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August 25, 2023

SK on comments on the ANNEX XV DOSSIER of the PFAS Restriction Proposal

August 2023

First Submission

About SK on

Leading future energy through technical innovations

SK on has developed innovative battery technologies in line with the growth of the electric vehicle market and changes in technological trends. As the leader of the world's most advanced high-nickel technology, we have successfully developed a high-energy density electric vehicle battery, have mass-produced the NCM622 battery (2014), the NCM811 battery (2018), and plan to produce the NCM9½½ battery (2022). We are opening up the era of electric vehicles with global automobile companies. We have signed supply contracts with global automobile companies that are leading the electric vehicle era and are working with various fields to expand the electric vehicle battery business. We are also continuing our partnerships with prominent companies based on cutting-edge technology and long-term reliability. We are creating social value through technology and products that contribute to improving the environment. To fulfill our social responsibilities, we are making the effort to develop battery technology that takes the environment into account. By developing high-efficiency, high-capacity lithium-ion batteries and supplying them to global electric vehicle companies, we are minimizing atmospheric pollution from CO2 emissions.

Last year, SK On's case of raising investment funds for its third Europe battery plant from three ECAs was selected as the European "Deal of the Year" by the British financial magazine "TXF" (Trade Export Finance).

In July of last year, SK On succeeded in raising a total of $2 billion (approximately KRW 2.624 trillion) in investment funds through Euler Hermes, a German trade insurance agency, the Korea Trade Insurance Corporation, and the Korea Export-Import Bank.

SK On has announced that it plans to use the investment funds secured through ECA to invest in the third plant under construction in Europe.

The third European plant, with a total investment of 3.31 trillion won, is expected to produce 30 GWh (gigawatt hour) of batteries that can be supplied to 430,000 electric vehicles annually starting next year.

SK on`s endeavor for ecosystem

SK On sets and operates waste management standards for the entire production process, such as storage, transportation, and treatment, in order to minimize and efficiently treat waste generated in the battery production process. To this end, the amount of waste generated and recycled is regularly monitored, and waste outsourcing companies are regularly checked to see if they are properly handling waste. In addition, in the case of low-quality battery cells that occur due to the nature of the business, we manage them so that they can be recycled through our partners.

SK On strives to establish a management system that meets global standards in order to improve the actual recycling rate of waste generated from business. In 2022, SK On acquired the "Gold" level of 'Zero Landfill Certification (ZWTL)' through an institution specializing in safety certification standards. The zero-waste landfill certification is a certification that evaluates the actual waste recycling rate and landfill amount during waste treatment by a company. We plan to continue working hard to make it happen.

In order to systematically manage greenhouse gas emissions, SK On is establishing a greenhouse gas emission measurement and management system for not only domestic business sites but also overseas business sites. In particular, in the case of overseas business sites, as greenhouse gas regulations vary by country, we have established a greenhouse gas emission measurement and management system in consideration of each country's regulatory status, and plan to continuously upgrade it.

TABLE

A. Executive Summary

SK on is one of the largest player in the European battery market. As such, SK on feels the urgency and responsibility to provide this comment addressing our grave concern that the proposed PFAS restriction will have adverse effects on the EU battery industry.

The Korean battery industry, include SK on, has been the pioneer of the battery manufacturing sector since the beginning. It took 30 years to fully commercialize batteries for Electric Vehicles ("EV") and other important environment-friendly applications, such as Energy Storage Systems ("ESS"). From our over 30 years of experience, we know that **the currently suggested 13.5/6.5-year derogation period to replace PFAS materials in the battery industry is unrealistic and not achievable.**

Since replacing PFAS in batteries is practically impossible and any replacement will likely be an inferior solution, **the battery industry in its entirety should be excluded from the PFAS restriction** for the following compelling reasons:

① The scope of the restriction is overly extensive, resulting in the inclusion of PFAS substances that have **not been proven to be harmful** on the prohibited use list;

② Rechargeable batteries **release minimal amounts of PFAS** into the environment and provide little to no exposure to the human body throughout their life cycle;

③ It is not feasible to develop viable alternative PFAS-free materials and respective technologies for the battery industry within the currently suggested derogation period. The data that we have collected in our 30 years of extensive experience with the commercialization of EV, ESS and other industrial batteries compels the conclusion that **it will take at least 40 years to achieve a stable commercialization of PFAS-free EV batteries;**

④ Even those 40 years may however not be sufficient to verify cell performance and reliability. **An insufficient verification of cell performance and reliability for EV due to time constraints would risk user's safety**;

⑤ The proposed restriction creates **extreme market uncertainties, leading to a halt in EU investments across the entire supply chain and hindering the achievement of the EU's Carbon Neutrality target.**

⑥ Including batteries in the PFAS restriction strongly contradicts the EU's general policy on batteries, especially the new EU Battery Regulation which emphasize **the core importance of batteries for the EU's sustainability/climate/green mobility goals**.

Given these facts, the only reasonable option is to **exclude EV, ESS and other industrial batteries from the PFAS restrictions or have an unlimited derogation period.** A derogation period, even one of 40 years, would endanger urgently needed industry investments and render a systematic manufacture planning impossible. **The exclusion of the 'Battery Industry' from the PFAS Restrictions is crucial to preserving the supply chain of lithium-ion batteries in the EU, supporting the realization of the EU's circular economy and a more sustainable eco-friendly environment**.

I. Introduction

SK on have been the pioneer of the battery manufacturing sector since the beginning.

At SK on, we embarked on our first battery development research in 1991 and has been dedicated to creating unparalleled material technologies and next-generation batteries ever since. With outstanding technological capabilities in the fields of Advanced Automotive, Mobility & ESS batteries, we are actively pursuing new product developments and securing a world-class battery production capacity while expanding the next-generation energy market.

SK ON has been bringing forward major investment in building manufacturing facilities in the EU. SK ON's local production facilities in Poland will significantly contribute to job creation in the EU and function as an essential part of the EU battery industry, the latter playing a pivotal role in the global battery supply chain.

SK ON has been recognized as one of the most environmentally cautious companies globally. For many decades, environmental concern and sustainable growth have been a high priority for us. SK ON aims to lead ESG management with the understanding that the consistent growth of the battery industry is the basis of the increasing use of green energy, contributing to a sustainable future for humanity. In particular, SK ON aims to achieve carbon neutrality of its value chain by 2050. Ultimately, we strive to go beyond carbon neutrality with the goal of being carbon negative.

From our over 30 years of experience, we know that **the currently suggested 13.5/6.5-year derogation period to replace PFAS materials in the battery industry is unrealistic and not achievable.**

The new EU Battery Regulation creates a well-structured framework that addresses and eliminates potential health and environmental risks of end-of-life batteries. The new EU Battery Regulation is a cornerstone of the European Green Deal and aims to improve the circular economy, resource use and efficiency, and the life cycle of batteries in terms of climate neutrality and environmental protection.

II. Reasons why the complete exclusion from the PFAS ban is required

1. Environmental Perspective

1) Overly extensive scope of the restriction: inclusion of PFAS not proven to be harmful

The scope of proposed restriction is excessively broad, encompassing PFAS substances that have not been proven to be harmful, leading to their placement on the prohibited use list. As per Annex XVII to REACH, restrictions are intended to ban the use of substances that have been confirmed to be harmful through the rigorous REACH process of registration and evaluation. PFAS types such as PFOA (Perfluorooctanoic acid), PFOS (Perfluorooctanesulfonic acid), and PFHxS (perfluorohexane 1 Sulphonic Acid), which have been confirmed to be harmful, are appropriately restricted under Annex XVII.

However, it is extremely vital to ensure that **only additional PFAS substances that have been conclusively demonstrated to be harmful are selectively made subject to restrictions**. A targeted and evidence-based approach is required to strike the right balance between environmental protection and allowing for legitimate and safe uses of PFAS substances in various applications.

2) Rechargeable batteries release minimal amounts of PFAS into the environment and provide little to no exposure to the human body throughout their life cycle. [1]

It is essential to emphasize that rechargeable batteries release minimal amounts of PFAS into the environment and provide little to no exposure to the human body throughout their life cycle. PFAS substances are contained solely inside the battery and do not escape into the environment. **At each stage of the battery life cycle – production, usage, collection, and disposal – there in no significant or non-controlled risk of exposure to humans or the environment.**

The only moments of potential exposure during battery collection are effectively regulated and resolved through the **EU Battery Regulation**. The EU Battery Regulation mandates the collection/recovery and recycling of used batteries with increased target rates over time, particularly for EV, by 2030**.** By enforcing this Regulation, any – potential – exposure to PFAS during the collection/recycling and disposal stages is tightly controlled. Consequently, for the battery industry, the current proposed PFAS restriction appears excessive as it restricts the use of crucial materials despite the ability to manage potential negative effects effectively through other regulation.

2-1) Rechargeable batteries release minimal amounts of PFAS into the environment

Slide 24 from the 5 April 2023 ECHA webinar[2] on the PFAS restriction highlights that the energy sector represents between 0 and 1% of the total emissions of PFAS. Nevertheless, we

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[1] See RECHARGE's dossier submission to ECHA for detailed description.

[2] Restriction of PFAS under REACH, ECHA webinar of 5 April 2023, available at: https://echa.europa.eu/-

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 controlled.[3]

2-2) In each stage of the battery's life cycle there is no significant risk of exposure to humans or the environment

(1) Battery Manufacturing Stage

There are no unintended or uncontrolled emissions of PFAS during the battery manufacturing process. During the battery manufacturing stage, PFAS handling facilities (input/mixer) are equipped with local exhaust systems, effectively preventing any scattering into the environment or the atmosphere. The use of sealed pipes during material transfer further minimizes exposure to the human body and the environment. Additionally, it is mandatory for workers handling PFAS substances to wear protective equipment, such as protective clothing, goggles, hats, and dust masks, ensuring their safety in the event of minimal emissions.

All battery manufacturing operations are conducted in facilities abiding by applicable permission requirements of the respective (EU Member) State, where any release of emissions is controlled and must be below regulation threshold limits. These include the limits of the Industrial Emissions Directive[4] ("IED"), aiming to prevent and limit levels of pollution. Under the EU Green Deal ("EGD"), the IED is in the process of being amended with a revision proposal released last year[5]. The proposed IED revision 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 gas emissions. The proposed IED also 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 Environment[6] directly addresses the production of safe and sustainable chemicals for batteries.

/restriction-of-per-and-polyfluoroalkyl-substances-pfass-under-reach.

[3] *Kirchhoff*, M./*Reichert*, D.: Emission Compliance in Battery Manufacturing and Recycling. Presentation slides of Desotec Activated Carbon, available at: www.desotec.com.

[4] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).

[5] Proposal for a Directive of the European Parliament and of the Council amending Directive 2010/75/EU and Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste (COM(2022) 156 final).

[6] 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.

(2) Battery Use Stage

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 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. Some alkaline batteries may need to have water additions during their working life and therefore may be equipped with 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.**

(3) Waste Battery Collection Stage

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 minimize emissions.** The new EU Battery Regulation[7] states that all waste starting, lighting and ignition ("SLI") batteries, waste industrial batteries and waste EV batteries should be collected.

For this 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 EV batteries (paragraph 112, page 70). The EU Commission Batteries FAQ[8] states that "***nearly 100% of automotive batteries and industrial batteries are already being collected***" and notes that the economic value of batteries motivates collection by professionals.

The European association of national collection schemes for batteries (Eucobat)[9] estimates that 19% of portable batteries placed on the EU market 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

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7 Regulation 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.

8 https://environment.ec.europa.eu/topics/waste-and-recycling/batteries-and-accumulat.

9 https://www.eucobat.eu/downloads/position-paper-collection-target-waste-batteries.

market is equivalent to achieving a 80% collection and recycling target based on the quantity of batteries that are available for collection.

In the meantime, Art. 59 sec. 3 EU Battery Regulation requires the industry to achieve the following collection and recycling targets based on the quantity of portable batteries placed on the market:

- 45% by 31 December 2023;
- 63% by 31 December 2027;
- 73% by 31 December 2030.

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

Increasing collection and recycling rates of portable batteries will also help with the large amounts of batteries stored by consumers. Surveys have shown that consumers tend to hoard electronic products that are old, broken, obsolete, or are no longer in use for different reasons. These waste portable batteries from consumer electronic products stored at home are currently not available for collection and recycling.

Once collected, the Waste Electrical and Electronic Equipment (WEEE) Directive[10] aims to achieve a separate recycling of Electrical and Electronic Equipment (EEE) and the batteries included in them. Art. 8 sec. 2 WEEE requires that the WEEE recycling process shall remove batteries from any separately collected WEEE, if possible. The removed batteries can then be recycled.

However, not all batteries can be removed from WEEE. Many electronic products include small batteries on the printed circuit boards to provide back-up power to clock functions and memory functions. The WEEE Directive requires (*inter alia*) the removal of printed circuit boards of mobile phones generally. These printed circuit boards are often sent for metal smelting including any batteries contained on the boards. The smelting of batteries at 1,600°C destroys the PFAS entirely and does not result in any PFAS emissions. This explains 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) Waste Battery Recycling Stage

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[10] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE).

The new EU Battery Regulation aims "*to make all batteries placed on the EU market more sustainable, circular and* ***safe***"[11] to achieve the EU circular economy and decarbonization ambitions from the sourcing of materials all the way through to battery collection, recycling, and repurposing. Once it enters into force, sustainability requirements such as disclosure of batteries' environmental footprint and recycled content will be introduced starting in 2024.

Batteries are recycled using pyrometallurgical processes and/or hydrometallurgical processes. 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 °C. The most stable PFAS, perfluoromethane (CF4), needs a temperature of 1380 °C to be dissociated. The temperature of the smelting reduction stage results in complete destruction of all these types of PFAS. **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.**

All battery recycling operations are conducted in facilities which are permitted by the competent authority within each EU 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 Directive[12] which sets limits on preventing and limiting levels of pollution.

2-3) By enforcing the new EU Battery Regulation, exposure to PFAS during the collection/recycling and the disposal stages can be tightly controlled.

The new EU Battery Regulation creates a well-structured framework that addresses and eliminates potential health and environmental risks of end-of-life batteries. The new EU Battery Regulation is a cornerstone of the European Green Deal and aims to improve the circular economy, resource use and efficiency, and the life cycle of batteries in terms of climate neutrality and environmental protection.

Regarding portable batteries – as the kind of batteries mainly used in EEE – it tightens the requirements for removability and sets new requirements to ensure replaceability. A battery will be considered removable if it can be removed and replaced with a comparable battery without affecting the device. Such batteries in the future have to be removed and replaced, with the old battery requiring recycling under the new EU Battery Regulation. The enforcement of these new provisions will drastically decrease the number of EEEE-batteries being discarded by consumers and ensure their safe collection and professional recycling. This will significantly reduce the risk of improper treatment of end-of-life batteries which could potentially lead to PFAS exposure.

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[11] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7588.

[12] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).

2. Technical Perspective

1) From our 30 years of extensive experience with the commercialization of EV, ESS, and other industrial batteries, we know that it would take at least 40 years to achieve a stable commercialization of PFAS-free EV batteries, and that the **currently suggested 13.5/6.5-year derogation period to replace PFAS materials in the battery industry is unrealistic and not achievable.**

The data that we have collected in the last 30 years of development of materials, optimization of the entire battery manufacturing process and supply chain **compels the conclusion that it would take at least 40 years to achieve a stable commercialization of PFAS-free EV batteries**.

This is especially due to the following reasons:

(1) Currently **no alternative cathode binder material**[13] **for PFAS (for example PVDF or PTFE) exists that simultaneously satisfies all required characteristics**, such as high voltage stability, thermal and chemical stability, mechanical properties, and processability. **The alternative material development period alone is predicted to be longer than 10 years at minimum.**

(2) After the alternative material is developed**,** it will **take at least 30 years to evaluate its commercialization,** which includes a new development and optimization of the entire battery manufacturing process as well as of the required facilities and equipment.

(3) The abovementioned minimum 40 years may not be sufficient to verify cell performance and reliability. **An insufficient verification of cell performance and reliability for EV due to time constraints would risk user's safety**.

(4) An **increased battery price** due to a decreased yield of battery manufacturing, an investment in mass production facilities/equipment, and binder supply shortage **will be an obstacle for the swift transition to carbon free EVs in the EU.**

At this point, it is unclear if and when a PFAS alternative for EV batteries can be found. Even in the most positive scenario assuming that it will be found within reasonable time, the **total estimated time for the development and commercialization of PFAS-free EV batteries is at least 40 years**. It is however likely that no alternative exists or that processes will take significantly longer, especially to ensure safety for consumers. Therefore, any derogation period for EV batteries would have to be unlimited.

Given these facts, the only reasonable option is to exclude EV, ESS, and other industrial

[13] The cathode binder indicates either the binder inside cathode itself or the binder added between the electrode and separator for adhesion during stacking or winding processes.

batteries from the PFAS restriction or have an unlimited derogation period. A derogation period, even one of 40 years, would endanger urgently needed industry investments and render a systematic manufacture planning impossible.

The battery manufacturers in Korea are consistently conducting technical reviews on alternatives for PVDF but have not found a material as good as PVDF in terms of productivity, quality, performance, and stability.

Recent academic research highlights materials such as polyimide, polyurethane, polyolefin, polyester, and epoxy, but as discussed in this report, none of these satisfies the desired processability, stability, and environmental aspects in the current lithium-ion battery design.

Some binders, for example, may seem feasible on a research level, but the actual commercialization involves various aspects not discussed in academic papers. This includes the productivity, quality, performance, safety, reliability, testing, and development, which will take at least 30 years based on our past experience.

In addition, in case the components of the lithium-ion battery need to be changed when the new binder is applied, the equipment, facility, and new material need to be developed and verified. This will further extend replacement times.

Also, the hazards of the newly introduced materials may be higher than those of PVDF and previous materials.

It therefore has to be concluded that replacing PFAS is practically impossible and that any replacement will likely be an inferior solution. **Therefore, the battery industry needs to be excluded entirely from the PFAS restrictions.**

1-1) No commercialized alternative candidate in the current market satisfies the most important characteristics of a cathode binder and it will take at least 10 years to develop an appropriate alternative.

There is **no commercialized alternative candidate** in the current market that satisfies the **following most important characteristics as a cathode binder, which need to be met simultaneously**: ① high chemical stability, ② electrochemical stability, ③ high thermal stability, ④ high mechanical properties, and ⑤ good processability.*14*

- **Minimum Requirements for Normal Lithium-Ion Battery Binders**

  The primary function of a binder for lithium-ion battery is to provide mechanical strength and electrode stability. Cathode binders, for example, limit volume expansion during the lithium-ion battery intercalation process to maintain structural stability, while performing as a buffer during delithiation

[14] The details regarding each property can be referred to Section 2.1.1 of RECHARGE 2nd draft.

to support return to its original structure.

The bare minimum requirements for cathode binders in lithium-ion batteries are discussed below. These properties need to be considered in various perspectives, such as mechanical stability, electrochemical stability, and processability.

(1) Mechanical Stability

Carbonate electrolytes used in a lithium-ion battery are of high polarity. A binder must maintain its function and work as an adhesive and not dissolve in the electrolyte.

Without an appropriate binder, repeated expansion/contraction caused by charging and discharging can lead to structural deformation, meaning ohmic resistance induced by a weakened bond between active materials and conductive additives, which could lead to an overall decline of battery capacity. Even electrode dropout can happen, which could result in a serious safety issue.

Thermal resistance and flame retardancy are also required for a binder since the drying process of electrodes generally happens at around 200℃. Only a limited group of polymer substances qualifies for such requirements.

(2) Electrochemical Stability

Oxidation resistance is also required with respect to the generation of active oxygen in an overcharging state of metal oxide, such as cathode materials. Furthermore, a binder should have a lithium-ion conductivity without any side reaction while it is soaked in electrolyte. High-molecular substances that qualify for such requirements cannot be specified.

For example, compared to organic electrolytes such as ethylene carbonate(EC) (-12.46 eV) and propylene carbonate(PC) (-12.33eV), fluorine-based materials such as PVDF (-14.08 eV) and PTFE (-15.47 eV) have a comparative advantage in terms of oxidation potential.

(3) Processability

A. Homogeneity

A binder should uniformly paste/adhere with either active materials, conductive agents, or additives, while ensuring certain properties such as stable coating.

B. Contamination

A binder should not experience problems such as detaching from collector during the slitting and notching processes.

C. Viscosity

A binder with adequate viscosity is required to apply high shear force to mix the slurry uniformly.

D. Environment

Residue and solubility should be considered so that solvent can be recovered and reused.

E. Fibrillation (Dry electrode process)

A binder with enough fibrillation ability is required to paste/adhere with either active materials, conductive agents or additives uniformly in dry mixing condition.

- **No "alternative candidate material" satisfies the most important characteristics that have to be fulfilled simultaneously by a cathode binder.**

The materials most mentioned as cathode binder alternatives can be classified as aqueous and non-aqueous binders:

(1) Aqueous Binder

According to our research, the Ni-based cathode active material is easily degradable with only a minimum amount of moisture (several hundred ppm)[15], which consequently leads to battery performance degradation. It has been confirmed that the use of aqueous binder leads to a drastic decrease of the battery lifespan. This cannot be avoided by controlling/adjusting the aqueous binder type, content, configuration. It was also confirmed that **it is practically impossible to produce an electrode on an aqueous base.**

Therefore, the use of PFAS is inevitable for cathode binder.

[15] Particularly, the extent of degradation becomes more severe as the content of Ni increases in the cathode material.

(2) **Non-Aqueous Binder**

Both battery makers and researchers have made enormous efforts to develop binder for non-aqueous solvent application to replace PVDF over the past 30 years, but none have been commercially successful.

The use of PVDF is dominant in non-aqueous and commercialized cathodes in lithium-ion batteries, and numerous studies have been conducted to replace fluorine-based polymers in industries. The candidates for alternatives however have critical flaws that bar their commercialization and the currently available candidates cannot be utilized.

A. Polyimide: while showing good adhesion and thermal resistance, the imide bond is not suitable for the required characteristics.

B. Polyolefin (PE, PP): electrochemically not suitable due to high HOMO energy level (i.e. the oxidation potential value is too low).

C. Polyester: while showing good adhesion and thermal resistance, the ester bond is not suitable for the required characteristics.

D. Epoxy: time needed to induce curing is too long in processing perspective.

- **The unique property of PVDF is suitable for lithium-ion batteries and the recycling of the non-aqueous solvent is well established, which is environmentally desirable.**

(1) Processability

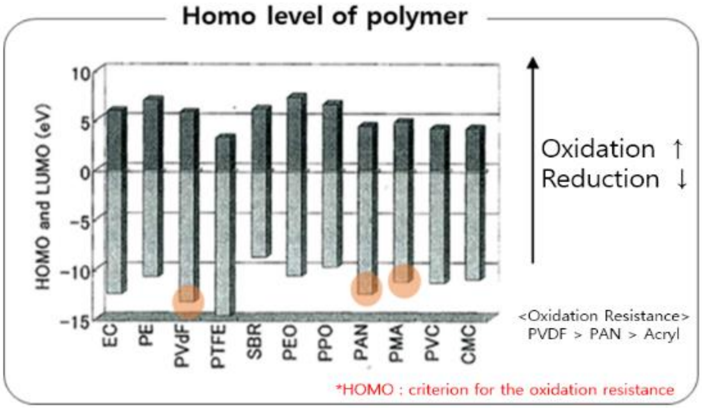
PVDF has a low crystallinity as a polymer, allowing it to have relatively high solubility and great processability. The viscosity range is highly controllable, which is important in deciding the slurry viscosity suitable for the specific ratio of the active material. It is advantageous for coating quality and the adhesion to the electron collector is decent. In addition, the slurry made with PVDF exhibits appropriate flexibility and stiffness when pressed making it suitable for a high density pressing.

(2) Stability

PVDF, compared to other polymers, has an unusually high dielectric constant and exhibits an excellent lithium-ion conductivity ($10^{-6} \sim 10^{-5}$ S/cm) when swollen by electrolyte. Also, the strong bond between carbon and fluorine within the polymer makes it resistant to chemical changes under almost all carbonate electrolytes. Thus, PVDF satisfies all necessary properties as a cathode binder in lithium-ion batteries.

(3) Oxidation Resistance

During charging, the cathode is under a strongly oxidizing environment. Oxidation resistant properties are mandatory for a cathode binder. The oxidation resistant properties become better as the Highest Occupied Molecular Orbital (HOMO) energy level decreases, and the low HOMO energy can be achieved by introducing an electron acceptor. The fluorine-based functional group (-F, -CF2) is one of the strongest electron acceptors, and there is no polymer found that exhibits oxidation resistant levels that are similar to PVDF or PTFE, which are composed purely of the aforementioned functional group.



(4) Environment

PVDF, which is synthesized by polymerization, uses NMP as solvent and the solvent has an ignition temperature of 346°C, making it highly stable. Also, the solvent recycling and reuse are well established and easier compared to other solvents. In addition, **PVDF exhibits relatively low toxicity compared to other aqueous alternatives suggested by RECHARGE.** [16] Overall, the toxicity and persistence – ECHA's main concerns – of PVDF are not much different from that of the alternatives.

Contents	PVDF	PTFE	SBR	CMC	polyacrylic acid
CAS No.	24937-79-9	9002-84-0	9003-55-8	9004-32-4	9003-01-4
H	- Skin irritation category2	- Skin irritation category2	- Carcinogenicit	- Skin irritation category2	- Carcinogenicit

16 See RECHARGE's dossier submission to ECHA for detailed description.

	- Eye irritation category2 - Specific target organ toxicity, single exposure category3	- Eye irritation category2 - Specific target organ toxicity, single exposure category3 - Aquatic chronic category4 - Specific target organ toxicity, repeated exposure category1	y category1A - Mutagenicity category1B - Skin sensitization category1 - Eye irritation category2 - Aquatic chronic category3 - Specific target organ toxicity, single exposure category3	- Eye irritation category2 - Aquatic chronic category3 - Acute toxic category4 - Specific target organ toxicity, repeated exposure category1	y category1A - Mutagenicity category1B - Skin irritation category2 - Skin corrosion category1B - Eye damage category1 - Eye irritation category2 - Acute toxic category4 - Aquatic acute category1 - Aquatic chronic category2 - Specific target organ toxicity, single exposure category3

Although it depends largely on the processing control during lithium-ion battery manufacturing, the solvent recycling is generally easier for non-aqueous solvents with lower flash point, i.e. more volatile, compared to water that has strong bonds and less volatility. Thus, the use of **PVDF requires less energy for solvent recycling and reuse, resulting in lower Global Warming Potential ("GWP") and is therefore more eco-friendly**.

Meanwhile, the dry process in which no solvent is utilized during the electrode manufacturing process also requires the use of a different type of fluorine-based polymer material, PTFE, as a key component. The fibrilization property along with the aforementioned requirements such as thermal, chemical, and mechanical properties, makes PTFE an irreplaceable material for dry processing. **PTFE also exhibits relatively low toxicity compared to other aqueous alternatives suggested by RECHARGE**[17].

1-2) Even if an alternative binder for PVDF is developed, the actual commercialization will take at least 30 years.

Replacing PVDF is not equivalent to merely replacing one material with another. Rather, the entire process including the binder dissolution, slurry preparation and transfer, electrode manufacture, and cell assembly is affected in a complicated way by changing the binder, and **a great deal of time and cost must be invested to verify the manufactured cells**. In other words, **it is not only difficult to replace the binder but doing so will also largely affect the entire battery manufacturing process and cell performance**.

In our experience, the required development of new processes, equipment, and large-scale facilities and the optimization of commercialization cannot be accomplished in less than 30 years. In addition, it will take decades to thoroughly evaluate the biological hazard and working environment safety, especially if the alternative has not already been evaluated for biohazard effects over generations.

It is also important to note that the 30 years period which was required for the first-time development of batteries did not even include the material development period. The battery industry has always utilized PFAS materials as key materials from the very initial stage of its development.

Thus, replacing PVDF with a new binder requires that all processes including the binder dissolution process, slurry preparation, electrode coating, drying, and electrolyte wetting are reviewed. During the 30 years of research for our current EV batteries, we have solved various problems of the electrode process and as a result, we have succeeded in the commercialization of EV batteries. A replacement of PVDF with a new binder would render these mass production

[17] See RECHARGE's dossier submission to ECHA for detailed description.

experiences and efforts to base zero. We would also have to repeat endless trouble shooting for processing issues and require several decades to successfully commercialize again.

When the processes listed below return to base zero, a minimum of 30 to 35 years will be required to rebuild them. Building equipment for each process, developing the process recipe, and verifying the semi-product are mandatory. Also, each step needs to be verified in lab-scale, then proceed to scale-up and pilot, followed by mass production. Realistically, the processes listed below cannot be validated simultaneously; each needs to be validated on a step-by-step basis because each step will have a significant influence on the following step. Also, the resources such as human resources, cost, infrastructure etc. are limited for the below contents to be carried out at the same time in the process.

Based on this, the **minimum estimated time required to verify each process** is as follows:

- at least 2 years for binder dissolution equipment;
- at least 3 years for main mixer disperser;
- at least 4 years for coater;
- at least 3 years for pressing equipment;
- at least 3 years for notching equipment.

Thus, the total time required for the process development alone is a minimum of 15 years. After development, the following steps are required:

- at least 4 years to verify the assembly processability and cell performance, which are needed in the 4M processes for customers;
- at least 10 years to build a plant to expand to mass production;
- at least 3 years to stabilize the yield, overall equipment efficiency, and quality.

Therefore, the total time required for a transition is minimum 30 years, but likely more. It should also be noted that **if the newly developed alternative turns out to be hard to handle in processing, these time estimations might not be enough to stabilize mass production at the same level as currently PVDF**.

The following describes **typical past experiences of battery manufacturers where development/commercialization times took much longer than anticipated** due to difficulties of developing at each step of the process:

(1) Binder Dissolution

When manufacturing the cathode slurry, a process of pre-dissolving the PVDF binder is required to uniformly disperse the binder. At this stage, the state of the binder greatly affects the raw material storage, weighing, dissolution vessel type, selection of process equipment, and condition setting. If the new substitution binder is in the form of a bale such as rubber, there may be great difficulties in preparing the process including cutting and quantitative weighing, and a new facility investment for these may be inevitable. In addition, the bale form has a low specific surface area, so it may take more time and cost more energy to dissolve it sufficiently.

If the new alternative binder is in the form of a solution, a dissolution process would not be required, but the additional mass of the solvent needs to be reflected in the transportation cost and there is a high risk of binder property being compromised due to the high temperature when passing through the equator. In addition, the solution type requires a large storage space, and the existing dissolution facilities are likely to become unused facilities.

If it is a powder type such as PVDF, it is highly likely that the new substitution binder has a higher molecular weight to compensate for lower physical properties compared to PVDF, a more complex structure such as a copolymer, or a composite of one or more polymers. In this case too, in order to sufficiently dissolve the binder, more thermal energy and process time as well as a solvent change, additional dissolution equipment, and the like may be required.

(2) Cathode Mixing

When manufacturing a cathode slurry, the binder uniformly disperses the active material and the conductive material, thus contributing to appropriate rheological properties. However, if the binder is changed, there is a high possibility that both the existing solvent and the mixing process equipment themselves need to be changed for the slurry to have an equal or better processability. Asides from the dispersibility of the cathode slurry, the phase stability of the slurry is important as well and the viscosity of the slurry should not rapidly increase or decrease before coating or drying. PVDF has been developed and improved to obtain the slurry properties that are optimized to assure the desired slurry stability in a non-aqueous solvent through a long period of research and development, including the development of recycling technology for reuse of the solvent.

(3) Cathode Slurry Transfer

In addition, one of the factors that is easily overlooked is the slurry transfer step, which is directly related to productivity in manufacturing. In the case of applying a new alternative binder replacing PVDF, if the slurry viscosity is significantly increased, the entire transfer system of the pipeline may need to be replaced.

This change includes increasing the transfer pump power according to the physical properties, readjusting the line of balance, and evaluating a full review of new facility investment.

(4) Electrode Production

From the viewpoint of electrode production, the slurry must have appropriate rheological properties, which are also greatly affected by the binder. The binder change causes a large change in the flow and thermal properties of the slurry (particularly, it affects the drying temperature and drying time), and is highly likely to cause electrode quality problems in the coating and drying process after slurry preparation.

In addition, certain binders are likely to require the introduction of an additional process different from the existing process for coating/drying. For example, a high temperature curing process of 300°C or higher may be required to improve the performance of the binder. In this case, it is necessary to develop a new temperature control process and related process equipment that can ensure the uniformity of the electrode, not to mention the need to build a new facility for the large-scale and high temperature that uses much more thermal energy.

(5) Cell Assembly

The binder greatly affects the physical properties of the electrode such as electrode adhesion force and flexibility. If the adhesion force is lower than that of PVDF, it cannot easily proceed to the subsequent process stage due to electrode detachment and even if the cell is manufactured, the capacity and cycle performance are inevitably degraded. In addition, if a design change such as an increase in binder is made to make-up the insufficient adhesion force, the electrode may become stiffer and lose flexibility. For the mass production of electrodes, the electrodes are wound and unwound in the form of rolls, and at this stage, the electrodes with low flexibility and brittleness cause additional problems of being easily broken and detached.

(6) Electrolyte Wetting

Once produced, the electrode undergoes an electrolyte wetting process where the degree of wetting is greatly affected by the affinity of the binder and the electrolyte. If an electrolyte-friendly functional group is additionally introduced into the binder, it may be helpful to solve this problem, but mechanical properties of the binder may be compromised. Thus, other problems such as a decrease in electrode adhesion force or a decrease in cell life may be the result.

(7) Cell Verification

When changing the binder, the cell needs to be verified for its safety and life span. This process takes a very long time and is high cost. For EV cells, it has been taking decades to obtain data from field tests regarding cell safety upon sudden temperature change and impact. It is obvious that a newly introduced binder will have to go through the same verification steps as PVDF did, which will take just as long. For example, in the case of EV and ESS cells, life verification of 3,000 cycles or more is required to guarantee at least 10 years of lifespan, but it takes more than 2 years for the verification of one condition. This applies for the case of continuous charge/discharge, and the actual field test will take more than 10 years because charge/discharge will not be continuous.

2) The abovementioned minimum 40 years may not be sufficient to verify cell performance and reliability. **An insufficient verification of cell performance and reliability for EV due to time**

constraints would risk user's safety.

In the beginning of the commercialization of batteries, there have been multiple fire incidents. The battery industry has invested around 30 years of research and development to ensure the reliability and safety of the batteries, and the EV and ESS industries are now blossoming due to the improved battery quality. **To assure the long-term reliability of EV and ESS, field test data under high temperature, low temperature, vibration, and impact was collected over 20 years through the Battery Management System ("BMS") embedded in the battery pack.** The battery industry has worked very hard to achieve the current level of reliability. The effort, time, and cost invested are valuable assets to the industry that cannot be calculated through a simple arithmetic. **If an alternative binder was applied without such extensive long-term verification, tremendous safety risks for end-users would be the consequence.**

3) Comprehensive exclusion from the ban is required for the entire battery industry

As it has been emphasized, developing viable alternative PFAS substances and their manufacturing technologies used in the battery industry within the currently suggested derogation periods is not feasible.

The proposed PFAS restrictions **not only affect the manufacturing of current cell materials, pack parts (used for electric vehicles and ESS), and electric/electronic devices but also hampers the development of key essential materials for the development of next-generation batteries.** Examples of these indispensable materials include "PVDF" and "PVDF Copolymer" utilized as cathode binders and separator binders, "PTFE" used as binders for dry process, and O-rings and gaskets employed in the top cap of cylindrical batteries.

These materials cannot be substituted with existing technologies or alternative materials. Over the course of more than three decades, the battery industry has dedicated extensive research and development efforts to optimize the performance and stability of these materials. **Replacing them with non-PFAS materials would inevitably impact the performance, stability, and – most importantly – the safety of the materials achieved through decades of innovation efforts.** The unique properties of PFAS substances played a crucial role in maximizing and ensuring the structural integrity, reliability, stability, and performance of lithium-ion batteries, making them suitable for EV applications. SK ON's experience strongly suggests that without PFAS substances, the performance, reliability, and safety of EV batteries will be drastically compromised, hindering the growth of the EV industry, and impeding the progress towards the realization of the EU's long-term eco-friendly strategies and goals.

In particular, the development of alternative materials for lithium-ion battery binders is an intricate task that requires substantial time and resources. The current restriction proposal suggests derogation periods of 6.5 years or 13.5 years. Even when assuming the existence of alternative materials, considering the time required for the development period of alternative substances, sample testing, facility modification, etc., it is impossible to develop viable substitutes for PFAS substances that meet the stringent performance and safety requirements demanded by lithium-ion batteries within these extremely short time lines. The introduction of alternative PFAS substances without extensive evaluation will most likely have a negative impact on battery performance and lifespan, potentially hindering the progress of the EU's "Green Mobility" plans and impeding a successful transition towards EVs.

3. Socio-Economic Perspective

1) Problems linked to the time required to build a new supply chain, price increases, and supply shortage of EV, ESS, and other industrial batteries during the transition.

Even if a new alternative binder could be found, an entirely new binder supply chain would have to be established. In the meantime, PVDF usage has already been minimized to increase energy density. Even if it is assumed that the replacement is carried out only to the minimum required amount, securing the raw materials for a new binder, developing the commercially viable polymerization process, selecting the binder supplier capable of producing the required amount, investing for mass production, **and establishing a stable new supply chain requires an enormous amount of time and financial investment**.

2) The proposed PFAS restriction creates significant market uncertainties which prevent EU investments throughout the entire supply chain.

This situation poses a considerable obstruction to achieving the EU's long-term strategies, including the "Green Deal Industrial Plan for the Net-Zero Age", "Net Zero Industry Act", and "Green Mobility".

In a world where global attention is focused on expanding the EV market, a PFAS restriction would set unachievable requirements for the battery industry, thereby slowing down and even preventing battery and EV production. The consequence will be substantial losses not only for the companies of the EU's battery and EV supply chains, but also for the broader EU economy. Many other EU industries actively promoting green policies, such as the "2030 carbon neutrality" goal, would also be affected.

As of 2022, the EU EV battery market stands at 2.4 million units. However, to meet the EU's target of 100% of new vehicles sold being zero-emission by 2035, there is a need for a 250% increase in the battery market until 2027, and a 550% increase by 2034.

Unfortunately, the uncertain market conditions caused by the proposed PFAS restriction have led material companies to be hesitant to expand their investments. Such difficult investment climate makes it challenging to meet the rapidly growing demand for EV batteries, which must expand by 2 or 3 times the current size within the next 5 years to achieve the EU goals. Material companies usually plan new investments 4 to 5 years in advance, but due to the uncertainty brought on by the PFAS restriction proposal, these companies are currently delaying their investment plans.

3) The huge costs incurred to develop commercially suitable materials and relevant application processes will challenge a swift transition of the EV industry.

In addition, if the PFAS restriction is passed as currently discussed, companies making fluorine-based binders will most likely stop their investments into capacity expansion immediately. In the short term, especially given that currently there is not even a suitable candidate as an alternative, this will most likely to lead to a rapid increase in battery and EV prices as well as a battery supply shortage.

Finally, the financial investment required to develop a commercially suitable material, new mass production facilities, manufacturing processes, and cell verification is estimated to be multi-billion USD. The investment for new mass production facilities for the new alternative material alone is expected to reach more than 1 billion USD/10GWh. **These costs will be reflected in the price of EV batteries. As a result, the burden on EU consumers will increase, and the EV industry itself may be challenged.** This further exacerbates the challenges faced in meeting the ambitious EU targets.

4. Regulatory Perspective

1) Strong contradiction with the new EU Battery Regulation

Including PFAS in batteries in the PFAS restriction strongly contradicts the EU's general policy on batteries, as most recently expressed in the new EU Battery Regulation.

On several occasions, the Recitals to the new EU Battery Regulation emphasize the core importance of batteries for the EU's sustainability/climate/green mobility goals. The Recitals deliver strong arguments making it clear that an exclusion of the battery sector from the planned PFAS restriction is required:[18]

- The transition to e-mobility is indispensable for the EU to reach its 2050 climate goals;
- Batteries will make this transition possible;
- The EU expects the EV-battery market to grow "massively" in the next years due to increased e-mobility demand;
- Batteries have strategic importance;
- It is required to provide legal certainty to all operators on the battery market and to avoid discrimination and barriers to trade;
- Rules for battery performance and safety are required.

[18] See Recital (2) to the new EU Battery Regulation.

Against the background, including the battery sector in the PFAS restriction would strongly contradict the explicit wording and policy considerations of the new EU Battery Regulation.

2) Lack of basis for enforcement and compliance checks of PFAS restriction

Companies in the development/mass production stages typically check for hazardous substances to adhere to relevant regulations. However, the proposed PFAS restriction lacks specific CAS numbers for prohibited substances, making it challenging to identify their presence in the materials.

Furthermore, adequate assessment methods for detecting PFAS substances in most cases have not been established. As a result, besides the material manufacturers, no downstream users can confidently confirm the absence of PFAS substances in their products. To facilitate compliance with proposed regulations, it is imperative to develop methodologies for testing PFAS content in materials and revise relevant laws and regulations prior to incorporating PFAS into the Safety Data Sheet ("SDS") as part of foundation for companies to comply.

III. Conclusion

Based on the aforementioned it has to be concluded that replacing PFAS is practically impossible and that any replacement will likely be an inferior solution. **Therefore, PFAS used by the 'Battery Industry' need to be completely excluded from the restriction.** We sincerely hope that ECHA realizes the magnitude of the abovementioned issues and takes a more practical approach in agreeing with the battery industry that a permanent exclusion from the PFAS restriction for the Battery Industry as a whole is really what is required at this point in time.