



Miljøministeriet
Miljøstyrelsen

Den 12. juli 2024

Aktdetaljer

Akttitel: Vs: Battery industry PFAS derogation requests and substitution timescales

Aktnummer: 170

Sagsnummer: 2023 - 11008

Akt-ID: 7370090

Dato: 25-04-2023 15:17:10

Type: Udgående

Dokumenter:

- [1] RECHARGE FIRST submission.pdf
- [2] Battery industry PFAS derogation requests and substitution timescales.html

Application for derogations from PFAS REACH restriction for specific uses in batteries



April 2023

First submission

By RECHARGE

RECHARGE Members

Industry Members



Association Members

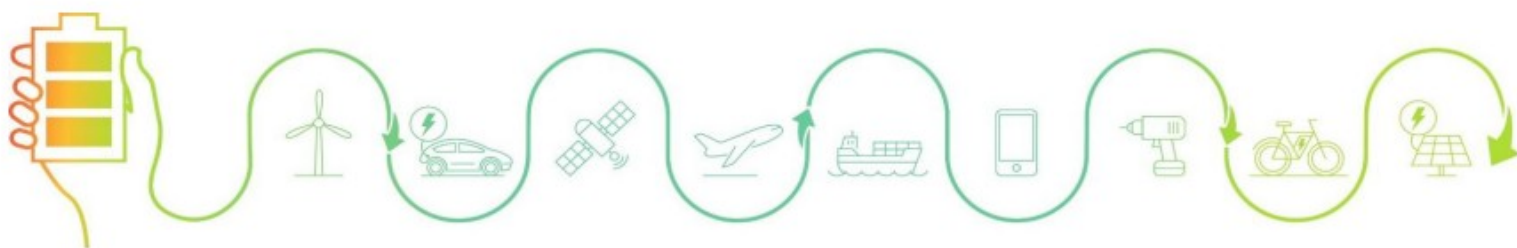


Executive Summary

The PFAS (Per and polyfluoroalkyl substances) REACH restriction proposal will have a major impact on the battery industry. This document provides RECHARGE's feedback to the public consultation and the latest proposal of 22 March. For specific applications where PFAS are used in batteries, RECHARGE is **requesting derogations and additional transition times to provide sufficient time for the battery industry to identify and implement alternative non-PFAS solutions.**

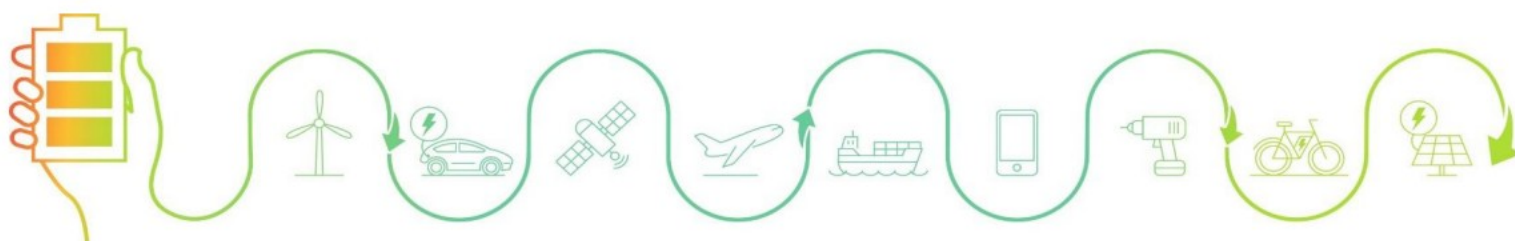
Batteries are a main enabler for the transition towards low-emission mobility, decarbonised energy generation and digitalisation. Batteries power a wide range of general public applications such as smartphones, tablets, power tools, hearing aids, defibrillators, safety lighting in public buildings, and provide many services to industry such as back-up power for mission critical industrial assets (from nuclear power plants to data centres), energy storage systems for electrical grids, traction power to forklift trucks and AGV's, and deliver energy to a wide variety of machines such as drones, rockets, satellites and IoT objects. Batteries also provide power to an increasing number of mobility solutions such as e-bikes, e-scooters and electric vehicles. They generate significant economic growth and provide jobs for millions of people.

This document details what types of PFAS are used in batteries and why, whether there are non-PFAS alternatives available, what are the tonnages of PFAS consumed and emitted, the socio-economic impact assessment of the proposed PFAS restriction for the battery value chain and finally proposes best practices that the battery industry and legislators could implement to further minimise emissions. All statements provided in this document are supported by scientific evidence.



Contents

Executive Summary	3
1 Introduction and scope	5
2 Why are PFAS used in batteries and where?	6
2.1 PFAS used in active material mass of electrodes	7
2.1.1 PVDF used in active material mass of electrode	9
2.1.2 PTFE used in active material masses of electrode	11
2.2 PFAS used in electrolytes	12
2.3 PFAS used in valves, gaskets, washers, permeable membranes	14
2.4 PFAS used in separator coatings	16
2.5 PFAS used in solid-state batteries	17
3 Missing uses – analysis of alternatives	19
3.1 Uses where alternatives are not yet available	21
3.1.1 Use of PVDF as the binder of the active material masses	22
3.1.2 Use of PTFE as the binder of the active material masses	25
3.1.3 Use of PFAS in electrolytes	26
3.1.4 Use of PTFE & FEP in gaskets & washers in chemically aggressive environments	27
3.1.5 Use of PFA, VDF, HFP, FKM in gaskets in high performance batteries which require very thin high performance gaskets	28
3.1.6 Use of PTFE in oxygen permeable membranes in Zinc air batteries	30
3.1.7 Use of PTFE / PVDF in solid electrolyte/ gel polymer in solid-state batteries	31
3.2 Uses where substitution is technically feasible but more time is required	31
4 PFAS consumption in tonnes and emissions during battery life cycle	35
4.1 PFAS consumption in tonnes	35
4.2 Emissions during the battery life cycle	35
4.2.1 Emissions during battery manufacturing	35
4.2.2 Emissions during battery use	36
4.2.3 Emissions during battery recycling	36
5 Socio economic impact assessment for battery value chain	37
6 Why RECHARGE seeks derogations and additional transition times, and industry best practices	37
Glossary	38



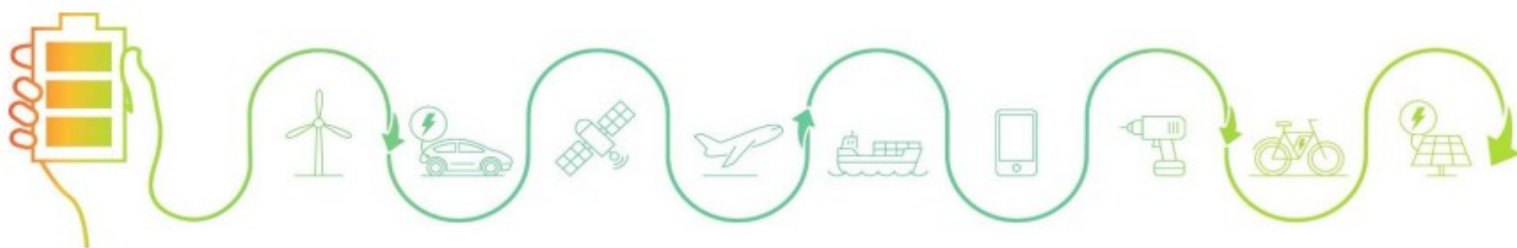
1 Introduction and scope

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

The only type of rechargeable battery which does not use PFAS is lead-acid batteries. However, lead-acid batteries have a low energy density. Lead-acid batteries cannot be used as suitable alternatives for the technologies presented above and applications they serve. These technologies serve applications where a variety of performances are required, amongst which are high energy, high power, very long life, superior reliability, ability to withstand extreme temperatures. Lead-acid batteries have limited capacity in these respects and cannot be considered as suitable alternatives. In addition, lead compounds used for battery manufacturing and lead metal have been recommended by ECHA for inclusion on Annex XIV respectively in the 6th and 11th recommendations.

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 (from nuclear power plants to data centers), **energy storage systems** for electrical grids, traction power to



forklift trucks and AGV's, and deliver energy to a wide variety of machines such as drones, rockets, satellites and IoT objects. Batteries also provide power to an increasing number of **mobility** solutions such as e-bikes, e-scooters and electric vehicles. 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 statements provided in this document are supported by scientific evidence.

This is a first submission. RECHARGE will update this document with additional information during the public consultation.

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.

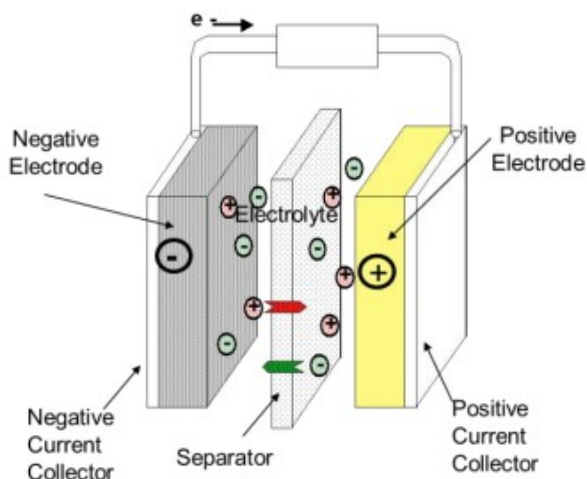
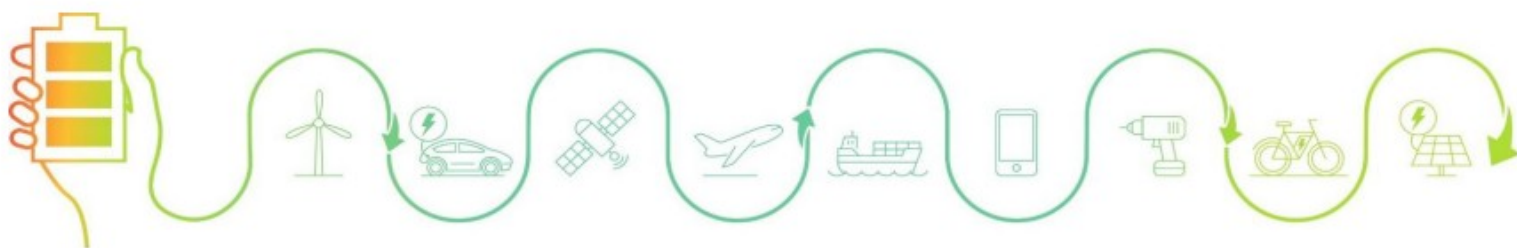


Figure 1. Components of a battery



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 are used in key components for all high performance and lithium battery technologies. PFAS are used in key components in:

- Active material masses
- Electrolytes
- Valves, gaskets, washers & membranes
- Coatings

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 2). The active material mass comprises an active material, conductive additives (when needed) and a binder material.

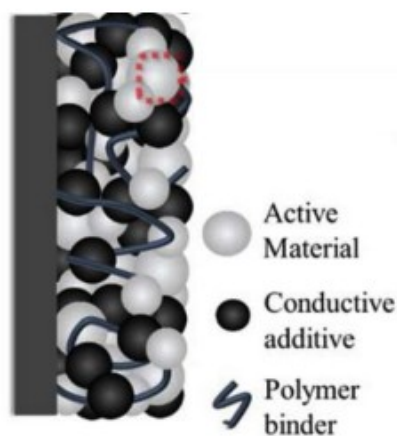
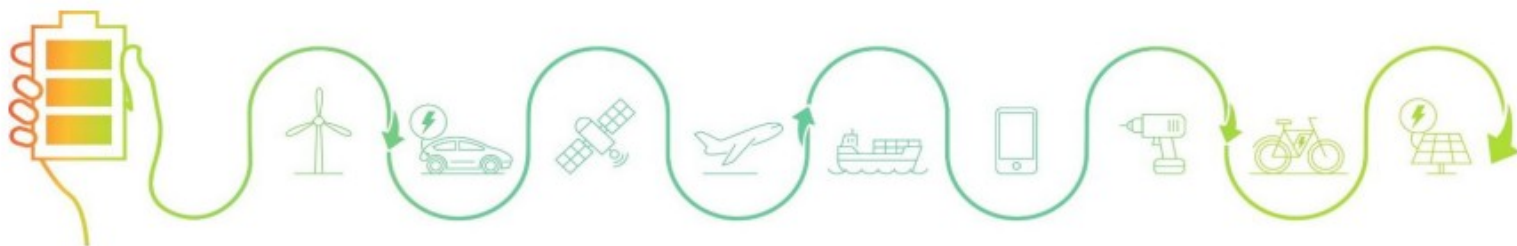


Figure 2: Composite electrode materials

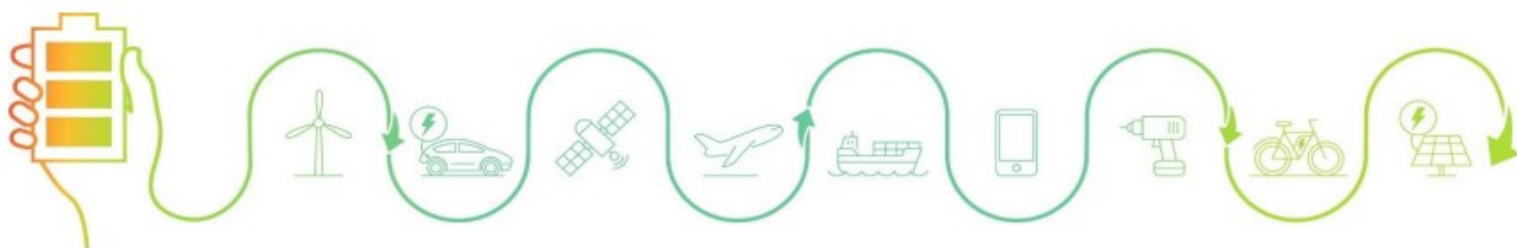


Binder material is used to hold the active material particles together within the composite electrode and to provide a strong connection between the electrode and the current collector. The binder material plays an important role in the manufacturability of the battery and in the battery performance.

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.

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	SBR/CMC with graphite anode, PVDF with LTO anode	Liquid organic electrolyte
Li-ion (dry process)	PTFE with NMC active mass	SBR/CMC 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
Lithium metal rechargeable	PVDF (and PTFE), 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

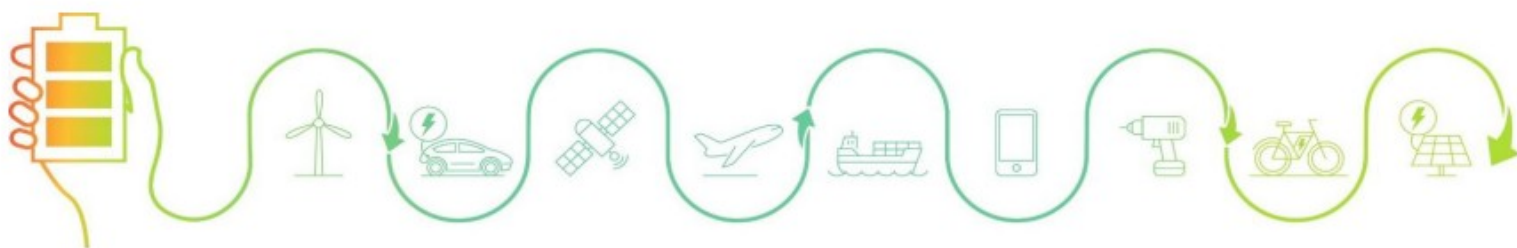
Although the PVDF binder comprises only a small portion of the composite electrode (typically 2–5% of the mass of the electrode¹), the binder plays four important roles in battery performance. The PVDF binder:

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

¹ 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>



- **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 cell) 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.

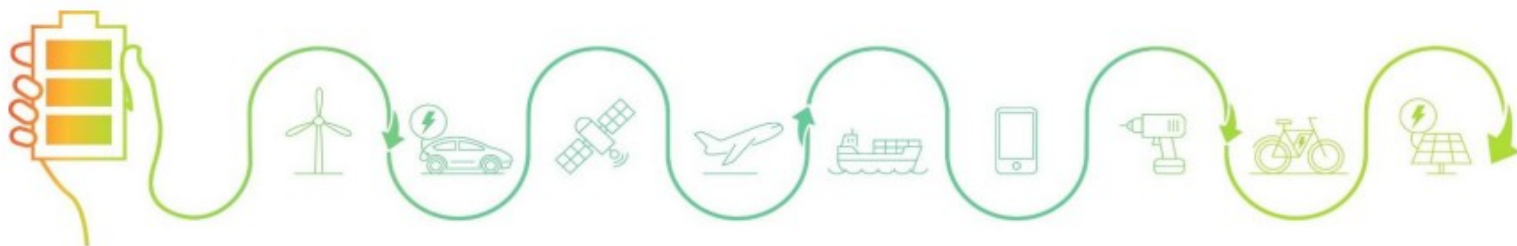
PVDF was previously also used as the binder material for all negative electrodes, however companies using graphite negative electrodes have successfully substituted PVDF with water-based CMC/SBR binder materials. For other types of negative electrodes using higher voltage materials such as lithium titanate oxide (LTO), NTO (Niobium Titanate Oxide)² 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 materials³ and with hard carbon⁴.

² 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>

³ 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>

⁴ 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>



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^{5,6}.

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 to 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:

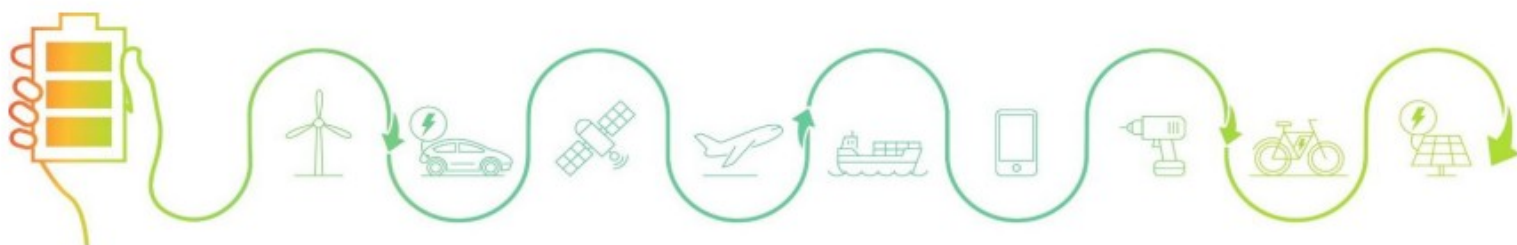
⁵ Xi, X., Mitchell, P., Zhong, L. & Zou, B., (2009). Dry particles based adhesive and dry film and methods. Unites States Patent Application Publication. Publication No.: US 2009/0239127 A1
<http://pdfs.oppedahl.com/US/20090239127.pdf>

⁶ 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>;

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>



- **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 3.9 V),
- **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 and provide adhesion to the current collector,
- **Good dispersion properties** to ensure the uniformity during the manufacturing of the electrodes,
- **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.

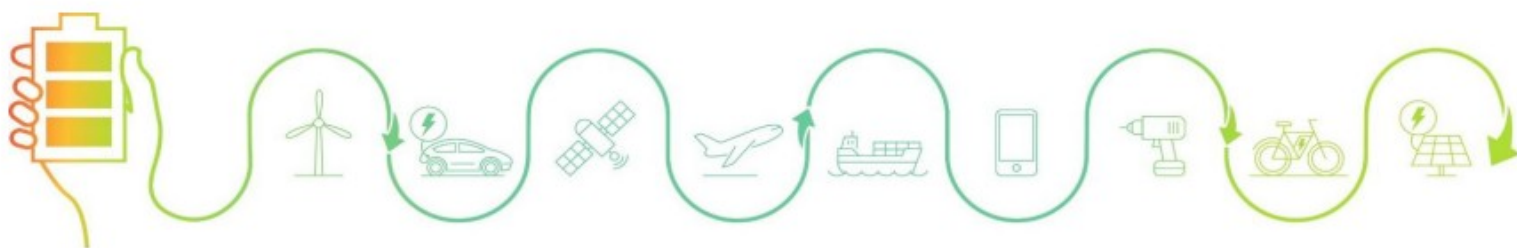
Polyvinyl alcohol (PVA, CAS 9002-89-5) or Poly(acrylic acid) (PAA, CAS 9003-01-4) may be added to the positive electrolyte binder material to create void volume after baking, this helps with electrolyte absorption.

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

PFAS is 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 in older battery technologies for many years. However, recent advances in battery technology have established the use of PFAS substances as state-of-the-art for high performance batteries today, including as additives and as Lithium salt with PFAS anion. These include Lithium salts of PFAS monomers such as Li-Triflate

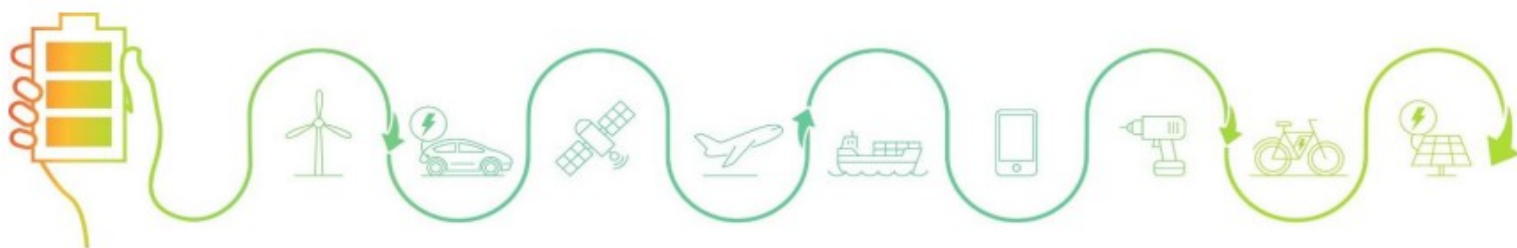


(CAS 33454-82-9), LiTFSI (CAS 90076-65-6), LiBETI (CAS 132843-44-8), LiFAP (LiPF₃(CF₂CF₃)₃n and LiTDI (CAS 761441-54-7). Examples of PFAS additives include Tris(2,2,2-trifluoroethyl)borate (TFEB CAS 659-18-7) and Trifluorotoluene (TFT CAS No. 98-08-8). PFAS substances are also used as gelifiers for Lithium-ion 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 are widely used in next generation Lithium-ion 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 primary Lithium 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 rechargeable Lithium-ion cells). The use of the PFAS salts instead of lithium perchlorate also provides increased stability and performance as well as 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 3 for cylindrical cells and Figure 4 for prismatic cells⁷, 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.

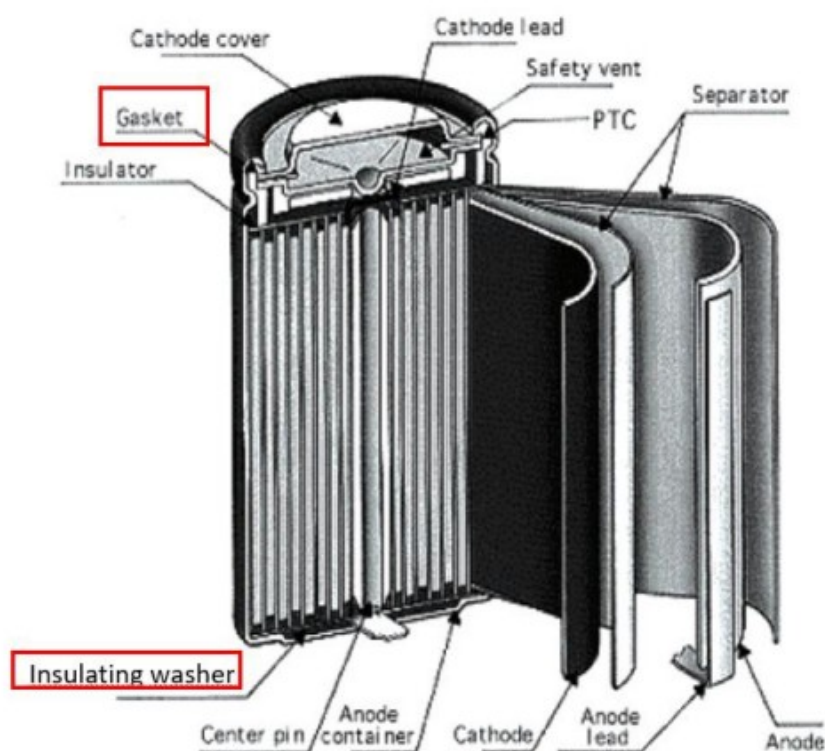
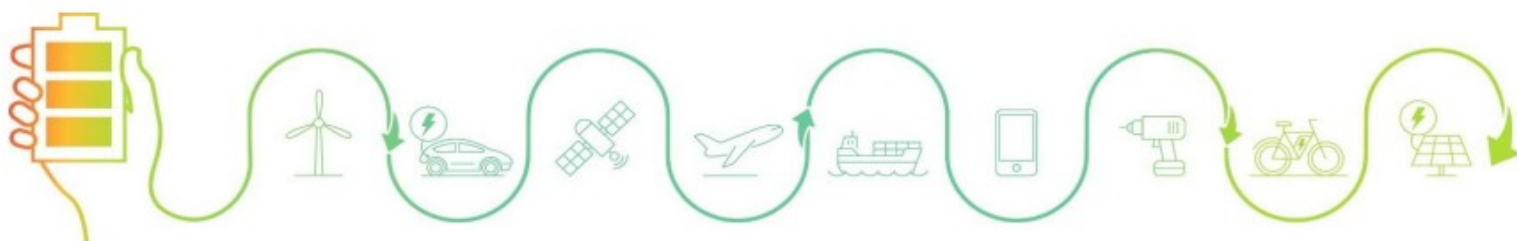


Figure 3. Gasket and washer in a cylindrical cell

⁷ Arora, P., & Zhang, Z. (John). (2004). Battery Separators. *Chemical Reviews*, 104(10), 4419–4462. <https://doi.org/10.1021/cr020738u>



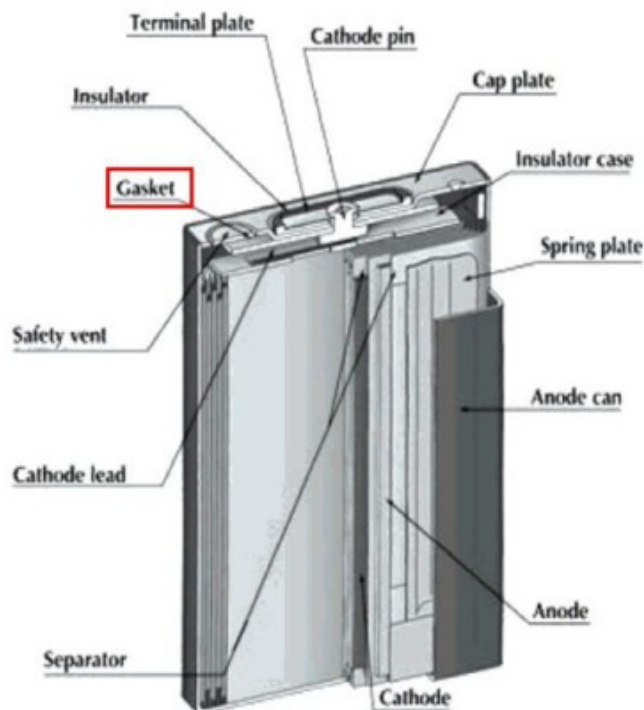
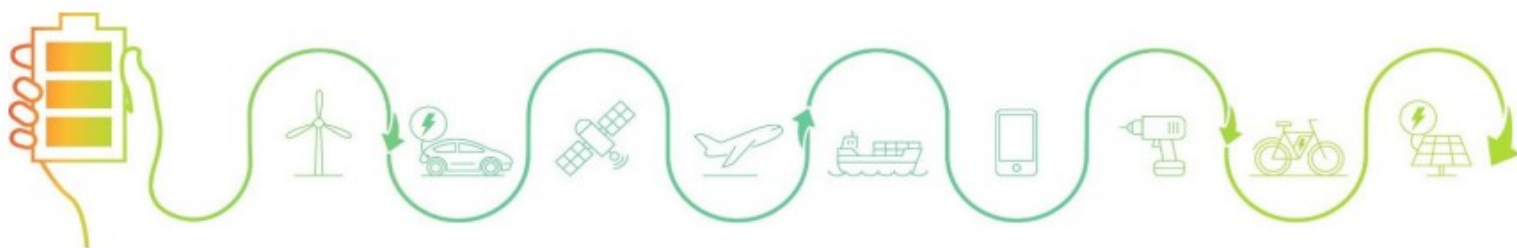


Figure 4. Gasket in a prismatic cell

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.

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 may be possible to replace PTFE with another high-temperature non-PFAS polymer in these applications.

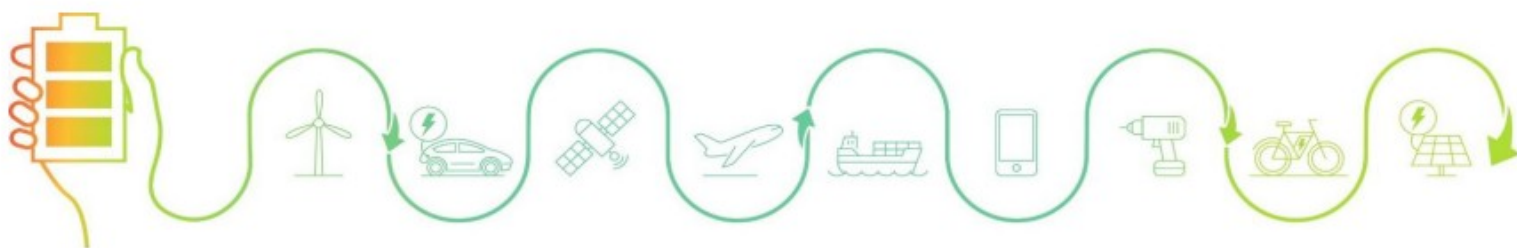
Zinc air batteries have the highest energy density of any practical battery system and operate by allowing oxygen to access the battery and react with the zinc. The oxygen is reacted on a catalytic surface inside the cell. Air permeable PTFE membranes are necessary to allow air to enter the battery whilst 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)⁸. 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

⁸ 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>



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 the separator. Other companies have developed non-PFAS binders which also provide good levels of adhesion to the separator and the electrolyte/composite electrode. Some organisations are researching the use of binder-free, thin-film ceramic-coated separators which may be able to provide improved safety for Lithium-ion batteries⁹.

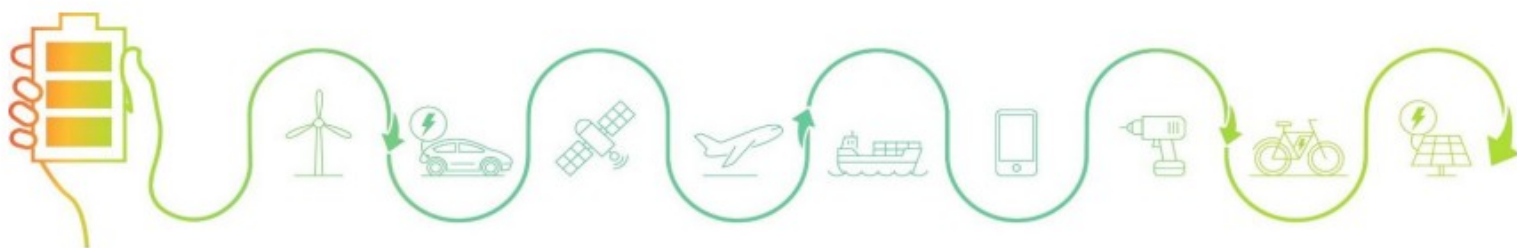
2.5 PFAS used in solid-state batteries

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 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.

⁹ 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>



The architecture of LMP batteries is illustrated in Figure 3 and is based on using polymers as electrolytes and managing their chemical interfaces.

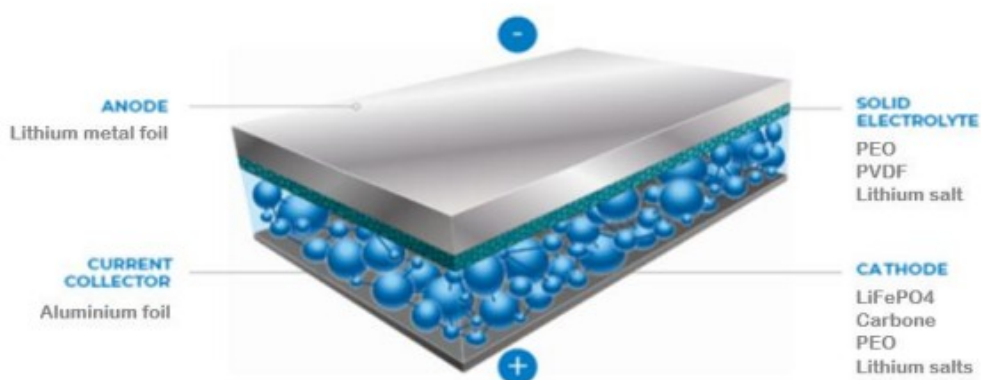


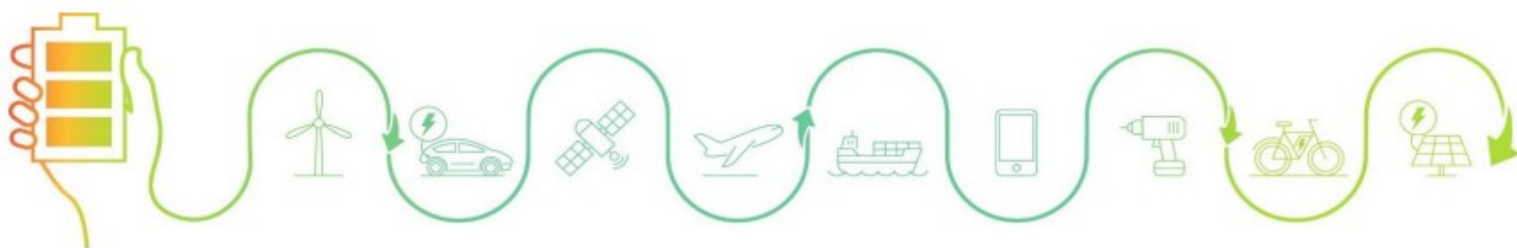
Figure 5. Schematic diagram of an LMP solid-state battery

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

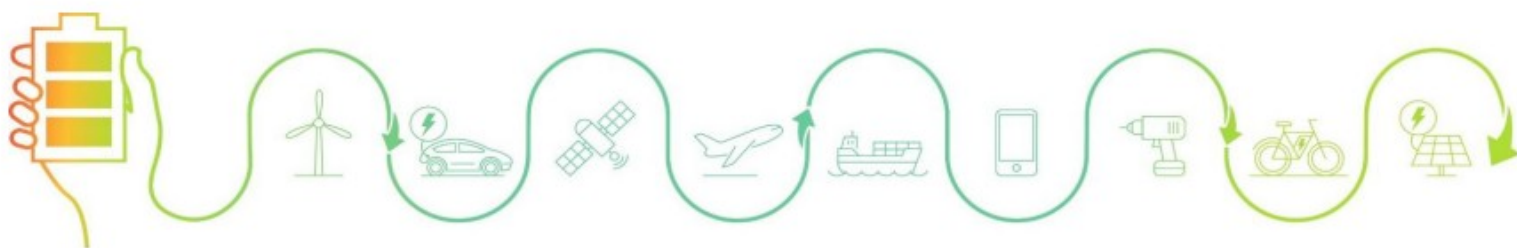
These PFAS represent less than 5% of the cell's weight, but their role is crucial for the battery. PFAS are foreseen as even more important for the next generation of solid-state batteries. TFSI will be part of the cell recipe for its superior conductivity performances. PVDF is also expected to be a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



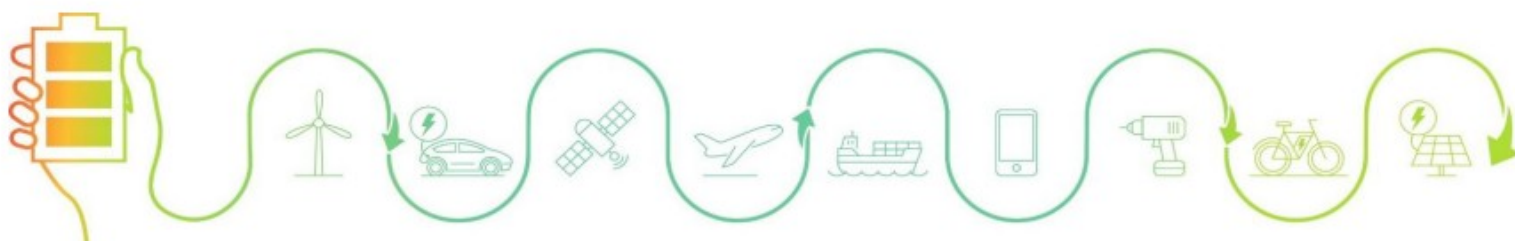
3 Missing uses – analysis of alternatives

Table 2. Summary of derogation/transition period requests for various PFAS types, used in different types of batteries depending on current alternatives or alternatives in development

PFAS type	Where used in the battery	Type of battery	Alternatives available today?	Alternatives in development?	Derogation / transition period
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
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
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 prevents 20% degradation of battery life.	13.5 years



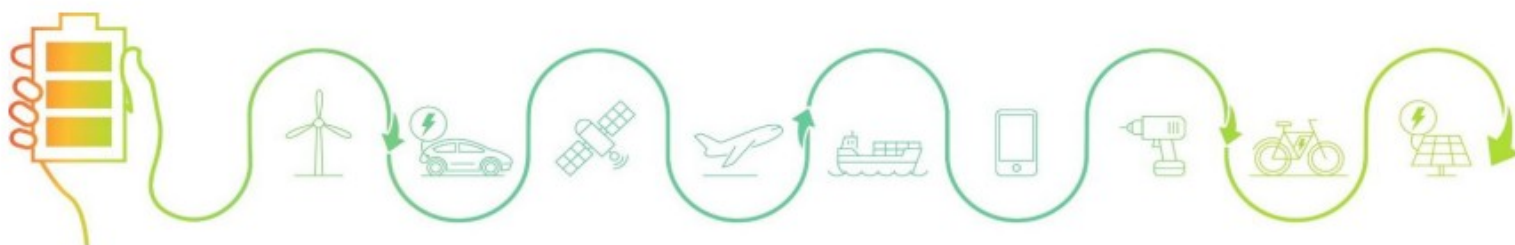
PFAS type	Where used in the battery	Type of battery	Alternatives available today?	Alternatives in development?	Derogation / transition period
PTFE, FEP	Gaskets, washers	Chemically aggressive environments where PFAS is needed for electrochemical stability such as Lithium primary batteries using Li-SO ₂ and Li-SOCl ₂	No	No	13.5 years
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	No other polymers have required mechanical properties and electrical insulation properties.	No	13.5 years
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
PVDF, PTFE	Solid electrolyte/ gel polymer electrolyte	Solid-state batteries	No	No	13.5 years



PFAS type	Where used in the battery	Type of battery	Alternatives available today?	Alternatives in development?	Derogation / transition period
PTFE, PVDF	In coatings on the separator	Li-ion rechargeable, Lithium primary	Yes	Yes	Transition time of 6.5 years
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 time of 6.5 years

3.1 Uses where alternatives are not yet available

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. As a result, the battery industry requires 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

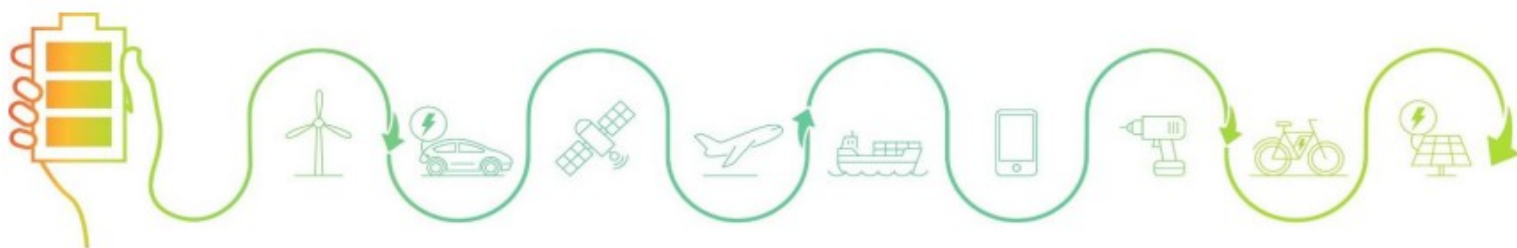
PVDF is used as the binder material in the active masses for electrodes for Li-ion wet process (except for the graphite anode), Na-ion, Lithium metal rechargeable, and solid-state batteries. For the positive electrode, all attempts to replace PVDF binder materials with other polymers have caused cell 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 210°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 NMP as the solvent. A peer reviewed academic article¹⁰ indicates 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

¹⁰ 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>



cell performance, lower cost and reduced environmental impact¹¹. For other types of negative electrodes using higher voltage materials such as Lithium titanate oxide (LTO), NTO (Niobium Titanate Oxide)¹² 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 materials¹³ and with hard carbon¹⁴.

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 polymers¹⁵. 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 properties¹⁶. 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.

¹¹ 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>

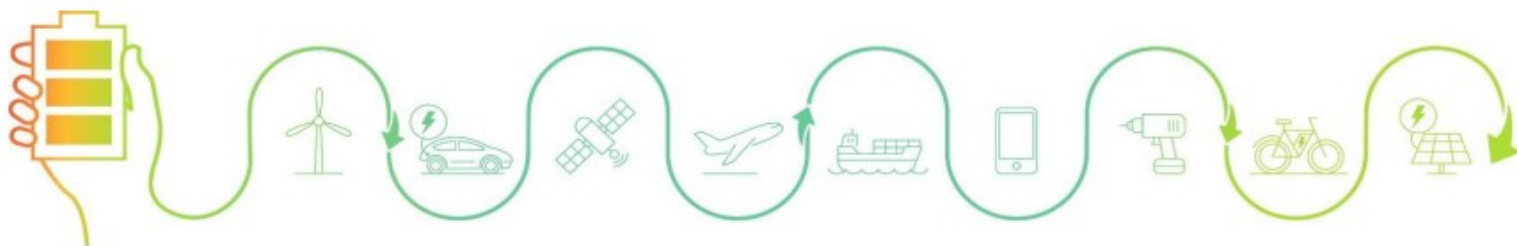
¹² Next-Generation SCiB™ supporting smart mobility in the age of MaaS, Using Niobium Titanium Oxide (NTO) as a next-generation anode material. (n.d.). <https://www.global.toshiba/ww/products-solutions/battery/scib/next/nto.html>

¹³ 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>

¹⁴ 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>

¹⁵ 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>

¹⁶ 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>



The Germany Government has funded the DigiBatt Pro 4.0¹⁷ 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 capacity. 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,
- 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.

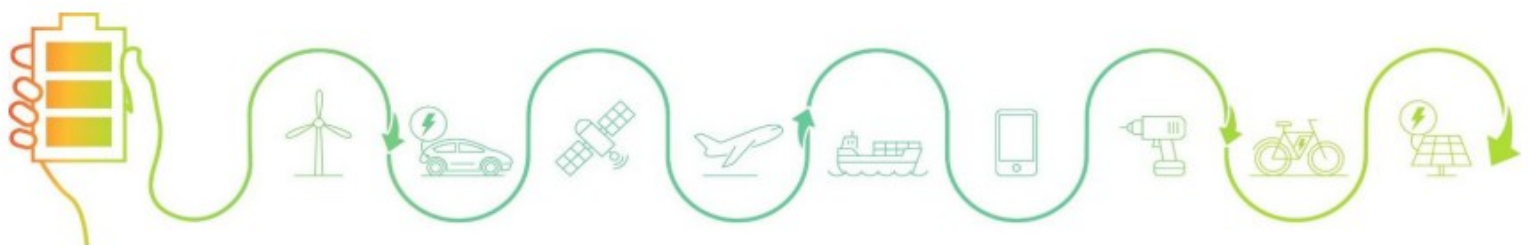
Further investigation of this research project confirms it focussed on a very specific high nickel NCM cathode active material at a moderate cell voltage of 4.2V. There is no evidence that this water-based binder material could be developed to meet the performance targets for positive electrodes with 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 applications. 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

¹⁷ “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



- swelling, fast charge cycling is unknown,
- electrode processability 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.

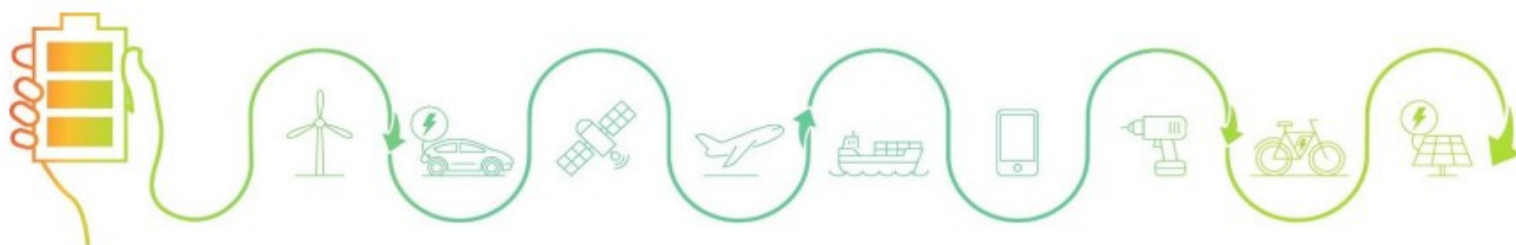
Furthermore, replacing the PVDF cathode binder likely requires the development of new cathode active material and Aluminium current collectors that are compatible with a new binder and solvent system. Water is known to cause poor cycle life and increased impedance growth in Lithium-ion cells. A new grade 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 at least 10 years, followed by 5 years to commercialise the new technologies.

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**.

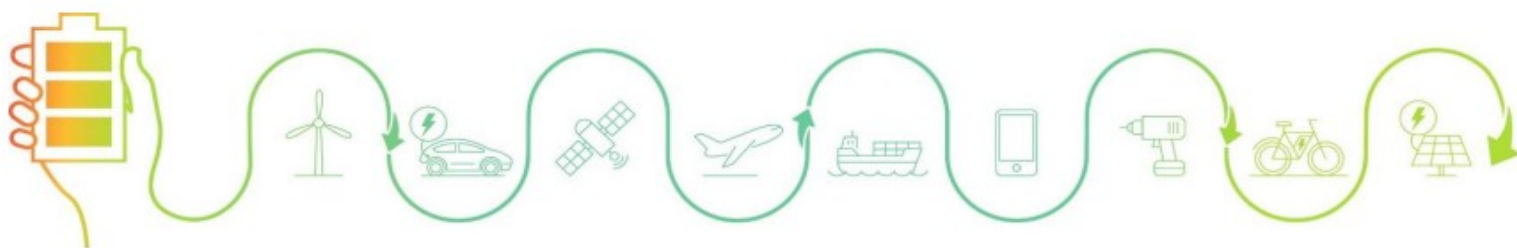
Alternative non-PFAS materials such as Polyvinyl alcohol (PVA, CAS 9002-89-5) and Poly(acrylic acid) (PAA, CAS 9003-01-4) have been tested as potential binder materials for the positive electrode and have been found to fail due to performance and manufacturability issues. The degradation of these alternative 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 the electrolytes for Lithium-ion rechargeable, Lithium primary, Lithium metal rechargeable, and Sodium-ion rechargeable batteries. LiPF₆ (which is not a PFAS) has been widely used in older battery technologies for many years. However, LiPF₆ has been found to cause degradation in Li-ion cells, primarily from its thermal decomposition or hydrolysis to form acidic species. Recent advances in battery technology have established the use of PFAS substances as state-of-the-art for high performance batteries today, including as additives and as Lithium salt with PFAS anion.

PFAS electrolytes are used in advanced batteries to provide higher stability, increased performance and higher safety levels. This stability is provided by the high strength of the carbon-fluorine bond in



the PFAS which is not present in the older electrolytes. As a result, the PFAS electrolytes provide 20% more battery life compared to LiPF₆ electrolytes. This increased battery life provides sustainability benefits by extending the lifetime of the product.

In rechargeable batteries, Lithium salts of PFAS monomers such as Li-Triflate (CAS 33454-82-9), LiTFSI (CAS 90076-65-6), LiBETI (CAS 132843-44-8) and LiFAP (LiPF₃(CF₂CF₃)₃n) are 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 at least 10 years, followed by 5 years to commercialise the new electrolyte chemistry.

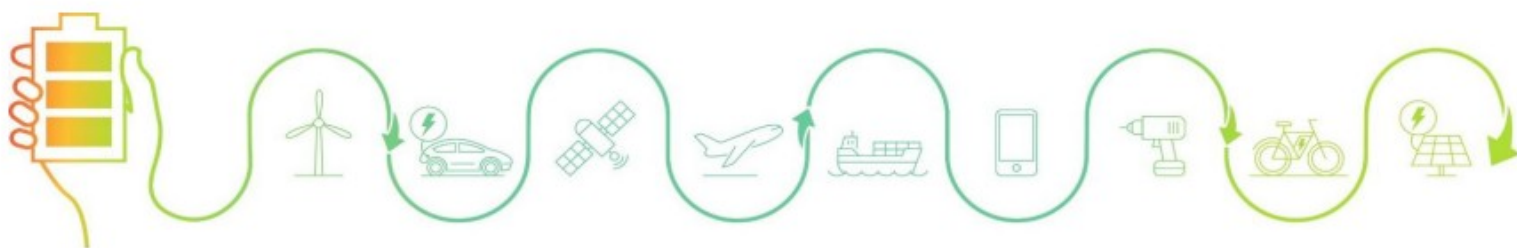
For Lithium primary batteries, Lithium salts based on monomolecular PFAS have been developed to replace the endocrine disruptor Lithium perchlorate and to improve the performance and durability of Lithium primary batteries (especially Lithium manganese dioxide batteries). Non-PFAS alternatives for Lithium perchlorate are currently not known and would have to be newly developed.

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 rates and lifetimes. This chemically inert solvent (in particular, inert to Li metal) has unique properties that can reduce the viscosity of the cell and therefore the conductivity of the Lithium metal rechargeable batteries. 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. There are no non-PFAS alternatives available today.

We estimate that research and development efforts to identify non-PFAS alternatives for electrolytes would take at least 10 years, followed by 5 years to commercialise the new electrolyte chemistries.

3.1.4 Use of PTFE & FEP in gaskets & washers 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, so that a derogation of 13.5 years is considered to be necessary.

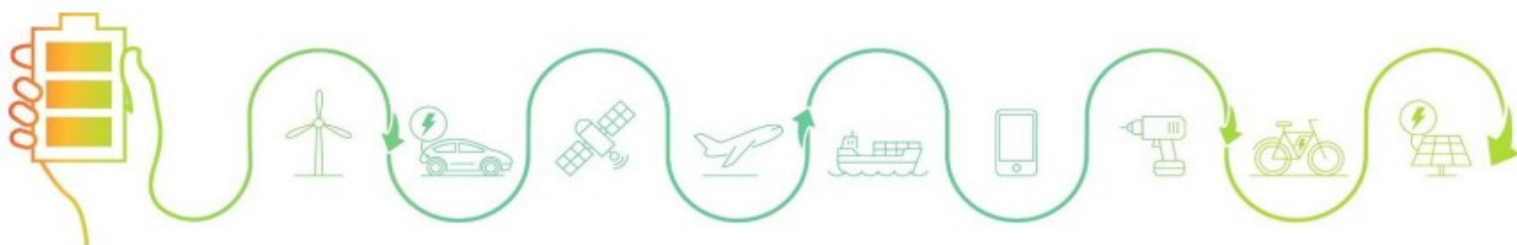
3.1.5 Use of PFA, VDF, HFP, FKM in gaskets in high performance batteries which require very thin high performance gaskets

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 high performance gaskets.

High power and high energy density batteries require very thin high performance gaskets¹⁸. Gaskets provide insulation between the positive and negative sides of the housings, a proper thermal functionality of the gasket is essential. This application needs a stable and compressive polymer which provides high levels of insulation to withstand the very high currents up to 280 amps which are found in these high performance batteries. Figure 6 compares the compressive properties of PFAS compared to other resins¹⁹.

¹⁸ Lui, 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

¹⁹ Battery materials, Fluorochemicals, Daikin Global. (n.d.).
<https://www.daikinchemicals.com/solutions/products/battery-materials.html#anchor04>



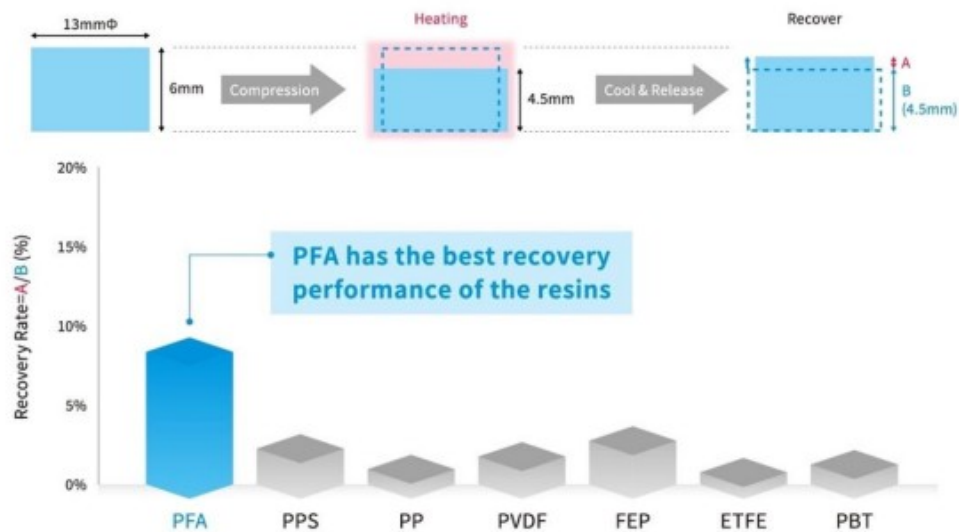
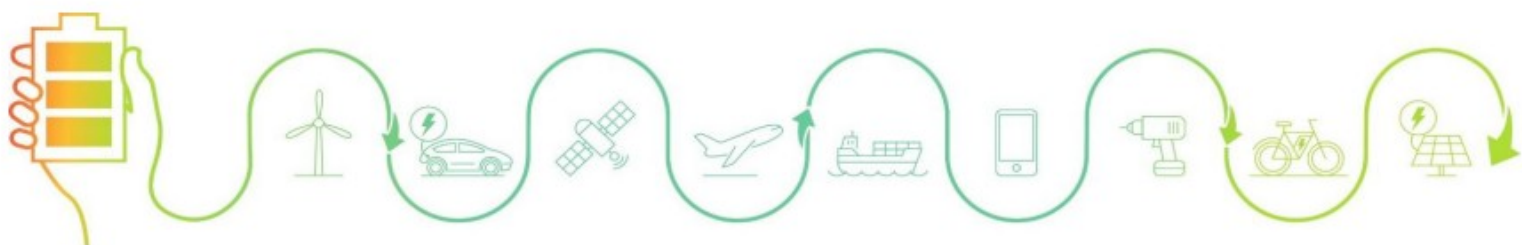


Figure 6. Compressive properties of polymer resins

PFAS provide a unique combination of electrical insulation and hydrophobic properties. Figure 7 compares the moisture permeation properties of PFAS compared to other resins²⁰. As a result, the efficiency of the gasket performance is improved because of the reduced humidity absorption even when used at very low thickness.

²⁰ Ibid



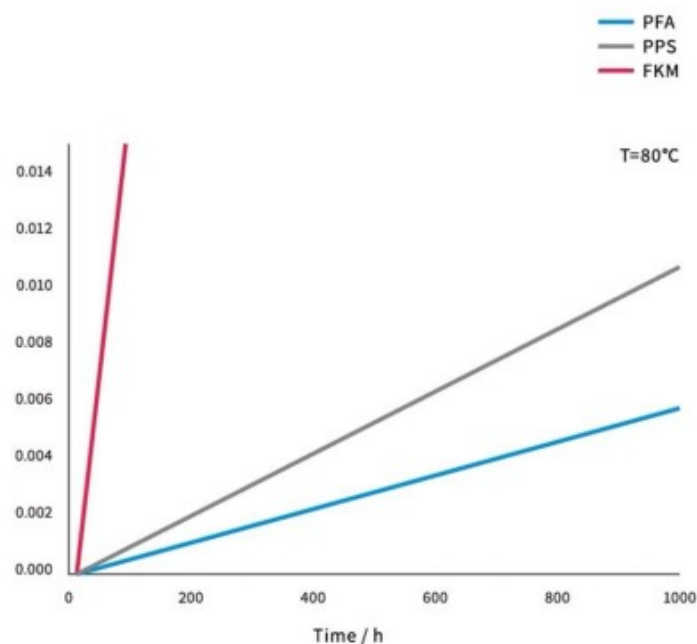


Figure 7. Moisture permeation of polymers

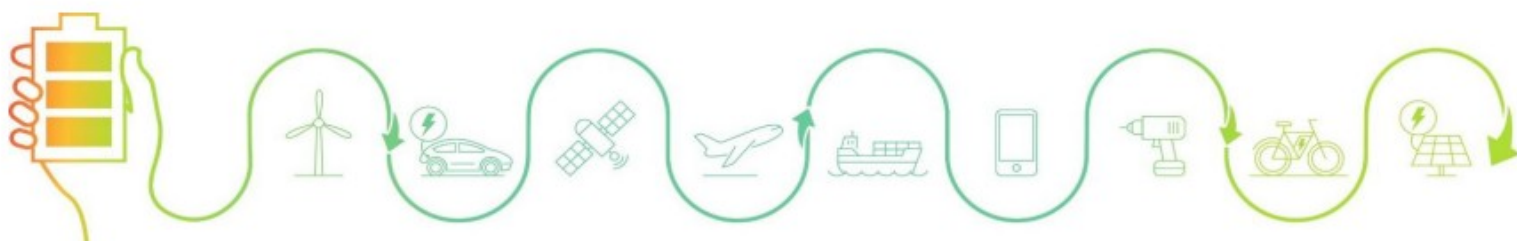
It will take significant time and effort for industry to investigate whether there are alternative polymers that can be used instead of PFAS in these gaskets. We estimate that research and development efforts to identify non-PFAS alternatives would take at least 10 years, followed by 5 years to commercialise the alternatives.

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.

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. We estimate that research and development



efforts to identify non-PFAS alternatives would take at least 10 years, followed by 5 years to commercialise the alternatives.

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

There are no available alternatives to the use of PVDF / PTFE as a binder in the solid electrolyte/ gel polymer in solid-state batteries. The PVDF / PTFE has unique properties that provide mechanical strength and act as an interface between the electrolyte and the electrodes in solid.

PVDF and co-polymers of PVDF are uniquely placed to enable solid electrolyte/gel polymers in batteries due to the presence of strong electron-withdrawing functional group ($-C-F$)²¹. These properties include high polarity, excellent thermal and mechanical strength, compatibility with organic solvents and chemical stability²².

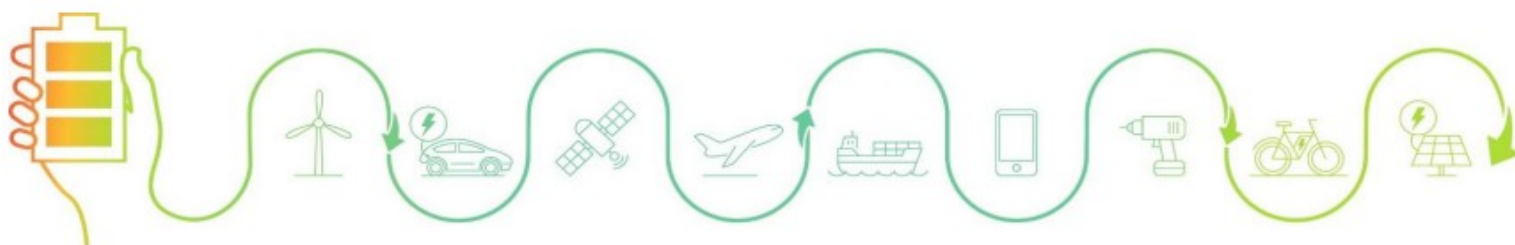
Extensive research would be needed to find alternatives. Research and development efforts to identify non-PFAS alternatives would take at least 10 years, followed by 5 years to commercialise the alternatives.

3.2 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 and therefore the battery industry requires a longer transition period of 6.5 years. 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. 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

²¹ 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>

²² 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>



need to make significant changes to their manufacturing equipment and process lines to accommodate the new subcomponents.

The below consecutive steps 1 to 4 are representative of the battery industry and present 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 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.

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: Substitute material identification 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 each new subcomponent: 14 - 21 months

This is the process of using the target substitute material to develop the new subcomponent and then to test it 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 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.

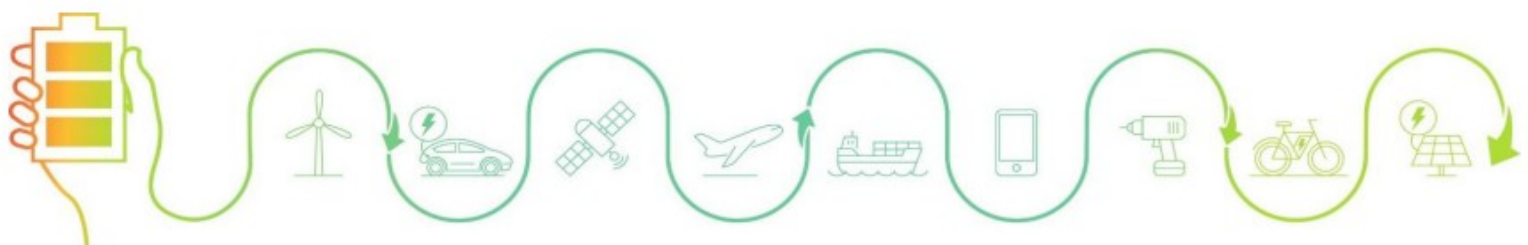
Step 3: Combination of all new subcomponents and chemistry development: 18 - 36 months

This is the process of integrating and developing all the new subcomponents into a next generation cell chemistry package. Each new subcomponent would need 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.

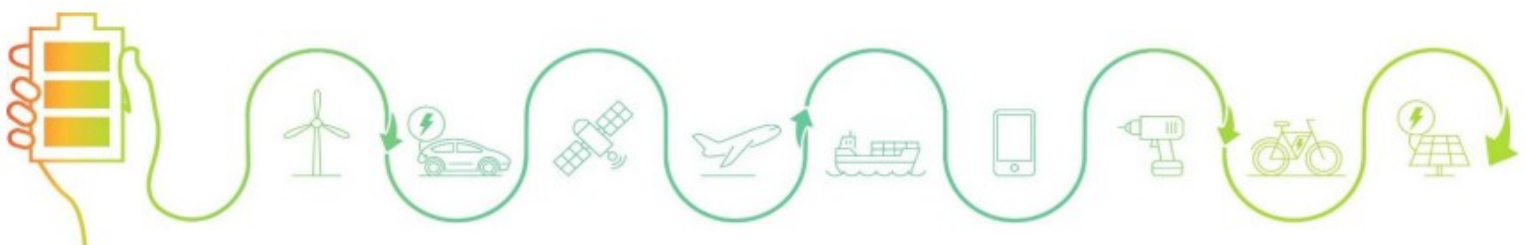
Step 4: Integration into existing product design and new product designs, and into manufacturing processes: 24 - 48 months

The next 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.



4 PFAS consumption in tonnes and emissions during battery life cycle

4.1 PFAS consumption in tonnes

Further information will be provided in subsequent submissions.

4.2 Emissions during the battery life cycle

NOTE: This text repeats the information already provided by RECHARGE in the second call for evidence submitted in October 2021. Updated information will be included in subsequent submissions.

4.2.1 Emissions during battery manufacturing

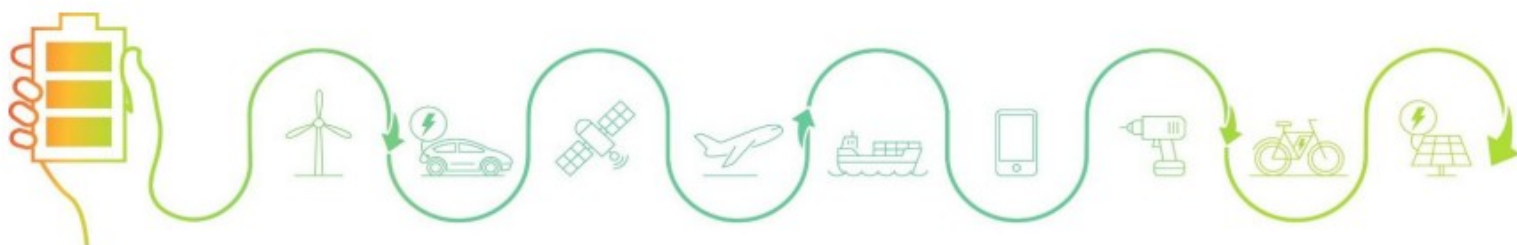
For technologies using PVDF as binder

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.

For technologies using PTFE as binder

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.

No unintended and uncontrolled PFAS emissions are foreseen during battery manufacturing.

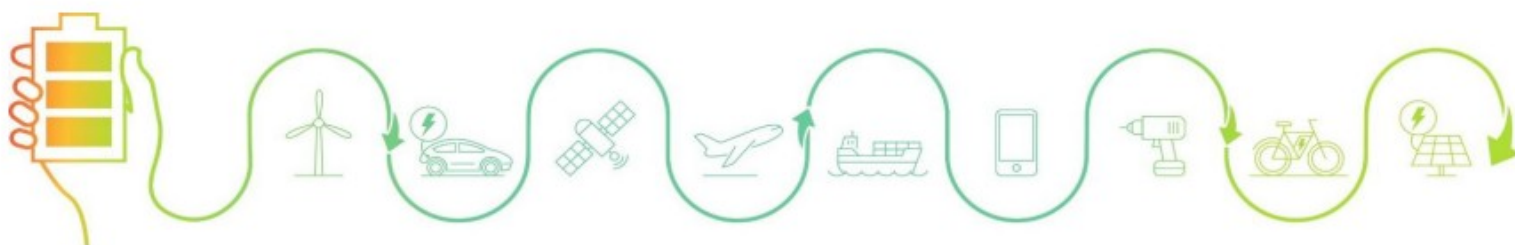
4.2.2 Emissions during battery use

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. This battery is defined in the REACH regulation as “an article with no intended release” meaning that, **under normal and reasonably foreseeable conditions of use, no end-user of this battery will be exposed to any chemical substances. No PFAS emissions are foreseen during battery use.**

4.2.3 Emissions during battery recycling

Battery recycling is mandatory in Europe since 2006 according to the Battery Directive and will remain mandatory with higher recycling targets in the upcoming Battery Regulation. Fluoropolymers are totally decomposed (as compounds), during the pyrometallurgical recycling processes. The fluorine reports to the flue dust. Flue dust is further processed in a hydro-metallurgical process to extract specific remaining metal content. Also, the PFAS containing waste streams and product streams from the hydrometallurgical recycling process may be treated in high temperatures where fluoropolymers are totally decomposed (as compounds). **No unintended and uncontrolled PFAS emissions are foreseen during battery recycling.**

Further information will be provided in subsequent submissions.

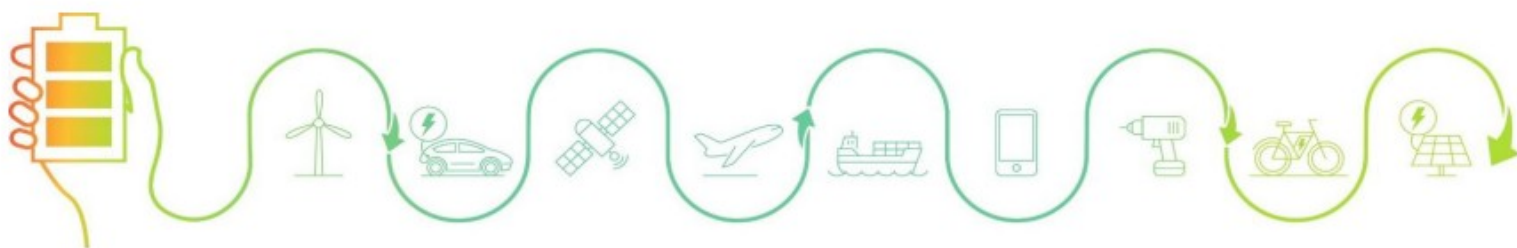


5 Socio economic impact assessment for battery value chain

Further information will be provided in subsequent submissions.

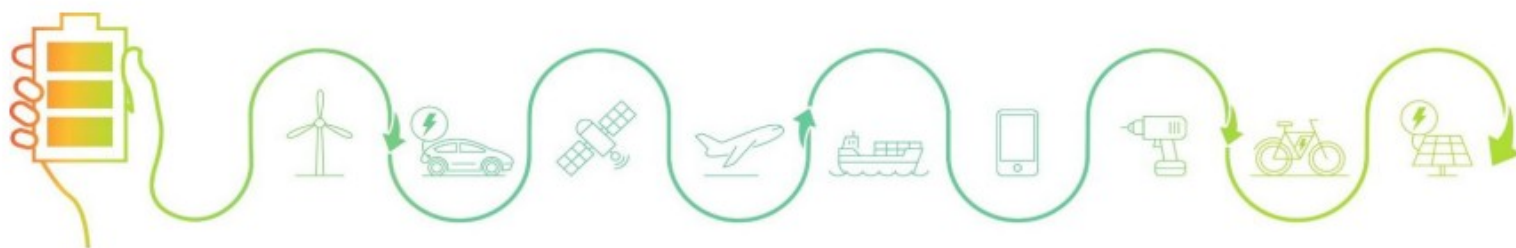
6 Why RECHARGE seeks derogations and additional transition times, and industry best practices

Further information will be provided in subsequent submissions.



Glossary

FEP	Fluorinated ethylene propylene
HFP	Hexafluoropropylene
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 TFSIL, i 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
PBA	Prussian Blue Analogues
PFAS	Per and polyfluoroalkyl substances
PTFE	Polytetrafluoroethylene
PVDF	Polyvinylidene difluoride (both homopolymer and copolymer)
VDF	Vinylidene fluoride
Zn-ion	Zinc-ion rechargeable batteries



Til: ' P1 ' (E1), P2 P3 (E2), P4
(E3), P5 , P6 (E4), ' P7 '
(E5)
Cc: DE (E6) (E6), restrictiePFAS (E4), P8
(E7), P9 (E8)
Fra: Peter Juhl Nielsen (████@mst.dk)
Titel: Vs: Battery industry PFAS derogation requests and substitution timescales
Sendt: 25-04-2023 15:17
Bilag: RECHARGE FIRST submission.pdf;

Dear all,

I have been contacted by P10 from Apple regarding a physical meeting - see below. They would very much like to have a discussion on batteries relatively soon so that they can submit information on alternatives and socioeconomics by the 20th of May, so this information can be considered during the SEAC meeting. As can be seen by the PDF attached, they have already submitted a lot of information on the use of PFAS in batteries but would like to have a more in depth talk on what to submit.

They suggest a meeting in Odense but as I am the only one involved from DK at the moment (new colleague from 01. May) it feels a bit much to have a meeting here with 6-7 stakeholders. Also, as the primary topics they would like to submit information on is the socioeconomics and alternatives in which, we have received a lot of support on. Any thoughts on such a meeting?

Best regards

Peter Juhl Nielsen
Scientific officer | MSc | Chemicals
+45 21 15 30 67 | +45 21 15 30 67 | █████@mst.dk

Ministry of Environment
Environmental Protection Agency | Tolderlundsvej 5 | 5000 Odense C | Tel. +45 72 54 40 00 | █████@mst.dk | www.mst.dk

[How we process your personal data](#)

Til: Peter Juhl Nielsen (████@mst.dk), P2 P3 (E2), P4
(E3), P9 (E8)
Cc: restrictiePFAS (E4), P11 (E9), P12
(E10), P13 (E11)
Fra: P10 (E12)
Titel: Battery industry PFAS derogation requests and substitution timescales
Sendt: 25-04-2023 14:51

Dear Mr Nielsen

Thanks for your time today. As discussed, [RECHARGE](#) represents 60 member companies across the battery value chain and is working closely with partner associations in the battery industry. We submitted the attached first submission to the PFAS public consultation on Friday 21 April which maps why and where PFAS are used in batteries and identifies

- uses where alternatives are not yet available and a derogation of 13.5 years is needed, and
- uses where substitution is technically feasible but due to the complexity of substituting new materials into several subcomponents in a company's battery manufacturing process the battery industry needs a longer transition period of 6.5 years.

We are now working with our member companies and partner industry associations to prepare a second

submission to the PFAS public consultation which will include additional information on

- PFAS consumption in tonnes and emissions during the battery life cycle
- Socio economic impact for companies, consumers and other affected sectors

We would like to arrange a meeting at your Denmark Environmental Protection Agency offices in Odense so that we could review our progress with you and discuss information gaps we should address in our second submission. We would be happy for your colleagues in Netherlands, Sweden, Germany and Norway to join this meeting by web-meeting.

Please could you let us know if you have availability for a meeting at your offices in Odense on Tuesday 2, Wednesday 3, Thursday 4, Tuesday 9, Wednesday 10 or Thursday 11 May. We will be staying overnight at a local hotel and can arrange to meet at your offices at any time in the morning that is convenient with you.

Thanks very much in advance for any support you can provide to this request.

Best regards

P10

Š | P10 | Program Manager EMEA, Material Declarations and Chemical Restrictions | Mobile: +44
T1