS consumption in 2020	Projected PFAS consumption in 2030	Derogation / transition period in line with dossier submitters' proposal
PVDF	Binder in active material mass	Li-ion wet process (except for the graphite anode), Na-ion, Lithium metal rechargeable, solid-state	1,500 tonnes	45,000 tonnes	13.5 years with review*
PTFE	Binder in active material mass	Li-ion dry process and semi-dry process, Lithium primary, Ni-Cd, Ni-MH, Zinc oxide, Metal air, Silver oxide, Zinc-ion rechargeable, Lithium metal rechargeable, solid-state	236 tonnes	311 tonnes (without considering the uptake of the dry process of Li-ion rechargeable batteries.)	13.5 years with review*
Various PFAS including LiTFSI, LiCF ₃ SO ₃ (triflate)	In electrolytes	Li-ion rechargeable, Lithium primary, Lithium metal rechargeable, Na-ion rechargeable batteries	84 tonnes	1562 tonnes	13.5 years with review*



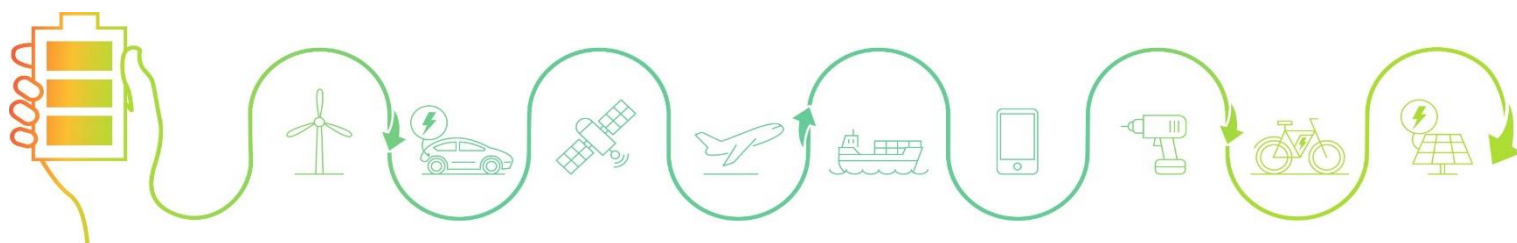
PFAS type	Where used in the battery	Type of battery	Estimated PFAS consumption in 2020	Projected PFAS consumption in 2030	Derogation / transition period in line with dossier submitters' proposal
PTFE, FEP	Gaskets, washers	Chemically aggressive environments where PFAS is needed for electrochemical stability such as Lithium primary batteries using Li-SO ₂ and Li-SOCl ₂	0.36 tonne	0.440 tonne	13.5 years with review*
PFA, VDF-HFP, FKM	Gaskets	High energy density batteries which require very thin high-performance gaskets such as Lithium-ion rechargeable batteries, Lithium metal rechargeable batteries	50 tonnes	250 tonnes	13.5 years with review*
PTFE	Oxygen permeable membrane	PFAS hydrophobic properties are needed to facilitate air permeation and prevent alkaline electrolyte leakage in Zinc air batteries	11 tonnes	10 tonnes	13.5 years with review*



PFAS type	Where used in the battery	Type of battery	Estimated PFAS consumption in 2020	Projected PFAS consumption in 2030	Derogation / transition period in line with dossier submitters' proposal
PVDF, PTFE	Solid / electrolyte gel polymer electrolyte industrialised today	Solid-state batteries	Confidential - only one company active in the EU in 2020	Uncertain - unknown number of companies will be active 2030	13.5 years with review*

***At the end of the 13.5 years derogation it may be possible that some uses could be identified for which alternatives will still not be available, or where the alternatives would be regrettable substitutions. We therefore request the European Commission should review the derogations for specific uses in the battery industry by 3 years before their expiry to assess whether alternatives are now available or whether further renewals of selected derogations for specific uses are needed and to publish amendments to the Regulation.**

The estimated 2020 consumptions for uses where alternatives are not yet available are shown in Figure 10. Volumes calculated are a consolidation made by RECHARGE from figures obtained from AVICENNE and other associations' data together with confidential data from RECHARGE members.



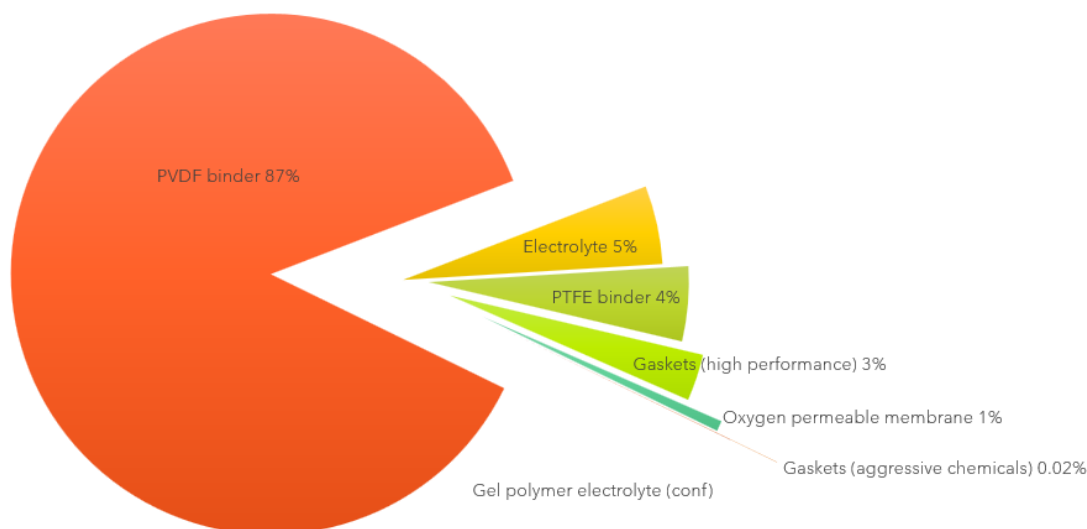


Figure 10. Estimated 2020 consumptions for uses where alternatives are not yet available (in percentages)

4.1.1 Use of PVDF as the binder of the active material masses

RECHARGE internal consolidated data confirms that about 150 000 tonnes of lithium-ion rechargeable batteries (including portable, industrial and automotive batteries) were put on the European market in 2020⁷¹. RECHARGE expects that the demand for lithium-ion rechargeable batteries will grow by a factor of 30 by 2030 and may reach 4,500,000 tonnes by 2030.

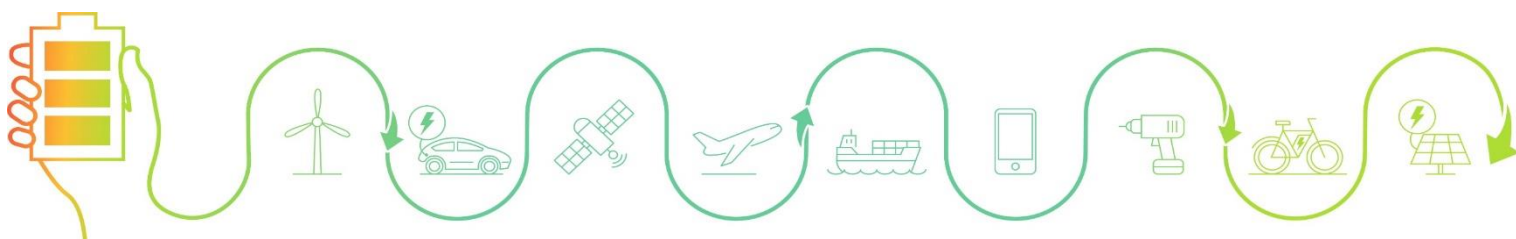
The PVDF binder typically comprises between 2–5% of the mass of the electrode⁷², for example the cathode for a typical lithium-ion rechargeable battery comprises 94% LiCoO_2 , 3% PVDF binder material and 3% carbon black as the conductive additive⁷³. The cathode electrode typically comprises between

⁷¹ PFAS restriction proposal, RECHARGE statement for 2nd Call for Evidence, October 2021

⁷² 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–. <https://doi.org/10.3390/polym13040631>

⁷³ Grillet, A. M., Humplik, T., Stirrup, E. K., Barringer, D., Mendoza, H., Roberts, S. A., Snyder, C. M., Apblett, C. A., Fenton, K. R., & Long, K. N. (2016). The Role of Composite Binder on Mechanics and Performance of Lithium Ion Battery Electrodes. *Meeting Abstracts (Electrochemical Society)*, MA2016-01(2), 368–368. <https://doi.org/10.1149/MA2016-01/2/368>.

Also presented at the 229th ECS Meeting, <https://www.osti.gov/servlets/purl/1420863>



25% and 33% of the lithium battery weight⁷⁴, and so the amount of PVDF in a typical Lithium-ion rechargeable battery is estimated at between 0.5% and 1.6% of the battery weight.

In view of these data, we estimate that the amount of PVDF cathode binder in lithium-ion rechargeable batteries placed on the market in the EU in 2020 (including portable, industrial and automotive batteries) was about 1,500 tonnes. RECHARGE expects the demand for lithium will grow by a factor of 30 by 2030 and so the amount of PVDF cathode binder in lithium-ion rechargeable batteries placed on the EU market may reach 45 000 tonnes by 2030.

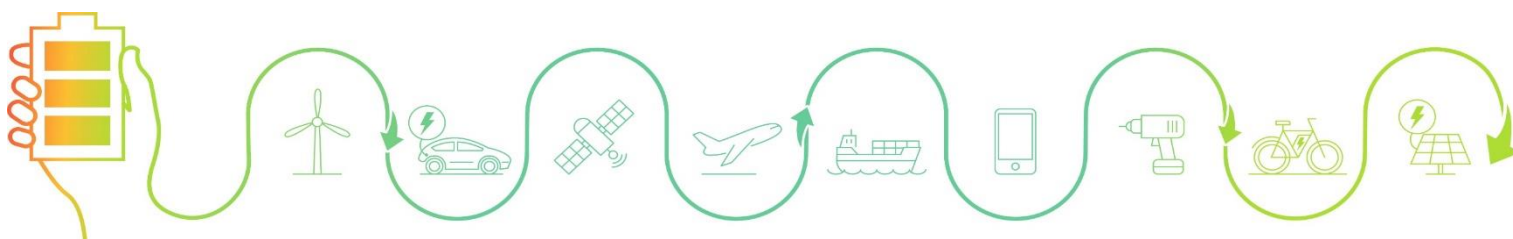
4.1.2 Use of PTFE as the binder of the active material masses

RECHARGE internal consolidated data confirms that about 15 000 tonnes of primary lithium batteries were put on the European market in 2020⁷⁵. The PTFE binder typically comprises between 2–6 % (with extremes at 1 % and 10 %) of the mass of the cathodes in lithium primary cells. The fraction of the cathode weight with respect to the overall weight of the cell depends very much on the cell design and the electrochemical system. It can vary between around 5% in bobbin-type lithium thionylchloride cells (comprising about 80 % of the market for industrial lithium primary batteries) and almost 50 % in lithium manganese dioxide cells (about 15 % of the market for industrial lithium primary batteries). The PTFE content in the cells therefore varies between 0.1 and 3 %, with a weighted average of about 1 % for industrial lithium primary batteries. For consumer batteries like CR 123 and coin cells, which usually employ lithium manganese dioxide, the average PTFE content is around 2 %.

Assuming an average content of 1.5 %, this translates into an overall amount of PTFE of 225 tonnes in active material mass of lithium primary batteries per year.

⁷⁴ Dunn, J. B., Gaines, L., Barnes, M., Sullivan, J. & Wang, M. (2012). Material and Energy Flows in the Materials Production, Assembly, and End-of-Life Stages of the Automotive Lithium-Ion Battery Life Cycle. Argonne National Laboratory, Energy Systems Division, ANL/ESD/12-3. <https://greet.es.anl.gov/files/lib-lca>

⁷⁵ PFAS restriction proposal, RECHARGE statement for 2nd Call for Evidence, October 2021



RECHARGE expects the demand for lithium primary batteries will grow by 2.7 % per year⁷⁶, and so the amount of PTFE in the active material mass of lithium primary batteries placed on the EU market may reach almost 300 tonnes by 2030.

The amount of PTFE in active material mass of nickel-based batteries (Ni-Cd and Ni-MH) is estimated at between 0.05 % and 0.3%. Based on RECHARGE internal consolidated data, the amount of PTFE used as a binder for nickel-based batteries is estimated at 10 tonnes for 2020.

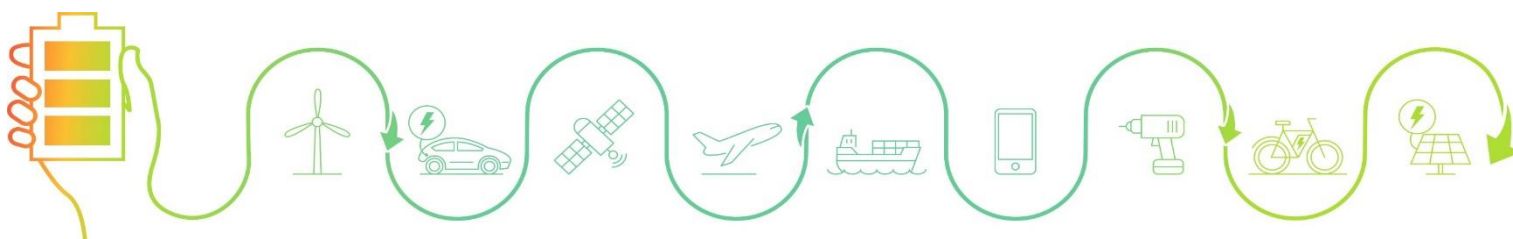
The amount of PTFE in active material mass of silver oxide batteries is estimated at 0.2%. Based on RECHARGE internal consolidated data, the amount of PTFE used as a binder for silver oxide batteries is estimated at 65 kg for 2020.

The amount of PTFE in active material mass of zinc-air batteries is also estimated at 0.2%. Based on RECHARGE internal consolidated data, the amount of PTFE used as a binder for zinc-air batteries is estimated at 1 tonne for 2020.

4.1.3 Use of PFAS in electrolytes

Recent advances in battery technology have established the use of PFAS substances as state-of-the-art for high performance lithium-ion rechargeable and lithium primary batteries today, including as additives and as Lithium salt with PFAS anion. The typical weight of the electrolyte in these batteries is about 15-20%. A typical electrolyte composition comprises about 80-90% of non-PFAS solvent and 10-20% of PFAS additives and lithium or sodium PFAS. Therefore, the overall amount of PFAS in the electrolyte of these advanced batteries is between 1.5% and 4% of the battery weight, with a typical average value of 2.7%.

⁷⁶ Lithium Primary Batteries Global Market Report 2023 – Market Size, Trends, And Global Forecast 2023-2032. from IPCEI Market Analysis Q4 2022, https://www.ipcei-batteries.eu/fileadmin/Images/accompanying-research/publications/2023-02-BZF_Kurzinfo_Marktanalyse_Q4_22-ENG.pdf.



In 2020, these state-of-the-art batteries represent about 1 to 2 % of the market⁷⁷. Therefore, the amount of PFAS in electrolytes in 2020 is estimated at about 900 tonnes. In 2030, we estimate that the amount of PFAS in electrolytes will reach 1562 tonnes.

4.1.4 Use of PTFE & FEP in gaskets & washers in chemically aggressive environments

FEP washers used in spiral wound Li primary cells weight between 0.1g to 0.2g. Based on RECHARGE internal consolidated data, the amount of FEP used in washers in chemically aggressive environments for Li primary batteries is estimated at 360 kg for 2020 and 440 kg for 2030.

4.1.5 Use of PFA, VDF-HFP, FKM in gaskets in high performance batteries which require very thin high performance gaskets

The estimated weight of the gaskets in these high-performance batteries is between 0.05% and 2% of the cell weight, typically about 0.5g per battery. Therefore, the estimated amount of PFAS-based gaskets in high performance battery cells in the market in 2020 is 50 tonnes. For 2030 it is estimated to be 250 tonnes.

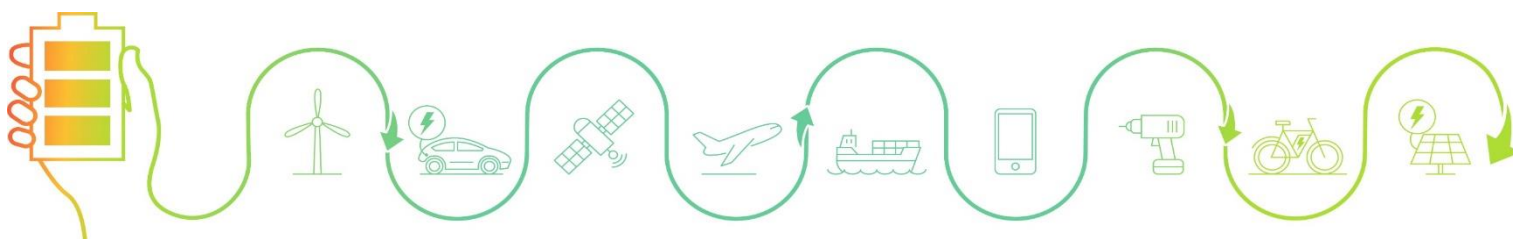
4.1.6 Use of PTFE in oxygen permeable membranes in Zinc air batteries

The amount of the PTFE membrane in zinc-air batteries is estimated at 2.2% in weight. Based on RECHARGE internal consolidated data, the amount of PTFE used as a binder for zinc-air batteries is estimated at 11 tonnes for 2020 .

4.1.7 Use of PTFE / PVDF in solid electrolyte/ gel polymer in solid-state batteries

The average weight of PFAS within solid-state batteries is less than 5%. In 2020 there was only one manufacturer of solid-state batteries in the EU. To protect confidential business information for this manufacturer, we do not provide data on the weight of lithium-ion batteries placed on the market in 2020.

⁷⁷ AVICENNE presentation AABC Mainz June 2022 – slide 98



We expect that more companies will start manufacturing lithium-ion batteries in the coming years. However, we are not able to estimate how many companies will start operations and what volumes of lithium-ion batteries they will manufacture.

4.2 Emissions during the battery life cycle

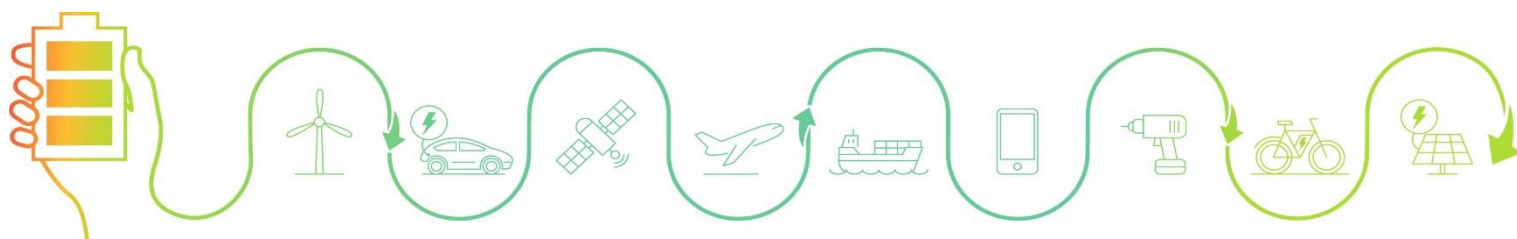
Slide 24 from the 5 April 2023 ECHA webinar⁷⁸ on the PFAS restriction, highlights that the energy sector represents between 0 and 1% of the total emissions of PFAS. Nevertheless, we present a detailed analysis of these emissions over the battery life cycle. Studies performed by Desotec, demonstrate that all sources of emissions (not just PFAS) during the entire battery life cycle are tracked and controlled⁷⁹.

During the process of gathering PFAS emission data measurements, RECHARGE members emphasised the limitations of such measurements. At present, the analytical methods used for water analysis primarily focus on detecting and quantifying well-known 'PFAS of concern'. These include fluorosurfactants or fluorotelomers listed in the Drinking Water Directive (Directive (EU) 2020/2184) or the draft Water Framework Directive (WFD)⁸⁰. For these substances, certified reference materials are available, and the most commonly employed technique is liquid chromatography coupled with mass detector LC-MSMS. The reference methods commonly utilized are ASTM D7979 (or EPA 8327) or ISO 21675 (or EPA 531.1), depending on the desired limit of detection. It is important to note that the current analytical methods for perfluoro-1-octanesulfonate (PFOS) may not provide adequate sensitivity to meet the EU's required limit of 0.00065 µg/L for freshwater, as specified in Directive 2013/39/EU.

⁷⁸ Restriction of PFAS under REACH, ECHA Webinar 5 April 2023, <https://echa.europa.eu/-/restriction-of-per-and-polyfluoroalkyl-substances-pfass-under-reach>

⁷⁹ Kirchhoff, M. & Reichert, D (n.d.). Emission Compliance in Battery Manufacturing and Recycling. Presentation slides of Desotec Activated Carbon, www.desotec.com

⁸⁰ Proposal for a Directive of the European Parliament and of the Council amending Directive 2000/60/EC establishing a framework for Community action in the field of water policy, Directive 2006/118/EC on the protection of groundwater against pollution and deterioration and Directive 2008/105/EC on environmental quality standards in the field of water policy. <https://environment.ec.europa.eu/system/files/2022-10/Proposal%20for%20a%20Directive%20amending%20the%20Water%20Framework%20Directive%2C%20the%20Groundwater%20Directive%20and%20the%20Environmental%20Quality%20Standards%20Directive.pdf>



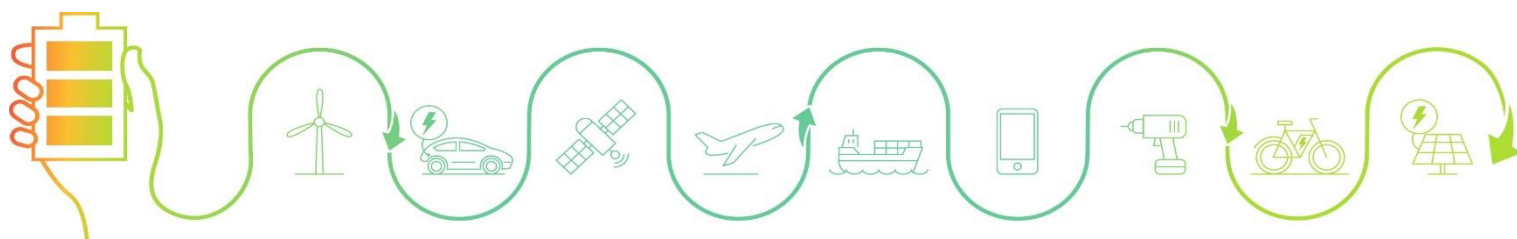
It is also important to note that there is a lack of validated analytical techniques for the detection of 'total PFAS':

- TOF analysis (Total Organic Fluorine) can quantify all molecules that contain fluorine-carbon bounds, including non-PFAS molecules. As a consequence, this 'non selective' technique can only give indication of presence of fluorine in the sample, but cannot identify the origin of it and in particular if related to 'PFAS of concern'.
 - For example, the presence of a fluoropolymer particle (like for instance PTFE or PVDF powder) in the water sample not well filtered before the TOF analysis can generate a high value of organic fluorine content that might overwhelm the signals of other PFAS of concern molecule and generate a wrong result if not combined with a targeted analysis (stepwise approach as described above).
- New techniques are currently under development for the analysis of PFAS meant in the broader definition of 'Total PFAS' which is still under discussion. It is worth noting that there exists a discrepancy between the definition of total PFAS in the Drinking Water Directive (Directive (EU) 2020/2184) and the PFAS definition in the ECHA PFAS restriction proposal. The development of these techniques may require several months or years.

A multi-step approach will probably be necessary to satisfy the future request of detecting/measuring 'total PFAS' in different environmental matrices.

EU member states are introducing additional regulations to control PFAS emissions. A France decree published in June 2023 states that industrial sites will need to achieve PFAS (according to the OECD definition) performance standards. In particular it relates to the analysis of PFAS in aqueous discharges from classified sites⁸¹. Twenty PFAS substances, covered by the European directive on water intended for human consumption, will be compulsorily and regularly analysed. In addition, any other PFAS substance, mentioned in the list drawn up by the operator must also be regularly analysed.

⁸¹ Arrêté du 20 juin 2023 relatif à l'analyse des substances per- et polyfluoroalkylées dans les rejets aqueux des installations classées pour la protection de l'environnement relevant du régime de l'autorisation.
<https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000047739535>



For each of the PFAS substances mentioned a quantification limit of 100 ng/L (100 ppt) must be respected. The estimation of the total quantity of PFAS substances present, expressed in fluoride equivalent must be determined using the Adsorbable Organic Fluorine method (AOF)^{82&83} with a quantification limit of 2 µg/L (2 ppb) required.

The France Action Plan⁸⁴ on PFAS states that ‘there are only a few standards, to date’. The main objectives of the Action plan are:

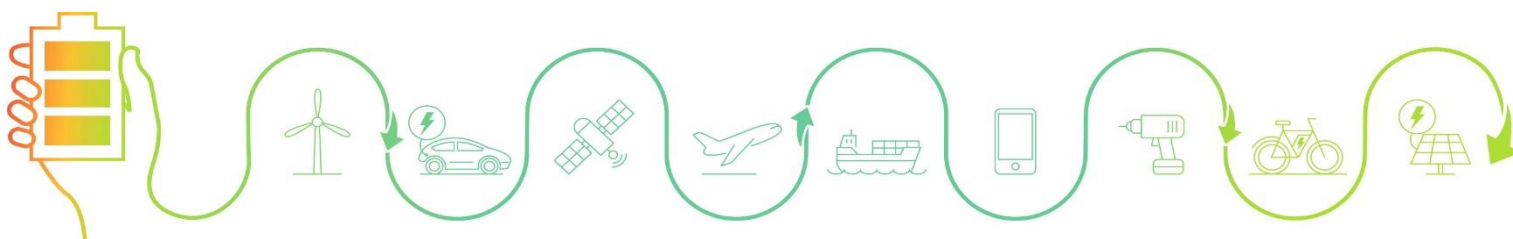
- Have standards to guide public action: ANSES received a request to determine, for the main PFAS, the maximum concentration values to be observed in environmental media.
- Introduce a broad ban at European level to eliminate the risks associated with the use or placing of PFAS on the market,
- Improve knowledge of discharges, as well as the impregnation of environments to reduce the exposure of populations,
- Significantly reduce industrial emissions,
- Ensure complete transparency on the information available,
- Integrate actions on PFAS into the French micropollutants plan.

In general, industry would prefer that PFAS emissions limits should become harmonised across EU Member States.

⁸² Han, Y., Pulikkal, V. F., & Sun, M. (2021). Comprehensive Validation of the Adsorbable Organic Fluorine Analysis and Performance Comparison of Current Methods for Total Per- and Polyfluoroalkyl Substances in Water Samples. *ACS ES&T Water*, 1(6), 1474–1482. <https://doi.org/10.1021/acsestwater.1c00047>

⁸³ Shoemaker, J.A. & Jones, J. L (September 2021). Development of Adsorbable Organic Fluorine (AOF) Screening Method with Detection by Combustion Ion Chromatography (CIC). https://www.epa.gov/system/files/documents/2021-09/cq1_br1_shoemaker.pdf

⁸⁴ Plan d’actions ministériel sur les PFAS, Janvier 2023. https://www.ecologie.gouv.fr/sites/default/files/22261_Plan-PFAS.pdf



4.2.1 Emissions during manufacturing of PVDF and PTFE

Fluoropolymers meet the OECD criteria of polymers of low concern^{85,86}, they are not water soluble, not mobile, not bioavailable and not toxic and thus are considered not to pose risks to human health or environment.

The aforementioned points are the specific reasons why the United Kingdom PFAS RMOA⁸⁷ has proposed a specific exemption for fluoropolymers, classified in the low hazard groups. The scientific data to support this conclusion are provided through our answer to the on-going public consultation.

There are different technologies to produce Fluoropolymers, they can be produced by suspension or emulsion polymerisation. Certain technologies require the formed hydrophobic polymer to stay in emulsion, by use of polymerisation aid. These can be a fluorinated-, non fluorinated or no added polymerisation aids.

The potential emissions as well as the end of life of fluoropolymers can be effectively managed through alternative regulations such as the Waste Directive (2008/98/EC), the Landfill Directive (1999/31/EC) and the Industrial Emissions Directive (2010/75/EU).

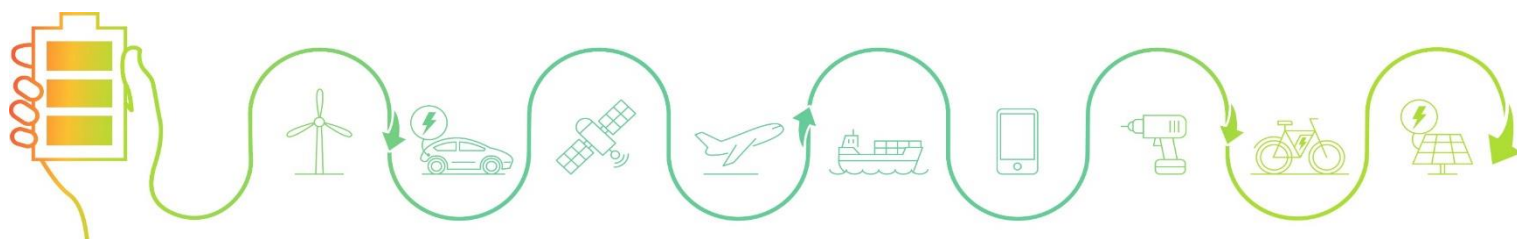
PVDF

PVDF is a polymer from VF₂ (Vinylidene Fluoride), it is partially fluorinated, semi-crystalline polymer with excellent thermo-mechanical and chemical properties. It can be produced by various polymerisation routes.

⁸⁵ Henry, B. J., Carlin, J. P., Hammerschmidt, J. A., Buck, R. C., Buxton, L. W., Fiedler, H., Seed, J., & Hernandez, O. (2018). A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers. *Integrated Environmental Assessment and Management*, 14(3), 316–334. <https://doi.org/10.1002/ieam.4035>

⁸⁶ Korzeniowski, S. H., Buck, R. C., Newkold, R. M., Kassmi, A. E., Laganis, E., Matsuoka, Y., Dinelli, B., Beauchet, S., Adamsky, F., Weilandt, K., Soni, V. K., Kapoor, D., Gunasekar, P., Malvasi, M., Brinati, G., & Musio, S. (2023). A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers. *Integrated Environmental Assessment and Management*, 19(2), 326–354. <https://doi.org/10.1002/ieam.4646>

⁸⁷ Analysis of the most appropriate regulatory management options (RMOA). Substance name: Poly- and perfluoroalkyl substances (PFAS) (March 2023). <https://www.hse.gov.uk/reach/assets/docs/pfas-rmoa.pdf>



All the PVDF grades developed and produced in Europe for the batteries' applications have been produced without PFAS polymerisation aids since their launch. PFAS polymerisation aids have been used historically within the emulsion process of production of PVDF. This category of PFAS has been under scrutiny as they are considered a PFAS of concern due to their (eco)toxicity profile. Some of the substances under this category are already under specific regulations like the updated Drinking Water Directive⁸⁸ (PFOA, PFOS, PFNA...). The PVDF grades used in batteries in Europe are produced with a suspension process – which do not require any polymerisation aids – or with an emulsion process using a non-fluorinated, non-PFAS polymerisation aid. The European PVDF producers have installed state-of-the-art emission control technologies to minimise any emission from PVDF manufacturing.

PTFE

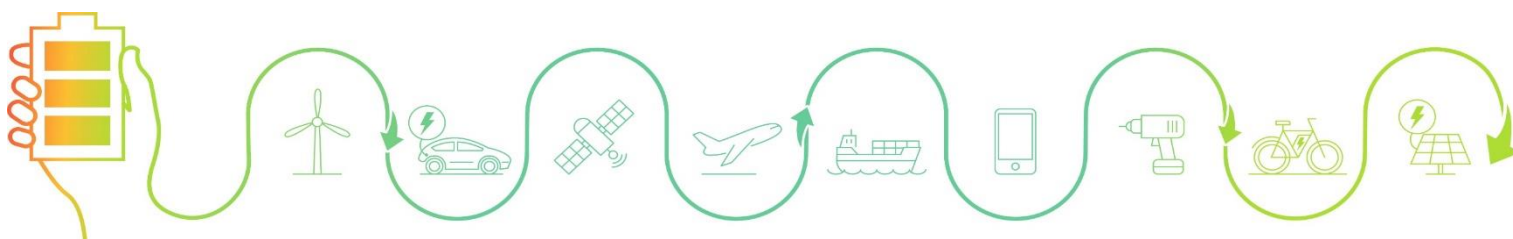
PTFE is a high molecular weight fluoropolymer made from TFE (TetraFluoroEthylene) monomer. Some grades have very small level of other monomers to achieve specific properties. PTFE can be produced by emulsion or suspension polymerisation. The PTFE grades required for battery binder applications are produced by emulsion polymerisation.

The high-end PTFE grades for the binder application are produced with the use of a fluorinated polymerisation aid. At this moment there is no technology available that can produce these high-end polymers without the use of a fluorinated polymerisation aid. Experimental grades of PTFE made without a fluorinated polymerisation aid do not meet the performance requirements and generate a higher level of different fluorinated residues⁸⁹.

The state-of-the-art emission control technology applied by the European manufacturers assure that emissions from the manufacturing process to the environment are minimised.

⁸⁸ DIRECTIVE (EU) 2020/2184 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2020 on the quality of water intended for human consumption (recast). <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020L2184&qid=1690795417343>

⁸⁹ See Chemours submission to the ECHA PFAS consultation, Reference 6337 in Document 37, <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/72301/term>



4.2.2 Emissions during battery manufacturing process

All battery manufacturing operations are conducted in facilities which are permitted by the competent authority within each Member State, where any release of emissions is controlled and must be below regulation threshold limits. These limits include those set by the Industrial Emissions Directive⁹⁰ which sets limits on preventing and limiting levels of pollution. Under the EU Green Deal (EGD) this Directive is in the process of being amended with a proposal released last year⁹¹, which not only addresses PFAS limits but also clarifies requirements for reviewing and updating permits to comply with environmental quality standards, measures under the water legislation permits as well as reducing emissions of pollutants and greenhouse gases emissions. The proposed IED specifically addresses the importance of the sustainable growth of batteries outlining all EU legislations in alignment to make this happen. In addition, the Chemicals Strategy for Sustainability Towards a Toxic-Free Environment⁹² directly addresses the production of safe and sustainable chemicals for batteries.

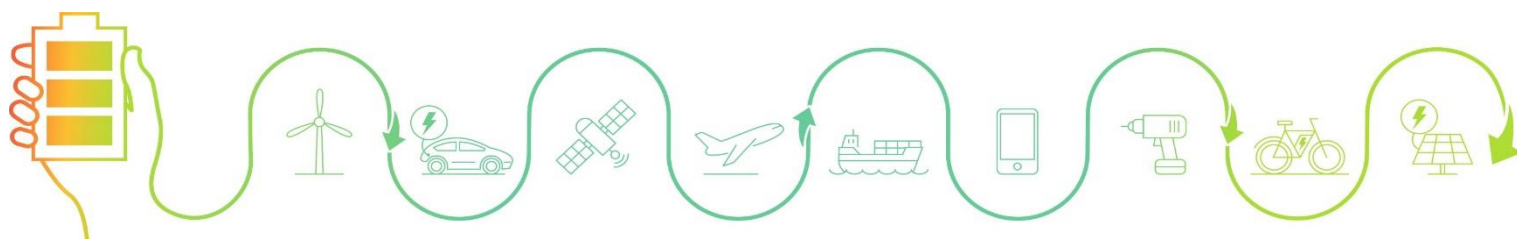
For technologies using PVDF as binder

PVDF is mixed with its organic solvent NMP and other electrode components. A PDVF latex can also be used. This wet mix is then coated on a metallic foil. This electrode is further heated below the degradation temperature of PVDF. The dried electrode is then further used for cell manufacturing. Empty bags of PVDF, PVDF containing residues from the processes as well as scrap cathodes are collected as chemical wastes and disposed of according to applicable European regulations.

⁹⁰ Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control), <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02010L0075-20110106>

⁹¹ Proposal for a Directive of the European Parliament and of the Council (COM(2022) 156 final/3) amending Directive 2010/75/EU and Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste, https://eur-lex.europa.eu/resource.html?uri=cellar:32d55555-c550-11ec-b6f4-01aa75ed71a1.0001.03/DOC_1&format=PDF

⁹² Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Chemical Strategy for Sustainability Towards a Toxic-Free Environment, 14 October 2020, https://eur-lex.europa.eu/resource.html?uri=cellar:f815479a-0f01-11eb-bc07-01aa75ed71a1.0003.02/DOC_1&format=PDF



For technologies using PTFE as binder

In the dry or semi-dry process, PTFE powders are mixed with electrode active and conductive materials. These electrode mixtures are subsequently calendered onto the current collector foils.

In wet processes, PTFE dispersion is mixed with electrode components and carbon black. This wet mix is then processed and heated below the degradation temperature of the PTFE. The dried mix is then further used for cell manufacturing.

Empty drums of PTFE dispersion, PTFE containing residues from the processes as well as scrap cathodes are collected as chemical wastes and disposed of according to applicable European regulations.

Potential residues of PFAS from binders or electrolyte (either empty packaging or cleaning solutions) are always collected as chemical wastes and disposed of according to applicable European regulations.

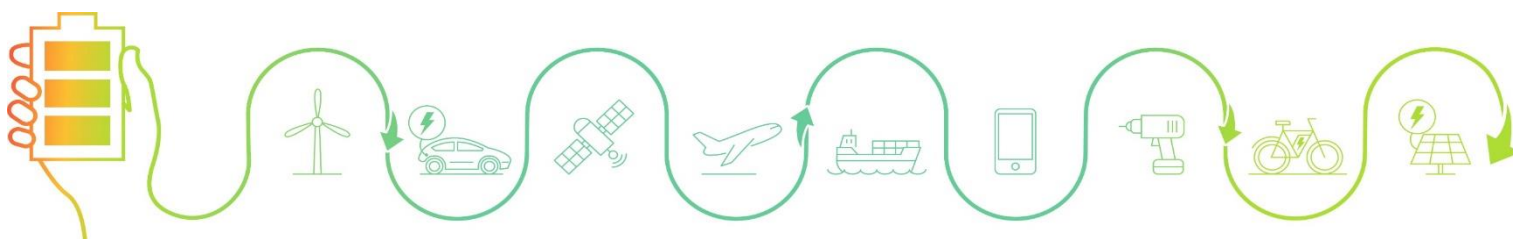
Confidential information submitted by our members to the ECHA consultation demonstrate that **there are no unintended or uncontrolled emissions of PFAS during the battery manufacturing process**⁹³.

Despite the fact that there is for the time being no mandatory requirements to measure PFAS emissions in battery manufacturing plants, certain RECHARGE members are currently performing voluntary PFAS measurements in wastewater in different European Member States. The first anonymized results are confidentially attached to this submission.

The wastewater samples analysed thus far confirmed that there is no detectable emission of PFAS to the environment during battery manufacturing. Analysed PFAS⁹⁴ are either not detectable or their sum is well below 100 ng/L.

⁹³ Northvolt ECHA Consultation feedback reference number 6133 (doc 30).

⁹⁴ 'Sum of PFAS' means the sum of per- and polyfluoroalkyl substances considered a concern in regards to water intended for human consumption listed in point 3 of Part B of Annex III of DIRECTIVE (EU) 2020/2184 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2020 on the quality of water intended for human consumption (recast). <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020L2184&qid=1690795417343>



4.2.3 Emissions during battery use

During battery manufacturing, active substances, binders (like PTFE and PVDF) and additives are embedded in a mechanical substrate to form electrodes. These electrodes are then further assembled with the other battery components such as separator, electrolyte, connectors, gaskets, washers and casing to obtain a finished battery. Lithium batteries are sealed by design and do not have any openings to the environment. Some alkaline batteries may need to have water additions during their working life and so may have a valve opening system. Although gasses can be emitted during the working life of these batteries, the valves are designed to prevent any PFAS liquids or solids emissions leakage. **There are no PFAS emissions from any type of battery during normal use of the battery.**

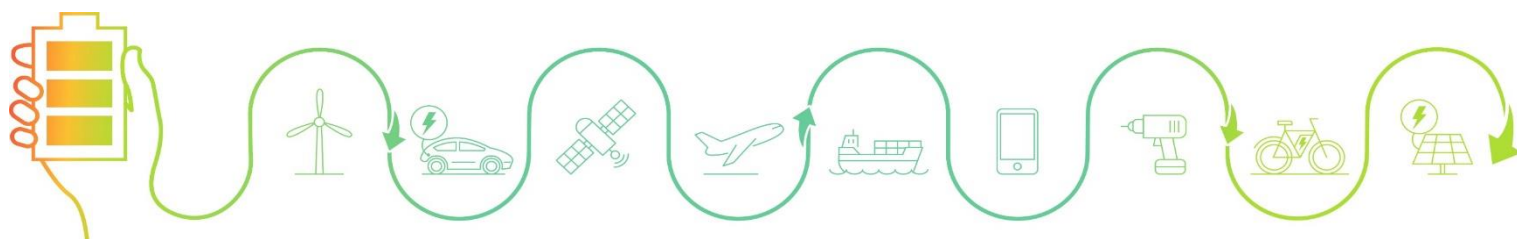
4.2.4 Emissions at end of life

4.2.4.1 Collection of waste batteries

The Batteries Directive 2006/66/EU, as amended by Directive 2013/56/EU, banned the disposal to landfill or incineration of automotive batteries and industrial batteries. Instead, all automotive batteries and industrial batteries that become waste in the EU are collected and recycled in closed loop systems which minimise emissions. The new Batteries Regulation⁹⁵ states that all waste starting, lighting and ignition (SLI) batteries, waste industrial batteries and waste electric vehicle batteries should be collected. For that purpose the producers of these batteries 'should be required to accept and take back free of charge, all waste batteries for their respective category from end-users. Detailed reporting obligations should be established for all producers, waste management operators and waste holders involved in the collection of waste SLI batteries, waste industrial batteries and waste electric vehicle batteries' (paragraph 112, page 19). The European Commission Batteries FAQ⁹⁶ states that "nearly 100 % of automotive batteries and industrial batteries are already being collected" and notes that batteries' economic value motivates collection by professionals.

⁹⁵ Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1542>

⁹⁶ https://environment.ec.europa.eu/topics/waste-and-recycling/batteries-and-accumulators_en



In 2020, about 47% of portable batteries placed on the market in the EU were collected for recycling through battery recycling schemes established under the Batteries Directive 2006/66/EU, as amended by Directive 2013/56/EU⁹⁷. However, that does not mean that 53% of portable batteries were disposed as municipal waste for landfill or incineration in the EU. According to the European Portable Battery Association⁹⁸, a large proportion of these waste batteries are not available for collection because they remain assembled into consumer electronic products which are:

- not discarded by users and are instead stored at home,
- collected and recycled under the Waste Electrical and Electronic Equipment (WEEE) Directive 2012/19/EU,
- exported to regions outside Europe.

The European association of national collection schemes for batteries Eucobat⁹⁹ estimates that 19% of the portable batteries placed on the market in the EU are exported in second hand or waste electrical products and therefore are not available for collection and recycling in the EU. Eucobat highlights that achieving a 65% collection and recycling target based on the quantity of batteries placed on the market is actually equivalent to achieving an 80% collection and recycling target based on the quantity of batteries that are available for collection.

In the meantime, the Batteries Regulation¹⁰⁰ will require industry to achieve the following collection and recycling targets based on the quantity of portable batteries placed on the market:

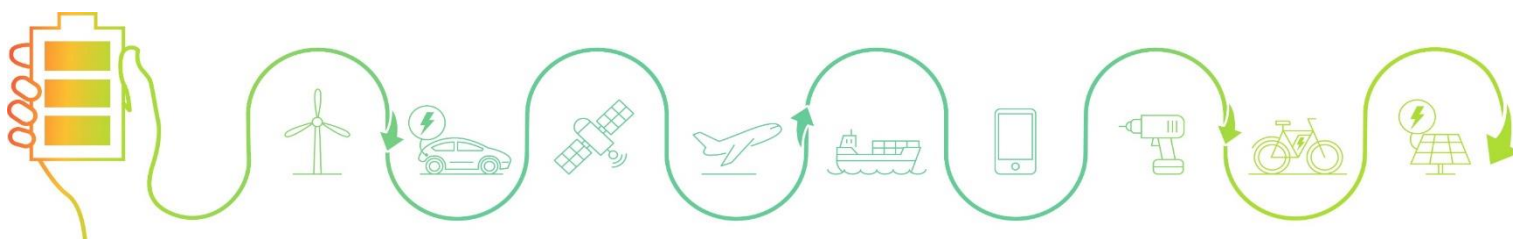
- (a) 45 % by 31 December 2023;
- (b) 63 % by 31 December 2027;
- (c) 73 % by 31 December 2030.

⁹⁷ https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics_-_recycling_of_batteries_and_accumulators&stable=0

⁹⁸ <https://www.epbaeurope.net/collection-targets>

⁹⁹ <https://www.eucobat.eu/downloads/position-paper-collection-target-waste-batteries>

¹⁰⁰ Article 59, point 3 Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1542>



Achieving these targets will move the collection and recycling of portable batteries towards a closed loop system which minimises emissions.

4.2.4.1.1 Portable batteries in consumer electronic products not discarded by users

Several surveys have demonstrated that consumers have a tendency to hoard electronic products that are old, broken, obsolete, or are simply no longer in use. A survey in summer 2022 of 8,775 households in six European countries (Portugal, Netherlands, Italy, Romania Slovenia and UK) found that the average household contains 74 electronic products (excluding lamps) and that about 13 (17%) are no longer used (9 working, 4 broken)¹⁰¹. Nearly 30% of mobile phones and game consoles in homes today are not in use, along with 20% of TV and video-player equipment, Figure 11.

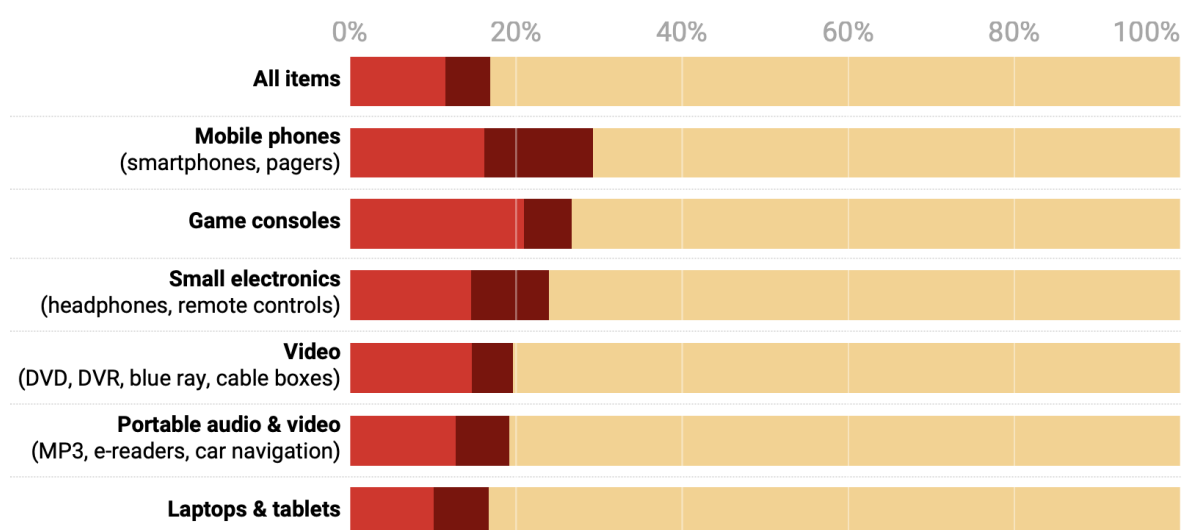
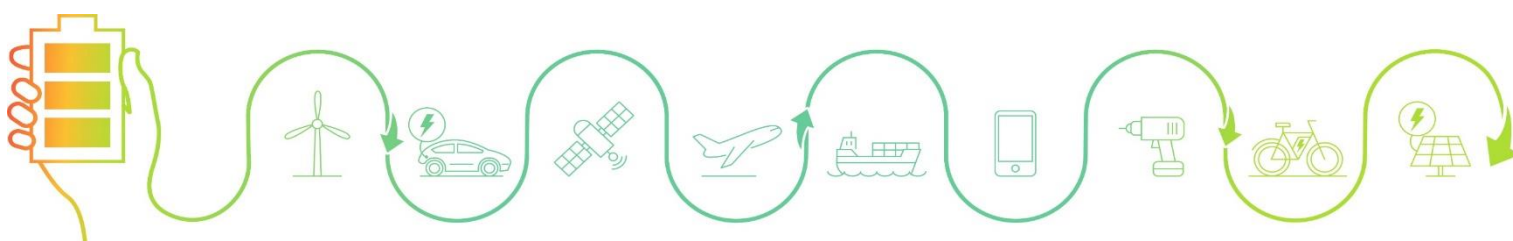


Figure 11. Electronics hoarding rates among European households

The survey results offer some insights about why people hoard their electronic products. The most common justification, for 46% of respondents, was that they might use an item again in

¹⁰¹ https://weee-forum.org/ws_news/of-16-billion-mobile-phones-possessed-worldwide-5-3-billion-will-become-waste-in-2022/



the future. Other reasons included sentimentality (13%), not knowing how to dispose of it (7%) and worry that it might contain sensitive data (2%) (see Figure 12).

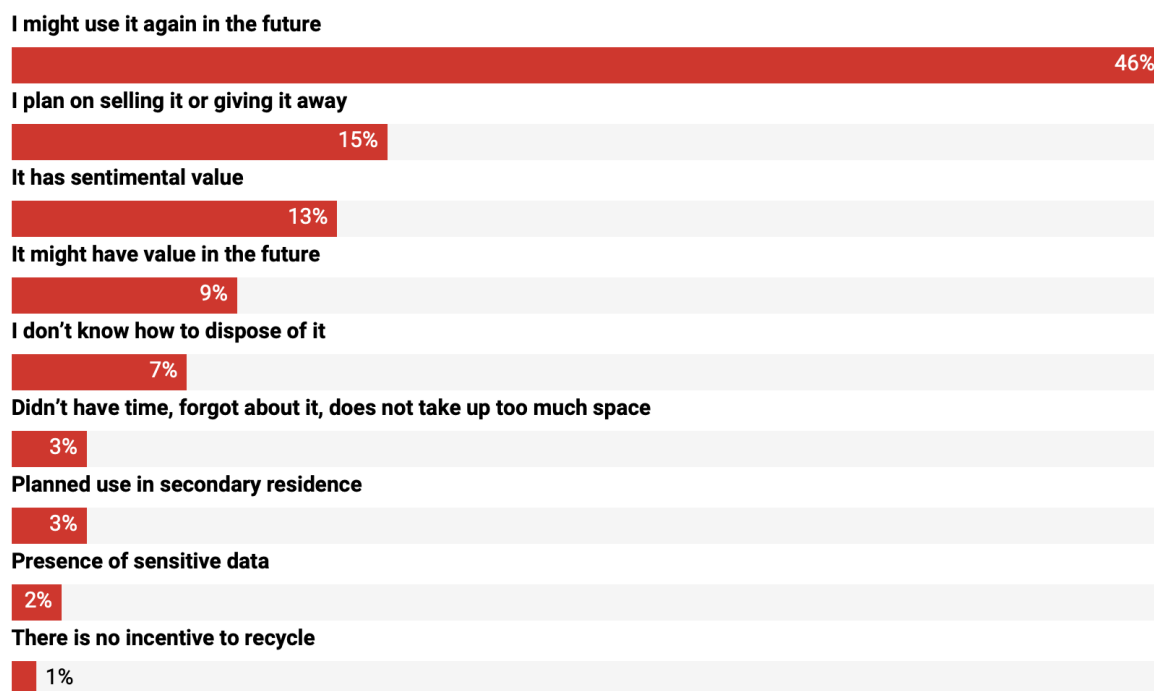
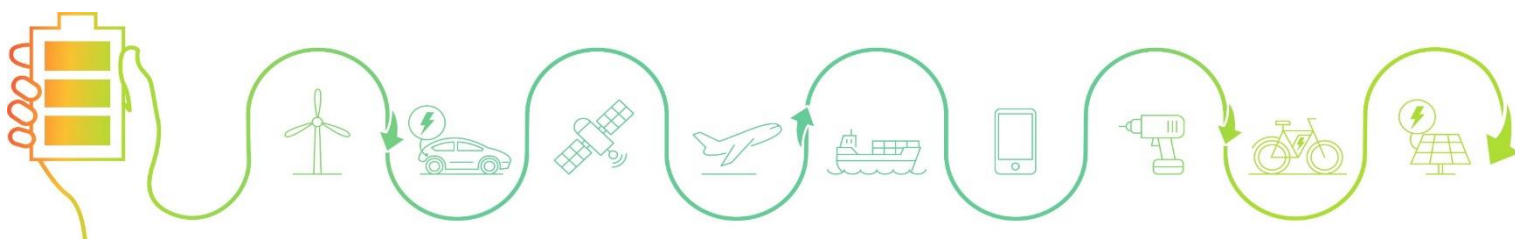


Figure 12. Top reasons for European households to hoard household electronics

The above findings were echoed in a survey commissioned by the Royal Society of Chemistry in 2019 of 2,353 people in the UK which found that 51% of households have at least one unused electronic products at home and 45% have up to five¹⁰². 69% of households intend to store these electronic products as spare devices.

These data explain why a large proportion of waste portable batteries in consumer electronic products are not available for collection and recycling because they are not discarded by users and are instead stored at home.

¹⁰² <https://www.rsc.org/new-perspectives/sustainability/elements-in-danger/#surveyfindings>



4.2.4.1.2 Portable batteries in consumer electronic products which are collected and recycled under the WEEE Directive

Article 8 (2) of the Directive Waste Electrical and Electronic Equipment (WEEE) Directive 2012/19/EU requires that the WEEE recycling process shall remove batteries from any separately collected WEEE. Article 3.1.I of the WEEE Directive defines ‘removal’ as meaning ‘*manual, mechanical, chemical or metallurgic handling with the result that hazardous substances, mixtures and components are contained in an identifiable stream or are an identifiable part of a stream within the treatment process. A substance, mixture or component is identifiable if it can be monitored to verify environmentally safe treatment*’.

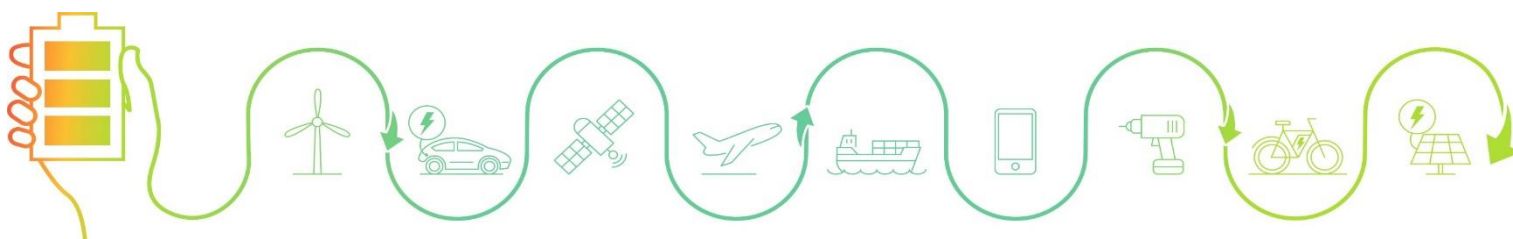
The European standard EN 50625-1¹⁰³ stipulates that batteries that are accessible in the waste equipment without using tools should be removed from WEEE before any treatment process that can cause damage to them. The WEEE Directive requires these accessible batteries shall be sent for recycling under the Batteries Directive 2006/66/EU, as amended by Directive 2013/56/EU. Batteries that are not accessible in the waste equipment without using tools should be part of an identifiable stream within the WEEE treatment process. Given the quantities of inaccessible portable batteries in consumer electronic products, this has a significant impact on the collection rate for portable batteries.

A EUCOBAT position paper published October 2020¹⁰⁴ estimates that less than 30% of portable batteries in waste consumer electronic products collected and recycled under the WEEE Directive are separately removed and sent for recycling under the Batteries Directive. The paper highlights that batteries in consumer electronic products represent 20 - 35% of the total amount of batteries put on the market by EUCOBAT members, and yet the batteries collected from the WEEE dismantlers only represent 4 - 13% of the total amount of collected batteries, which is less than 30%.

Small batteries in small consumer electronic products are often not separately removed during WEEE recycling. For example, small batteries in electronic cigarettes, remote controls, electric toothbrushes, etc are often not removed. Instead, it is common practice in the WEEE recycling industry to shred

¹⁰³ <https://knowledge.bsigroup.com/products/collection-logistics-treatment-requirements-for-weee-general-treatment-requirements/standard>

¹⁰⁴ <https://www.eucobat.eu/downloads/collection-target-waste-batteries>



these small consumer electronic products and use air filtration or centrifugal processes to separate the shredded fractions for further treatment. Many electronic products include small batteries on the printed circuit boards to provide back-up power to clock functions and memory functions. For example, some real-time clock chips include a button cell integrated into the chip packaging. The WEEE Directive requires the removal of printed circuit boards of mobile phones generally, and of other devices if the surface of the printed circuit board is greater than 10 square centimetres. These printed circuit boards are often sent for metal smelting including any batteries contained on the boards. As highlighted in section 4.2.3.2, smelting of batteries at 1,600°C completely destroys the PFAS and does not result in any PFAS emissions.

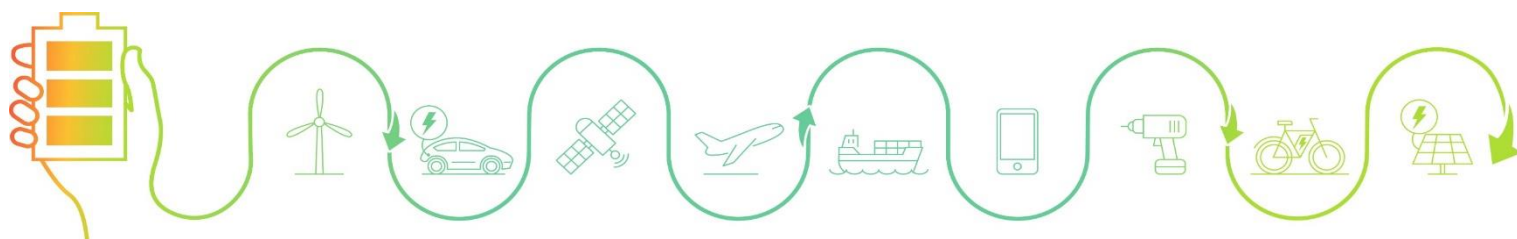
These data explain why a large proportion of waste portable batteries in consumer electronic products are not available for collection and battery recycling because they are not separately removed during the WEEE recycling process.

4.2.4.1.3 Portable batteries in consumer electronic products disposed in municipal waste in the EU

EUCOBAT data points to less than 10% of portable batteries put on the market ending up in household waste¹⁰⁵. Since 2016, most European countries have introduced restrictions on landfilling waste which have generally been implemented in Member States as bans on landfilling specific waste streams such as plastic, textiles and carpet wastes, and these wastes are increasingly incinerated. Furthermore, the revised Waste Framework Directive has set a target for reducing the amount of municipal waste sent to landfills of 10% of total waste by 2035.

Waste batteries in the remaining municipal waste are treated in municipal waste incinerators alongside other PFAS containing materials such as waste textiles and waste food contact materials. The operation of municipal waste incinerators is controlled under the Industrial Emissions Directive which includes permitted maximum emission of pollutants such as PFAS emissions.

¹⁰⁵ <https://www.epbaeurope.net/news/epba-s-feedback-to-the-inception-impact-assessment-on-modernising-the-eu-s-batteries-legislation>



4.2.4.1.4 Portable batteries in consumer electronic products which are exported outside of the EU

The European association of national collection schemes for batteries Eucobat¹⁰⁶ estimates that 19% of the portable batteries placed on the market in the EU are exported in second hand or waste electrical products and therefore are not available for collection and recycling in the EU. This includes exports to developing countries which may not operate controlled landfills or controlled incineration to the same performance levels that are required in the EU. When these devices reach their end of life, they may be treated in uncontrolled landfill or incineration processes which can give rise to higher emission levels of PFAS and other decomposition products than would be the case if these devices were disposed to landfill or incineration in the EU.

4.2.4.2 Recycling of waste batteries

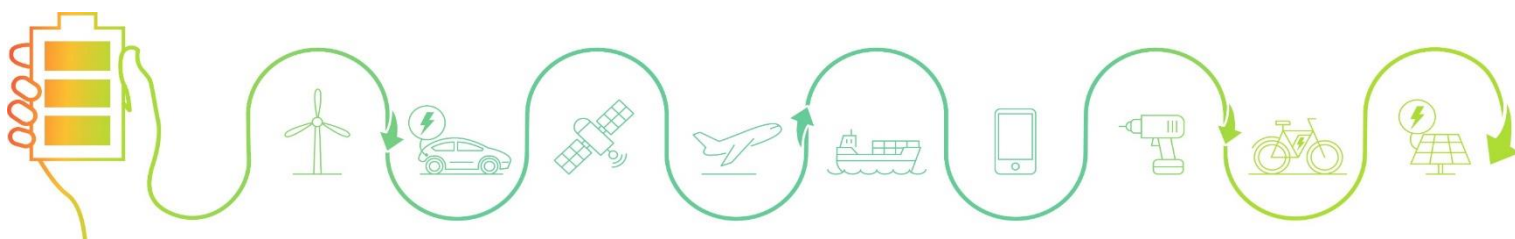
The Batteries Regulation aims ‘to make all batteries placed on the EU market more sustainable, circular and **safe**’¹⁰⁷. Specifically, this new law aims to achieve the circular economy and decarbonization ambitions of the EU from the sourcing of materials all the way through to battery collection, recycling and repurposing. Under this new Regulation, sustainability requirements such as disclosure of batteries’ environmental footprint and recycled content will be introduced starting in 2024. Even until then strong incentives for, domestic and sustainable recycling of batteries exist in Europe today¹⁰⁸:

- To reduce the dependency on imports of battery raw materials which are essential for EU's energy transition, it is critical that the capacity to recycle end-of-life batteries and battery manufacturing waste in Europe is built now. This will lead to resilient supply chains to secure raw material and reduce supply bottlenecks.

¹⁰⁶ <https://www.eucobat.eu/downloads/position-paper-collection-target-waste-batteries>

¹⁰⁷ ‘Green Deal: EU agrees new law on more sustainable and circular batteries to support EU’s energy transition and competitive industry’, Press release, 9 December 2022. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7588

¹⁰⁸ Molina, L., (December 2022). ‘The sustainable future of batteries in Europe rests on a developed recycling industry’, EIT InnoEnnery, co-funded by the European Union. <https://www.eba250.com/the-sustainable-future-of-batteries-in-europe-rests-on-a-developed-recycling-industry/>



- End customers, investors, and auto-OEMs demand that battery manufacturing and recycling meet the highest sustainability standards. This is likely to be a source of competitive advantage for cell manufacturers and automotive OEMs.

The battery recycling industry in Europe is still in its early stages and caters to the need for domestic recycling for portable electronics. However, as the manufacturing capacity of lithium batteries in the EU grows rapidly along with the exponentially increasing demand for batteries in electric vehicles and stationary energy storage projects, domestic and sustainable recycling of lithium batteries will be essential.

Batteries are recycled using pyrometallurgical processes and/or hydrometallurgical processes.

In the pyrometallurgical process, the batteries are treated at high temperatures to extract the metal elements (Nickel, Cobalt, Copper) in one or more stages, similar to ore smelting. In the first stage, the battery modules are dismantled from the larger battery packs. There is no fraction of the battery packs or battery cells which are disposed of to landfill. Instead, the battery cells are treated in the smelting reduction stage at between 1400°C and 1600°C to recover the Copper, Cobalt, Nickel, Lithium and small amounts of Iron.

All types of PFAS used in batteries are fully dissociated into fluorine compounds at these high temperatures. PVDF rapidly decomposes in the temperature range 400 – 510 °C, followed by gradual decomposition between 510 – 700 °C¹⁰⁹. The most stable PFAS, the perfluoromethane (CF₄) needs a temperature of 1380 °C to be dissociated¹¹⁰. The temperature of the smelting reduction stage results in complete destruction of all these types of PFAS.

¹⁰⁹ de Jesus Silva, A. J., Contreras, M. M., Nascimento, C. R., & da Costa, M. F. (2020). Kinetics of thermal degradation and lifetime study of poly(vinylidene fluoride) (PVDF) subjected to bioethanol fuel accelerated aging. *Heliyon*, 6(7), e04573–e04573. <https://doi.org/10.1016/j.heliyon.2020.e04573>

¹¹⁰ Table 5 from Bakker, J., Bokkers, B. & Broekman, M. (2021). Per- and polyfluorinated substances in waste incinerator flue gases. RIVM report 2021-0143. <https://www.rivm.nl/bibliotheek/rapporten/2021-0143.pdf>

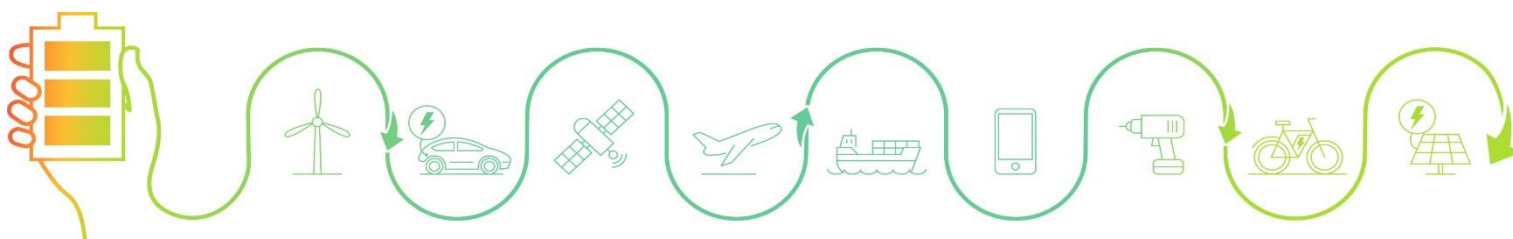


Table 4. Homolytic bond dissociation energies for fluorinated compounds*

Bond	BDE (kcal·mol ⁻¹)	Reference	T _{deg start} [*]	T _{deg 99} [^]
CF ₃ -F	131	1	1100	1380
CF ₃ -OH	115	1		
CF ₃ -H	106	1		
CF ₃ -CF ₃	99	1	750	930
CF ₃ -COOH	89	1		
FCI ₂ C-F	80	2		790
C ₈ F ₁₇ -C(O)OH	~79	&	200	~350
CF ₃ -SO ₂ NHCH ₃	78	4		
CF ₃ -SO ₂ OH; C ₂ F ₅ -SO ₂ OH	72.8; 70.7	3		
Cl ₃ C-Cl	71	2		670
CF ₃ -SO ₂ NH ₂	68	4		
C ₈ F ₁₇ -SO ₂ OH; C ₃ F ₇ -SO ₂ OH	64	4	450	600
CF ₃ -I	54	1		
C ₄ F ₉ -I	49	1		

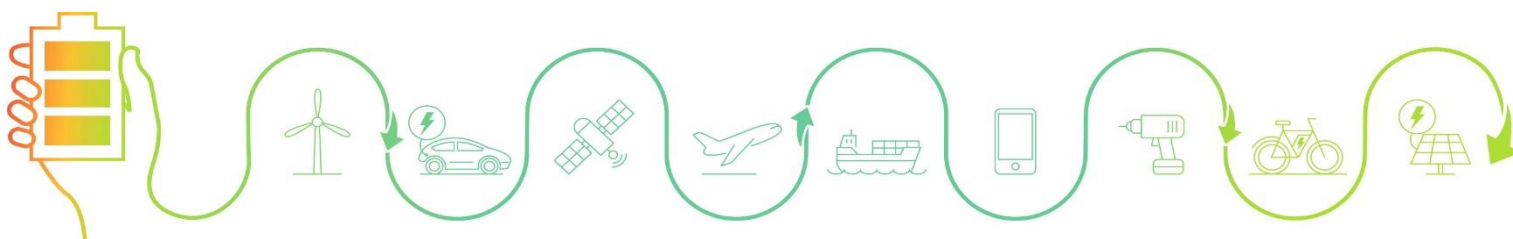
1) Luo (2007); 2) Taylor and Dellinger (1987); 3) Khan et al. (2019); 4) Dixon (2001). * T_{deg, start} is the temperature in °C at which decomposition starts. T_{deg, 99} is the temperature in °C at which 99% of the substance is decomposed at 2 seconds residence time. & own assessment.

*Table 4 is taken from Table 5 of Bakker, J., Bokkers, B. & Broekman, M. (2021). Per- and polyfluorinated substances in waste incinerator flue gases. RIVM report 2021-0143. <https://www.rivm.nl/bibliotheek/rapporten/2021-0143.pdf>

The degradation products depend on the incineration conditions and may include fluorine salts, hydrofluoric acid and carbon dioxide. Smelters are equipped with flue gas cleaning technologies which destroy any residual emissions. Hydrofluoric acid can be removed from incinerator flue gas and neutralized as fluorine salts¹¹¹. The fluorine salts are collected in the flue gas and are safely disposed or can potentially be recycled as Calcium Fluoride. The flue dust can also be further processed in a hydrometallurgical process to extract any specific remaining metal content, particularly lithium. At the end of the pyrometallurgical process, the PFAS-free metal alloys can be further refined into battery grade materials using hydrometallurgical processes. **As the materials are smelted at between 1400°C and 1600°C during the pyrometallurgical process, there are no PFAS emissions from the pyrometallurgical process.** This is confirmed in the Rensmo et al (2023)¹¹² study, which states that this process is sufficient for PFAS mineralisation.

¹¹¹ WanYuan, C., ShihLi, L., TianCheng, C., ChihHao, W., ChingChih, S., Peng, W., ChienChih, L., MingYeung, L., & ChengLung, S. (2020). Performance analysis of an online lime separation system in a refuse incineration plant. *Powder Technology*, 363, 300–309. <https://doi.org/10.1016/j.powtec.2019.12.050>

¹¹² Rensmo, A., Savvidou, E. K., Cousins, I. T., Hu, X., Schellenberger, S., & Benskin, J. P. (2023). Lithium-ion battery recycling: a source of per- and polyfluoroalkyl substances (PFAS) to the environment? *Environmental Science--Processes & Impacts*, 25(6), 115–13. <https://doi.org/10.1039/d2em00511e>



Lithium recovery is possible through both hydrometallurgical processes, and combined pyrometallurgical and hydrometallurgical processes, via the slags or via the flue dust. The rapid increase in demand for battery recycling in Europe in the coming years is expected to mostly be met by new pyrometallurgical and new hydrometallurgical processes which are currently in construction. In the hydrometallurgical process, the metals are extracted through solvent extraction or resin extraction technologies. Fluorinated compounds such as PVDF and PTFE are captured in the waste solvent / resin and other waste fractions. Confidential information submitted by our members to the ECHA consultation provide evidence that **there are no unintended or uncontrolled emissions of PFAS during the hydrometallurgical process**¹¹³.

When we will have extensive usage of the hydrometallurgical processes, the recovered PFAS may be treated in high temperatures where the fluoropolymers are totally decomposed (as compounds). There is also some R&D work performed in the hydrometallurgy process to recover directly the PVDF without any damage or degradation (via a thermal process leading to PVDF decomposition) using solvent extraction or dissolution techniques^{114, 115 & 116}.

All battery recycling operations are conducted in facilities which are permitted by the competent authority within each Member State, where any release of emissions is controlled and must be below regulation threshold limits. These limits include those set by the Industrial Emissions Directive¹¹⁷ which sets limits on preventing and limiting levels of pollution. Under the EU Green Deal (EGD) this Directive is in the process of being amended with a proposal released last year¹¹⁸, which not only addresses

¹¹³ Northvolt ECHA Consultation feedback reference number 6133 (doc 30).

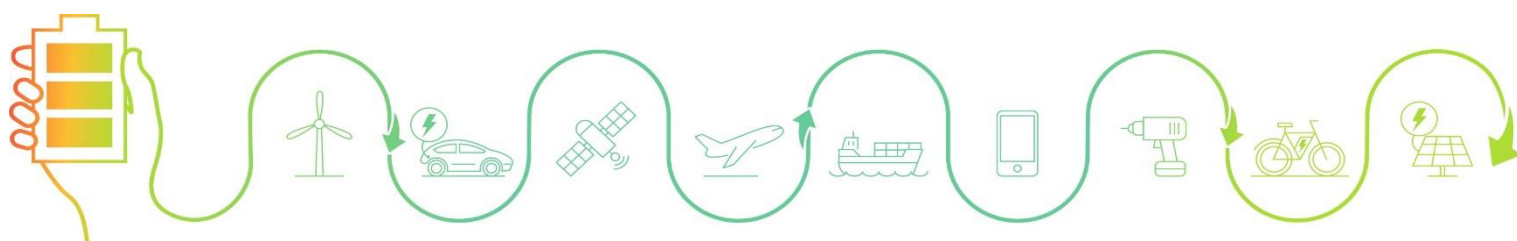
¹¹⁴ Fu, Y., Schuster, J., Petranikova, M., & Ebin, B. (2021). Innovative recycling of organic binders from electric vehicle lithium-ion batteries by supercritical carbon dioxide extraction. *Resources, Conservation and Recycling*, 172, 105666–. <https://doi.org/10.1016/j.resconrec.2021.105666>

¹¹⁵ Sarkar, A., May, R., Ramesh, S., Chang, W., & Marbella, L. E. (2021). Recovery and Reuse of Composite Cathode Binder in Lithium Ion Batteries. *ChemistryOpen (Weinheim)*, 10(5), 545–552. <https://doi.org/10.1002/open.202100060>

¹¹⁶ Bai, Y., Hawley, W. B., Jafta, C. J., Muralidharan, N., Polzin, B. J., & Belharouak, I. (2020). Sustainable recycling of cathode scraps via Cyrene-based separation. *Sustainable Materials and Technologies*, 25(NA), e00202–. <https://doi.org/10.1016/j.susmat.2020.e00202>

¹¹⁷ Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control), <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02010L0075-20110106>

¹¹⁸ Proposal for a Directive of the European Parliament and of the Council (COM(2022) 156 final/3) amending Directive 2010/75/EU and Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste, https://eur-lex.europa.eu/resource.html?uri=cellar:32d55555-c550-11ec-b6f4-01aa75ed71a1.0001.03/DOC_1&format=PDF



PFAS limits but also clarifies requirements for reviewing and updating permits to comply with environmental quality standards, measures under the water legislation permits as well as reducing emissions of pollutants and greenhouse gases emissions. The proposed IED specifically addresses the importance of the sustainable growth of batteries outlining all EU legislations in alignment to make this happen.

5 Socio economic impact assessment for battery value chain

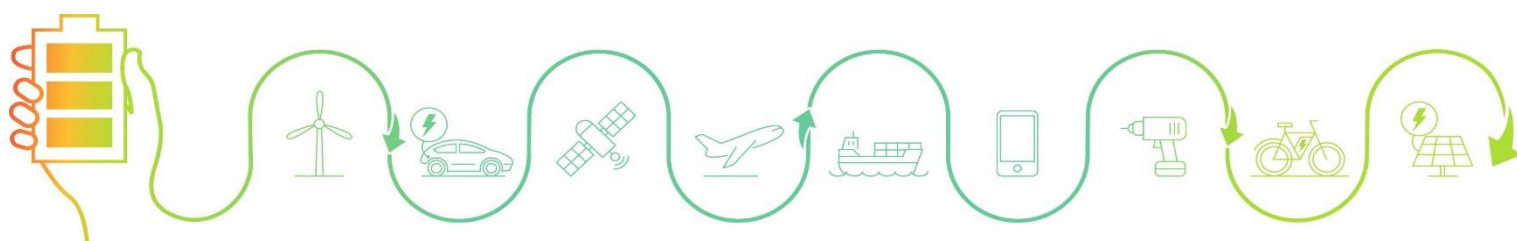
The European Green Deal is one of the world's most ambitious climate policies to usher the European Union into the net zero economy by 2050. The Green Deal relies on batteries to achieve objectives for low-emission mobility, decarbonised energy generation and digitalisation. **A PFAS restriction without derogations and transition periods for batteries, and without review clauses, will limit the Green Deal and prevent Europe from achieving a net zero economy by 2050.**

Batteries have been identified by the European Commission as a strategic value chain. The Commission states:

'Batteries are thus an important source of energy and one of the key enablers for sustainable development, green mobility, clean energy, and climate neutrality'¹¹⁹.

More than EUR 20 billion has been devoted to the EU battery value chain via the European Commission framework on Important Projects of Common European Interest (IPCEI), the European Investment Bank and research funding in the last few years. Dozens of billions more are available via the European Union InvestEU fund and the European Commission Recovery and Resilience Facility. 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 biggest battery cell manufacturer by the end of the

¹¹⁹ Page 1, REGULATION (EU) 2023/1542 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC, <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1542>



decade¹²⁰. As a direct effect, this will require 800 000 workers by 2025¹²¹. The installation and maintenance of batteries as well as end of life recycling could potentially create between 3-4 million jobs by 2025¹²².

- Europe is on track to produce 6.7 million battery electric cars (BEV) by 2032, or just over half of all the cars produced, which is in line with the recently agreed -55% CO2 target for carmakers for 2030 that is expected to result in a 50-60% share of BEV sales¹²³.
- Half of the lithium battery cells used in electric vehicles and energy storage systems in the EU were already made in the bloc in 2022, notably in Poland, Hungary, and to a lesser extent in Germany and Sweden. Transport & Environment analysis of the battery cell capacity announcements to date shows that Europe can be self-sufficient in battery cells, i.e. produce 100% of our lithium battery cell demand from 2027¹²⁴.
- Europe has secured much investment: the continent is projected to produce up to a third of lithium-ion batteries globally by 2030 (from just a few % today)¹²⁵.

However, this investment will likely not proceed if the derogations are limited to 13.5 years only. A company is not likely to invest in building a battery cell production factory with the knowledge that they will have to close the factory in 13.5 years.

¹²⁰ A European Response to the US Inflation Reduction Act, T&E report January 2023, <https://www.transportenvironment.org/discover/a-european-response-to-us-inflation-reduction-act/>

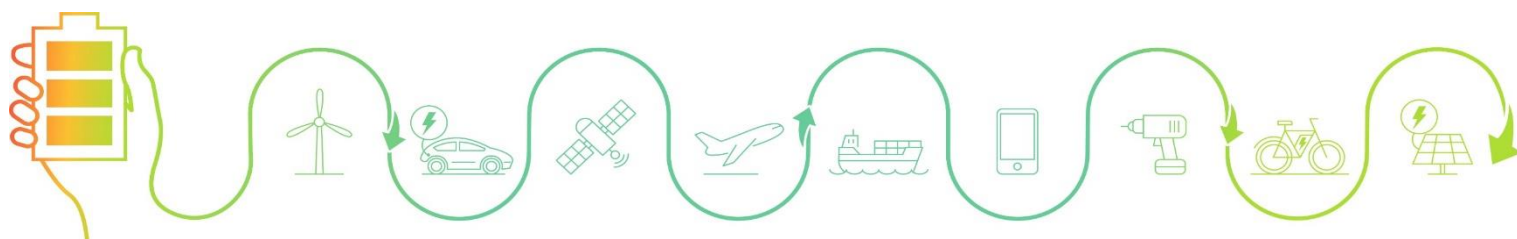
¹²¹ Commission Staff Working Document. Accompanying the document, Report from the Commission to the European Parliament and the Council. Progress on competitiveness of clean energy technologies. 1-Macroeconomic. SWD (2021) 307 final. October 2021. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD:2021:307:FIN#footnote114>

¹²² Entwicklung und Umsetzung eines Monitoringsystems zur Analyse der Akteursstruktur bei Freiflächen-Photovoltaik und der Windenergie an Land, https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2021-06-28_cc_49-2021_monitoringsystem_akteursstruktur_wind_pv.pdf

¹²³ Commitments but no plans, T&E 2021 report, https://www.transportenvironment.org/wp-content/uploads/2021/08/202106_EV_Report-Final-1.pdf

¹²⁴ A European Response to the US Inflation Reduction Act, T&E report January 2023, <https://www.transportenvironment.org/discover/a-european-response-to-us-inflation-reduction-act/>

¹²⁵ A European Response to the US Inflation Reduction Act, T&E report January 2023, <https://www.transportenvironment.org/discover/a-european-response-to-us-inflation-reduction-act/>



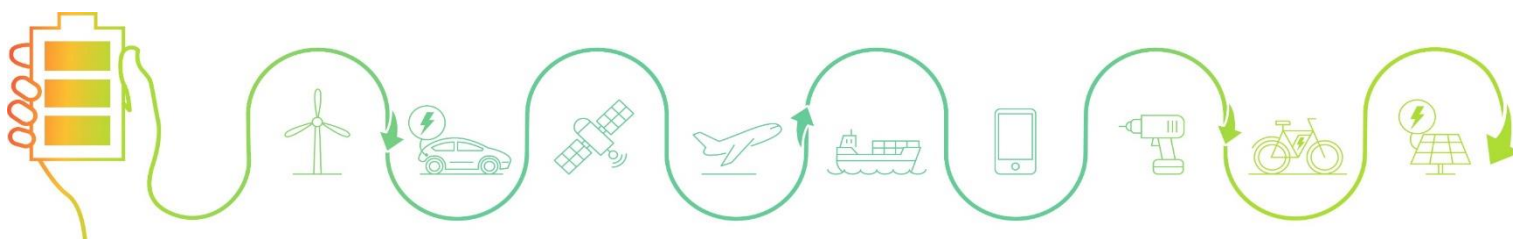
We have followed the time periods proposed by the 5 Member States of 6.5 years transition period and 13.5 years derogation period, however this does not mean that we believe these time periods are sufficient. **Even if these derogations and transition periods are granted with review clauses, this still does not provide sufficient certainty for companies to invest in new battery cell production in Europe because there is risk that the derogations may not be renewed.** This uncertainty is already diverting some new investments from Europe and putting a high risk on the current investments in Europe, which could jeopardise the future European batteries value chain. For this reason, RECHARGE proposes an alternative approach to manage the PFAS emissions risk in a different way (see section 5.4 Final remarks on the socio economic impact). Companies thinking about future investments in the EU Batteries Industry need a swift decision on the PFAS restriction to support these new investment plans.

Figure 13 summarises the battery cell production sites in Europe that are in planning, under construction or partly already in operation¹²⁶. These 45 sites represent over 56 billion Euros of investment and more than 43,000 jobs and provide the potential for Europe to become self-sufficient in battery cells as early as 2028 as an integrated value chain. Restrictions on PFAS inclusion in batteries placed on the EU market may imperil investments in all parts of the value chain - from manufacturing to recycling.

For example, a joint study by PwC and Aachen University (published in August 2023) estimate investments of more than 2 billion Euros in the EU recycling market by 2030 and additional investments in recycling capacity of around 7 billion euros are required to handle all recyclable material in 2035¹²⁷. As batteries containing PFAS placed on the market 10 - 15 years from now will only be available for recycling in 20 - 25 years, any planned battery recycling facilities anticipate

¹²⁶ Figures include EU Member States and European Economic Area countries – therefore Russia, UK & Serbia have not been included in our calculations. Figures obtained from IPCEI Market Analysis Q4 2022, https://www.ipcei-batteries.eu/fileadmin/Images/accompanying-research/publications/2023-02-BZF_Kurzinfo_Marktanalyse_Q4_22-ENG.pdf.

¹²⁷ Page 17, Joint study between Strategy& (Part of the PwC network) and PEM of RWTH Aachen University, (August 2023). European battery recycling market analysis, A profitable and sustainable business before 2035. <https://www.strategyand.pwc.com/de/en/industries/automotive/recycling-european-battery.html>



market, technological, and regulatory changes. This will have an impact on current investment in the battery recycling market.

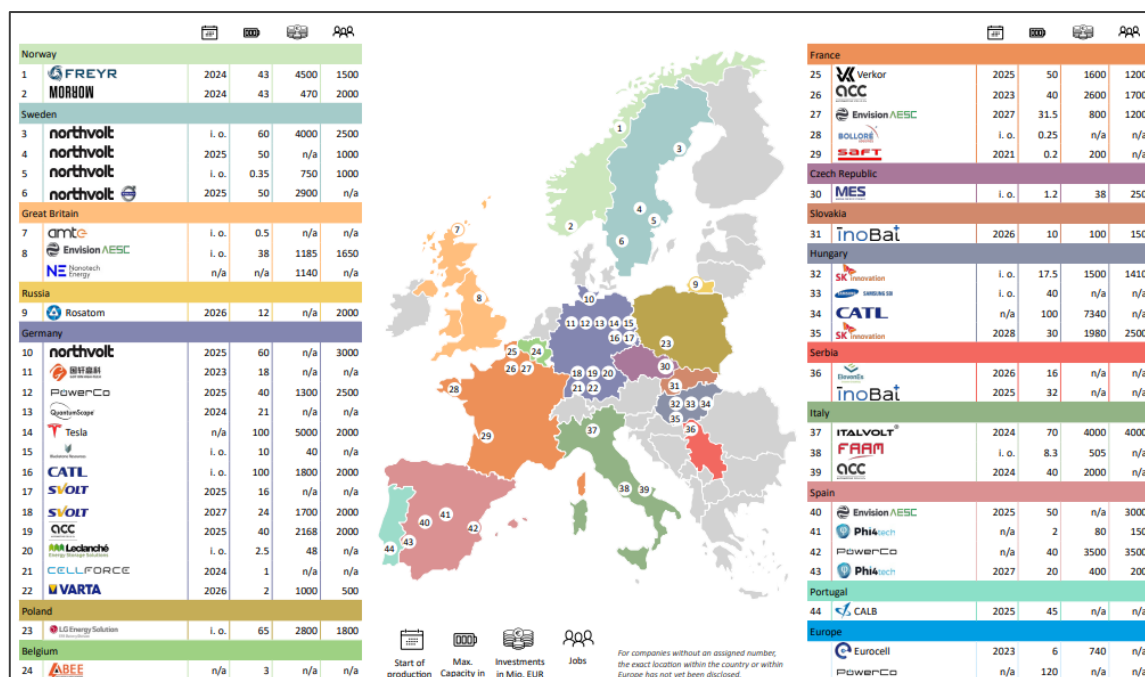
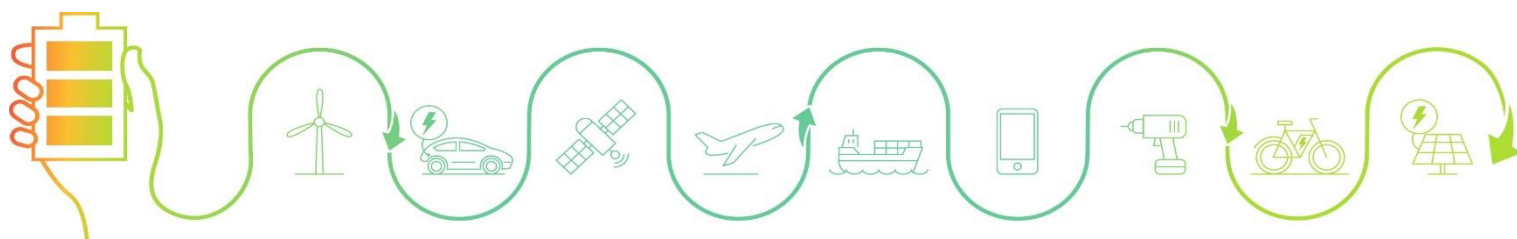


Figure 13. Battery cell production sites in Europe¹²⁸

A PFAS restriction without derogations, transition periods and review clauses, for batteries will stop existing and new investment in battery cell production sites and battery recycling facilities operating in Europe. Both the battery manufacturing and recycling industries need a swift decision on the PFAS restriction to protect existing and new investments in the EU Batteries Industry

¹²⁸ From Figure 2 of from IPCEI Market Analysis Q4 2022, https://www.ipcei-batteries.eu/fileadmin/Images/accompanying-research/publications/2023-02-BZF_Kurzinfo_Marktanalyse_Q4_22-ENG.pdf.



5.1 EV batteries

Batteries are critical to the functioning of society to enable electric vehicles to replace sales of new combustion engine vehicles by 2035. On 29 June 2022, all climate ministers of the 27 EU member states agreed to the European Commission's proposal (part of the 'Fit for 55' package) to effectively ban the sale of new internal combustion vehicles by 2035 (through '[introducing] a 100% CO₂ emissions reduction target by 2035 for new cars and vans')¹²⁹. Requiring new cars sold in the EU to emit zero CO₂ from 2035 would make it impossible to sell new internal-combustion engine cars. In 2026, the Commission will assess whether hybrid vehicles or CO₂-neutral fuels could comply with the goal with future technological developments. The Commission commented that it would keep an “open mind” but that at present, hybrids did not deliver sufficient emissions cuts and alternative fuels were prohibitively expensive.

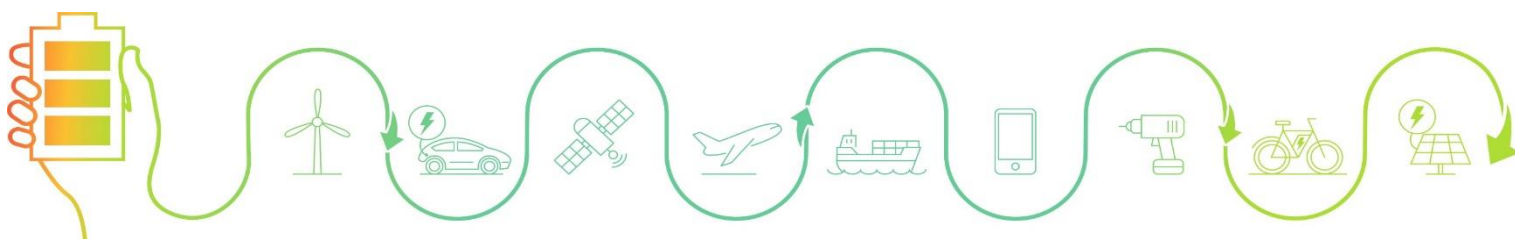
Most EU Member States have also signed up to the COP26 declaration on accelerating the transition to 100% zero emission cars and vans¹³⁰. All signatories support an accelerated transition to zero emission vehicles in line with achieving 100% of new car and van sales being zero emission in leading markets by 2035, and by making them accessible, affordable and sustainable in all regions by 2030.

These climate proposals aim to ensure the EU – the world’s third-biggest greenhouse gas emitter – reaches its 2030 target of reducing net emissions by 55% from 1990 levels. Doing so will require governments and industries to invest heavily in electric vehicles.

A PFAS restriction without derogations, transition periods and review clauses for batteries will stop sales of new and second-hand electric vehicles in Europe.

¹²⁹ <https://www.consilium.europa.eu/en/press/press-releases/2022/06/29/fit-for-55-council-reaches-general-approaches-relating-to-emissions-reductions-and-removals-and-their-social-impacts/>

¹³⁰ <https://www.gov.uk/government/publications/cop26-declaration-zero-emission-cars-and-vans/cop26-declaration-on-accelerating-the-transition-to-100-zero-emission-cars-and-vans>



5.2 Industrial batteries

In electricity generation, batteries enable grids to install more renewable energy capacity using solar and wind sources. One of the well-known shortcomings of solar and wind energy sources is their large variability in power generation - the sun does not always shine, and the wind does not always blow. Battery storage helps renewable generators reliably integrate with existing grids by storing the excess generation and by smoothing the energy distribution.

Batteries also help traditional suppliers manage the stability of energy distribution thanks to their unique ability to quickly absorb, store, and deliver electricity as needed. Among its many uses, batteries help operators regulate the frequency of the electrical current - an important aspect of electricity transmission – to help store electricity until transmission capacity is available and help maintain capacity reserves. Batteries also make isolated and off-grid installations viable and less dependent on diesel generators.

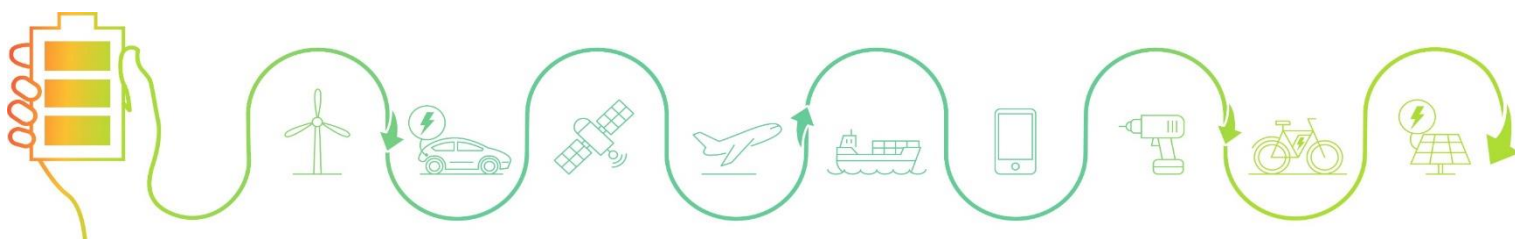
Industrial batteries also provide continuous and stable supply of energy with backup services.

While there are many technologies used for utility-scale energy storage, rechargeable lithium batteries have become favoured in new installations due to their flexibility and scalability, and their declining costs. At the beginning of the 1990s, the storage capacity that is required to power a regular-sized house for a day would have cost about 75,000 Euro and the battery package would have weighed 111kg¹³¹. The same level of capacity can now be obtained at a cost of around 2,000 Euro from a 40kg, small backpack-sized cell.

Industrial batteries also include small primary lithium batteries, which are essential for applications that require long battery lifetimes (up to 25 years) or instant readiness after long standby periods (for applications such as pacemakers, defibrillators, emergency alarm systems, and remote IoT applications).

A PFAS restriction without derogations, transition periods and review clauses for batteries will inhibit the growth of renewable energy and stop the sales of life saving equipment.

¹³¹ <https://www.economist.com/graphic-detail/2021/03/31/lithium-battery-costs-have-fallen-by-98-in-three-decades>



5.3 Portable batteries

The public in Europe rely on their electronic devices to continue to function in an emergency when mains power source is not available. For example, a long battery life is needed in communication devices such as smartphones, tablets and laptops so that in case of a health or safety incident, the device can continue to function to enable people at risk to continue to communicate effectively with the emergency response authorities. Batteries provide indispensable back-up power to these communication devices in case of a power cut.

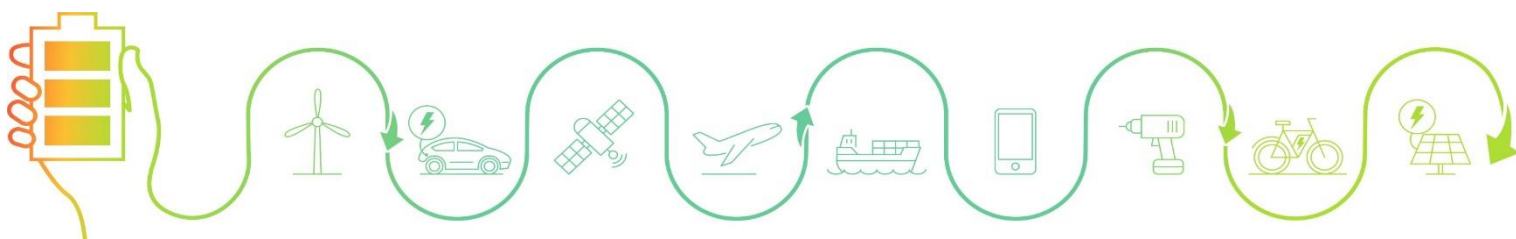
Today's society is an information-rich world which is becoming more and more portable. Portable electronic devices including laptops, tablets, mobile phones, and wearable electronic devices are critical to support the rapid growth of information processing and sharing in society. Without batteries, these devices would not be portable and instead would require permanent connection to a fixed power source.

From VOIP to global telecom carriers, portable electronic devices enable people to travel the world and stay connected. To respond effectively to global pandemics such as COVID 19, remote workers and international businesses need to be able to utilize video calls and conference calls via the Internet to keep their businesses going without interruption. Portable electronic devices support increased productivity by enabling working from home opportunities that simply were not available previously. At the same time, more flexible working arrangements have enabled a larger cross-section of society to contribute their knowledge and skills into the workplace.

Portable electronic devices have enabled more people to access education opportunities. Online seminars allow people to learn in a faster, more convenient, and efficient fashion.

Portable electronic device help people to carry out complex tasks in a simpler, quicker manner. Smart bracelets and health apps enable people to monitor, analyse and alter personal health habits. Many hospital systems have online gateways that allow patients to obtain their medical records, or communicate with their physician online, nearly instantly. Batteries are indispensable to make these devices portable so that they can deliver these critical functions to society.

A PFAS restriction without derogations, transition periods and review clauses for batteries will stop Europe from achieving Green Deal digitalisation objectives.



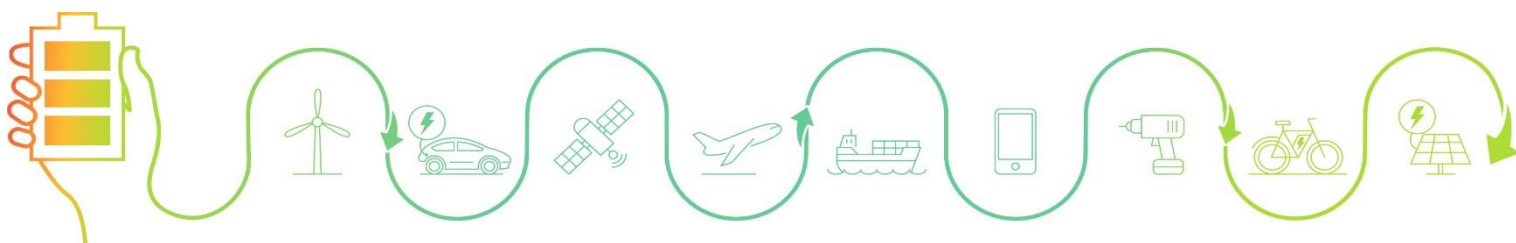
5.4 Final remarks on the Socio economic Impact

In Section 5 we have made clear the impact a PFAS restriction will have on the industry. It must be emphasised the proposal itself is having a detrimental impact on the battery value chain industry right now. In this submission we have demonstrated:

- that all those involved in battery value chain industry comply with stringent local and national policies and hence **emissions are controlled during the manufacturing and recycling processes.**
- that PFAS are embedded well within the battery and **there is no direct contact of PFAS to consumers and end users during battery use.**

The ECHA PFAS restriction proposal is **creating high uncertainty for the battery value chain industry and diverting forecasted growth and investment away from the EU. This forecasted growth and investment (which does not factor in the ECHA PFAS restriction proposal) is now in direct jeopardy.**

As mentioned in the introduction RECHARGE and its members understand the concern behind the regulatory action and support efforts to restrict PFAS which are widely used across the EU and pose unacceptable risk to human health or the environment such as perfluorooctanoic acid (PFOA). **We believe a reduced scope that would exclude PFAS which have been characterised as non-hazardous, and applications that can demonstrate non-dispersive use of the PFAS, and where recycling obligations at the end of life are applicable – is answering the need of phasing out toxic PFAS. This condition would be applicable to the usage of batteries.**



Glossary

FEP	Fluorinated ethylene propylene
FKM	Fluoroelastomer
LiCF ₃ SO ₃	Lithium trifluoromethanesulfonate
Li-ion	Lithium-ion battery
LiSO ₂	Lithium sulfur dioxide battery
LiSOCl ₂	Lithium-thionyl chloride
LiTFSI	also known as TFSILi Lithium bis(trifluoromethanesulfonyl)imide
LMP	Lithium-metal-polymer
LTO	Lithium titanate oxide
Na-ion	Sodium ion rechargeable battery
NFM	Layered oxide of Ni, Fe, Mn (for Na-ion)
Ni-Cd	Nickel Cadmium battery
Ni-MH	Nickel metal hydride battery
NTO	Niobium Titanate Oxide
PAA	Polyacrylic acid
PBA	Prussian Blue Analogues
PEI	Polyethylenimine
PFA	Perfluoroalkoxy
PFAS	Per and polyfluoroalkyl substances
PTFE	Polytetrafluoroethylene
PVDF	Polyvinylidene difluoride (both homopolymer and copolymer)
VDF	Vinylidene fluoride
Zn-ion	Zinc-ion rechargeable batteries

