General Comments

Additional comments to be added to submitted document No. 4233

1. Information on the Stratified Dipole Array (SDA) theory

New Scientific Interpretation of Molecular Structure and Properties of PFAS

- The stratified dipole-arrays (SDA) theory -

We support the implementation of the regulation to restrict the manufacture and use of certain hazardous PFAS such as PFOS, PFOA. However, we believe that the proposed restriction should not regulate all substances defined as PFAS, but rather identify more detailed group of substances that have similar toxicity profiles based on scientific evidence, and should set appropriate restrictions for each group of substances based on their impact on human health and the environment.

In order to establish such science-based reasonable restrictions, we would like to share a new scientific interpretation of the molecular structure and properties of PFAS, which is known as "**the Stratified Dipole Array (SDA) theory**".

This theory captures the intermolecular interactions of PFAS mainly as dipole-dipole interactions (orientation effects), and by considering the twisted structure and molecular association structure of Rf chains (chains consisting of CF_2 groups), it is possible to explain the properties of PFAS from the perspective of individual molecules and bulk. This theory has been experimentally verified and is proposed as a new way to understand the bulk properties of PFAS in a unified manner.
(Hasegawa 2016, 2017, 2022, 2023)

The current restriction proposal defines a large number of substances as PFAS, but does not provide a consistent scientific interpretation of their relevance in terms of molecular structure, properties, and safety concerns. At a minimum, it is necessary to divide the defined chemicals into several groups to allow for scientific discussion and consensus on the safety and relevance of the regulatory proposal.

References

Hasegawa(2016) : Hasegawa, Ken, Oleo Science, 16, 2016, 129-136. (Language: Japanese)
https://www.jstage.jst.go.jp/article/oleoscience/16/3/16_129/_pdf/-char/ja

Hasegawa(2017) : Takeshi Hasegawa, Chem. Rec., 17, 2017, 903–917.

https://onlinelibrary.wiley.com/doi/full/10.1002/tcr.201700018
https://www.researchgate.net/publication/316844031_Physicochemical_Nature_of_Perfluoroalkyl_Compounds_Induced_by_Fluorine

Hasegawa(2022) : Takashi Hasegawa, OECD Webinar, Advances in Understanding Per- and Polyfluoroalkyl Substances, OECD Chemical Safety and Biosafety, On 6 December 2022. (Accessed 2023/8/7) https://youtu.be/Lp_cS8Vi-FE?t=1584

Hasegawa(2023) : Takeshi Hasegawa and Takafumi Shimoaka, Acc. Mater. Surf. Res. 2023, Vol.8 No.2, 70-81. (Language: Japanese)
https://zairyo.org/wp-content/uploads/2023/06/wp-content_uploads_papers_vol8_no2_hasegawa_hasegawa_0608.pdf

2. Resubmission of Specific Information Requests from Submission Number 4233

Upon review of the publicly available document, it has become apparent that the format of the text is disorganized, making it difficult to understand the content. As a result, we have converted the text to PDF format to improve readability for both the Committees and interested parties.

Specific Information Requests

Application: Energy | Lithium-ion battery | Binder for electrodes

1: Sectors and (sub-)uses:

A-1: Energy	Lithium-ion battery	Binder for electrodes（PVDF, PVDF-HFP, PVDF-CTFE）
A-2: Energy	Lithium-ion battery	Binder for electrodes（PVDF etc.） for EVs (Electric Vehicles)
A-3: Energy	Lithium-ion battery	Separator coatings, Gel electrolyte（PVDF, PVDF-HFP）

2: Emissions in the end-of-life phase:

a. Please provide, at the (sub-)use level, an indication of the share of emissions (as percentages) attributable to these three different stages. An indication of annual emission volumes in the end-of-life phase at sector or sub-sector level would also be appreciated.

A-1, A-2, A-3

Manufacturing stage (cell manufacturing, battery manufacturing) :
Since the positive electrode material contains rare metals, the cell is sent to resource recovery. In smelting for metal recovery, it is incinerated at elevated temperatures.
The percentage and quantity of emissions are unknown.

Use stage: No loss during use. Broken or defective batteries are collected for resource recovery.
The ratio and quantity of emissions are unknown.

End-of-life: Resource recovery (same as above). Emission rate and quantity are unknown.

A-2

After being installed in EVs (Electric Vehicles) and used, LIBs (Lithium-ion Batteries) are either reused as stationary storage batteries or discarded for resource recovery.
The ratio and quantity of emissions are unknown.

b. If possible, please provide for each (sub-)use what share of the waste (as percentages) is treated through incineration, landfilling and recycling. Please provide information to justify the estimates as well as information on the form of recycling referred to.

A-1, A-2, A-3 Almost the entire amount is incinerated. Details are unknown.

3: Emissions in the end-of-life phase:

A-1, A-2, A-3

LIB resource recovery

~ Collection and recycling of EVs and storage batteries ~

Metals such as Co, Ni, Cu, and Li used in LIBs are recovered as resources from the perspectives of scarcity, economic efficiency, and environmental safety. Many companies and academia have started investing and operating as resource recovery businesses and research.
These cases are described in References.

References

ABAJ (2021): Automobile Business Association of Japan, *Automotive lithium-ion batteries Recycling activity in Japan and overseas, 2021.* https://www.aba-j.or.jp/info/industry/15613/ (last accessed 21.04.2023)

BASF (2022): *BASF to build commercial scale battery recycling black mass plant in Schwarzheide, Germany*, 2022. https://catalysts.basf.com/files/pdf/P249e_Black_Mass_Plant.pdf (last accessed 10.05.2023)

BASF (2023a): BASF and Tenova Advanced Technologies enter into a joint development agreement for efficient recycling of lithium-ion batteries, 2023. https://catalysts.basf.com/news/basf-and-tenova-advanced-technologies-enter-into-a-joint-development-agreement-for-efficient-recycling-of-lithium-ion-batteries (last accessed 20230421)

BASF (2023b): Lithium-Ion Battery Recycling, BASF Catalysts, 2023. https://catalysts.basf.com/industries/recycling/lithium-ion-battery-recycling (last accessed 21.04.2023)

DOWA (2018): *DOWA ECO-SYSTEM Increases Processing of Lithium-Ion Batteries and Enables Both Safe Treating and Efficient Metal Recycling*, DOWA HOLDINGS, 2018. https://ir.dowa.co.jp/en/ir/news/news-5617789479587210707/main/0/teaserItems1/012/linkList/0/link/release181217_e.pdf (last accessed 10.05.2023)

DOWA (2021): *DOWA ECO-SYSTEM Expands Used Lithium-Ion Battery Recycling Capacity*, DOWA HOLDINGS, 2021. https://ir.dowa.co.jp/en/ir/news/news20210419.html (last accessed

10.05.2023)

JARP (2023): *About the LiB Joint Collection System*, Japan Automobile Recycling Cooperation Organization (JARP), 2023. https://jarp.org/duties/lib/ (last accessed 25.04.2023)

JOGMEC (2019): Japan Organization for Metals and Energy Security (JOGMEC), *Outline of Lithium Production Technology, JOGMEC Metal Resources Information*,2019. https://mric.jogmec.go.jp/reports/mr/20190329/112230/ (last accessed 23.04.2023)

JERA (2022): JERA and Sumitomo Chemical Start a Demonstration Project to Develop a Low Environmental Impact Recycling Process for Electric Vehicle Lithium-ion Batteries, JERA Co., Inc.,2022. https://www.jera.co.jp/en/news/information/20220419_885 (last accessed 19.04.2023)

JOGMEC (2019): *Outline of Lithium Production Technology, Metal Resources Information, 2.4.4 Recycling from Lithium-ion Batteries (LiBs)*, 2019. https://mric.jogmec.go.jp/reports/mr/20190329/112230/ (last accessed 17.04.2023)

JXNMM (2021): JX Nippon Mining & Metals Corporation, *Establishment of a New Company in Europe to Promote LiB Recycling and Battery Materials Projects | FY2021.* https://www.jx-nmm.com/english/newsrelease/fy2021/20210705_04.html (last accessed 21.04.2023)

MM (2018): *Joint Development of Recycling Technology of Cobalt, Nickel and Other Metals with Nippon Magnetic Dressing*, Mitsubishi Maerials, 2018. https://www.mmc.co.jp/corporate/en/news/2018/news20180921.html (last accessed 10.05.2023)

MM (2023): *Efforts for xEVs resource recovery toward a recycle-oriented society*, Mitsubishi Materials, 2023. https://www.mmc.co.jp/corporate/en/product/ev/recycling/index.html (last accessed 10.05.2023)

NISSAN (2023): *Nissan, Sumitomo Corp. and 4R set up plant to recycle electric-car batteries*, Nissan Motor, 2023. https://global.nissannews.com/en/releases/180326-01-e (last accessed 21.04.2027)

SC (2022): *JERA and Sumitomo Chemical Start a Demonstration Project to Develop a Low Environmental Impact Recycling Process for Electric Vehicle Lithium-ion Batteries*, Sumitomo Chemical, 2022. https://www.sumitomo-chem.co.jp/english/news/detail/20220419e.html (last accessed 25.04.2023)

Tokoro et al (2021): Chiharu Tokoro, Soowon Lim, Kaito Teruya, Masataka Kondo, Kazuhiro Mochidzuki, Takao Namihira, Yasunori Kikuchiet, *Separation of cathode particles and aluminum* *current foil in Lithium-Ion battery by high-voltage pulsed discharge Part I: Experimental investigation*, Waste Management, 125, 2021, p58-66. https://www.sciencedirect.com/science/article/abs/pii/S0956053X21000131

WASEDA (2023): *A Novel, Single Electrical Pulse Method for the Recycling of Lithium-Ion Battery Cathodes*, Research Activities, Waseda University, 2023. https://www.waseda.jp/inst/research/news-en/74099 (last accessed 09.05.2023)

4: Impacts on the recycling industry:

b. The measures that recyclers would need to take to achieve the proposed concentration limits.

A-1, A-2, A-3

Collection and incineration

When collecting LIB and recovering precious metals, there is a concern that new PFAS will be generated from the refining process. However, it is thought that the generation of new PFAS can be avoided by controlling the sintering temperature to elevated temperatures (>850°C). (Zackrisson and Schellenberger 2020) Incineration at 1,000 to 3,000°C is industrially possible with an electric furnace.

References

Zackrisson and Schellenberger (2020): *Toxicity of lithium ion battery chemicals -overview with focus on recycling*, Mats Zackrisson, Steffen Schellenberger, Research Institutes of Sweden, 06.18.2020.

8: Other identified uses – Analysis of alternatives and socio-economic analysis:

a. The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use.

A-1, A-2, A-3

Estimation of PVDF quantity contained in LIB installed in EV

LIB production at Gigafactories in the EU is expected to reach 1,100 GWh (gigawatt hours) in 2024. (FARADAY 2022a, b, Gifford 2022) According to another survey, the capacities of the factories are 455 GWh in 2020 and 1,447 GWh in 2025. (Yu and Sumangil 2021) These figures do not include LIBs themselves or LIBs installed in electric vehicles imported from outside the EU. There is also a survey that the total amount of LIB demand in the world will reach 9,300 GWh in 2030 as the demand for EVs rapidly increases, and LIB manufacturing within the EU will reach more than 10% of the world production. (Bhutada 2022)

The amount of PVDF used in LIB for EV is estimated from the amount of PVDF binder used in the positive electrode. (Appendix A) As a result of the estimation, 1,100 GWh in the EU is equivalent to 40,000 tons of PVDF.

References

Bhutada (2022): Govind Bhutada, Mapped: EV Battery Manufacturing Capacity, by Region, 2022. https://www.visualcapitalist.com/sp/mapped-ev-battery-manufacturing-capacity-by-region/ (last accessed 10.04.2023)

FARADAY (2022a): Growing optimism for the UK battery manufacturing industry but redoubling of efforts needed to keep pace with investments across Europe, The Faraday Institution, 2022. https://www.faraday.ac.uk/ev-economics-study-2022/ (last accessed 21.04.2023)

FARADAY (2022b): *UK electric vehicle and battery production potential to 2040*, THE FARADAY INSTITUTION UK GIGAFACTORY OUTLOOK (JUNE 2022), THE FARADAY INSTITUTION, 2022. https://www.faraday.ac.uk/wp-content/uploads/2022/06/2040-Gigafactory-Report_2022_Final_spreads.pdf (last accessed 21.04.2023)

Gifford (2022): Stephen Gifford, The Gigafactory Boom: The Demand for Battery Manufacturing in the UK, FARADAY INSIGHTS - ISSUE 2 UPDATE: JULY 2022. https://www.faraday.ac.uk/wp-content/uploads/2022/07/Faraday_Insights_2_update_July_2022_FINAL.pdf (last accessed 21.04.2023)

JRC (2018): Lithium-ion batteries for mobility and stationary storage applications: Scenarios for costs and market growth. Joint Research Centre (JRC), European Commission, 2018. https://visitors-centre.jrc.ec.europa.eu/sites/default/files/poster_flyer/jrc114616_li-ion_batteries_two-pager_final.pdf (last accessed 29.12.2022)

Yu and Sumangil (2021): Alice Yu and Mitzi Sumangil, *Top electric vehicle markets dominate lithium-ion battery capacity growth*, S&P Global Intelligence, 2021. https://www.spglobal.com/marketintelligence/en/news-insights/blog/top-electric-vehicle-markets-dominate-lithium-ion-battery-capacity-growth (last accessed 20.04.2023)

Appendix A

Trial calculation of the amount of PVDF used in EV batteries from the amount of PVDF binder used for positive electrodes.

(1) Estimation of cell's specific capacity

Amount of binder in positive electrode: 2 wt% (0.5-4.0 wt%)

Positive electrode specific capacity: 150 Ah/kg

Cell average voltage: 3.7 V

Cell average specific capacity: 555 Wh/kg

(2) Estimation of Binder Amount in Battery

1 GWh cell's positive electrode weight: 1.0*10^9/555 = 1.8*10^6 kg = 1.8*10^3t

Binder weight equivalent to 1 GWh cell: 1.8*10^3*0.02 = 36 t

Binder in 100 GWh cell: 3,600 tons,

(3) Result

EU 1,100 GWh in 2024: 39,600 t ≒ 40,000 t (10,000 - 80,000 t)

b. The key functionalities provided by PFAS for the relevant use.

A-1, A-2, A-3

Fabrication of LIB electrodes and function of binder

The binder makes the slurry viscous and bonds and adheres materials in electrodes

LIB is a secondary battery that uses a metal oxide such as lithium cobalt oxide (LCO) as the positive electrode active material, a carbon material such as graphite as the negative electrode active material, an organic solvent and lithium salt as the electrolyte, and a separator between the positive and negative electrodes. The active material is usually powder composed of particles of about 1 to 20 μm diameter. The active material is mixed with a binder and a conductive material such as carbon black to form a slurry, which is applied onto a metal foil such as aluminum or copper and dried to form an electrode. (Nagai 2009)

The binder is a polymer material that imparts an appropriate viscosity to the organic solvent-based slurry and imparts dispersion stability to the filling material such as the active material when producing the electrode.

When the organic solvent in the coated electrode dries, the binder binds the active materials in the electrode together and adheres the active material to the metal foil current collector. At this stage, the binder coats the surface of the active material and affects the electrochemical properties of the battery (resistance, rate performance, battery life, etc.). (Nagai 2009, Yoshino 2010, Amin-Sanayei, He 2015, Despotopoulou, Burchill 2002, KKS 2021)

Organic solvent application is essential

In water-based slurries, Li ions in positive electrode materials (lithium transition metal oxide compounds, LCO, etc.) are replaced with hydrogen ions in water, degrading the performance of the material. Therefore, there is no substitute for PVDF binders in organic solvent electrode systems. (Watanabe et al 2021)

Binder is a key material that affects various battery performances

In the cell, Li ions move between the positive electrode active material and the negative electrode active material through the electrolytic solution, thereby repeating discharging and charging to transfer the electric capacity.

Li ions are intercalated and deintercalated at the interface between the electrolyte and the active materials. The greater the amount of active material, the greater the electric capacity of the cell.

The resistance of the cell depends on the movement of lithium ions in the electrolyte and the active material, and the intercalation/deintercalation at their interfaces. Therefore, the smaller the active material, the larger the specific surface area, and the larger the coating area of the electrode layer, the better the input/output characteristics of the cell.

Binders hold the components in the electrode together to ensure ionic and electronic conductivity.

Electrochemical oxidation resistance at positive electrode

Since Li metal has the most noble potential, the potential of the positive electrode is as high as 4.2 to 4.5 V (Li/Li^+), so the surface of the positive electrode material becomes an electrochemically highly oxidizing atmosphere. Therefore, the non-fluorine-based polymer has low oxidation resistance and is easily oxidatively decomposed on the surface of the positive electrode material. PVDF has excellent oxidation resistance and does not decompose for a long period of time. (Kurihara, Nagai 1998, Inaba et al 2013, Nagai 2009)

In addition, organic solvent molecules in the electrolytic solution are likely to be oxidatively decomposed when the potential of the positive electrode becomes high. The PVDF binder thinly coats the surface of the positive electrode active material, absorbs several tens of percent of the electrolyte, and swells. It does not interfere with the disinsertion and insertion of Li ions at the interface between the positive electrode active material and the electrolyte and acts as a passive film, ‘SEI (Solid Electrolyte Interphase)’, suppressing the decomposition of the electrolyte solvent. It is essential to suppress the redox reactions of the organic solvents in the electrolyte to prevent deterioration of battery performance (lifetime, ionic conductivity, etc.). (Inaba et al 2013)

Since PVDF binders have excellent properties that are indispensable especially for positive electrodes, even after commercial production began in 1991, numerous developments have been made by companies and research institutes. No alternative to PVDF binder has been found yet.

References

Amin-Sanayei, He (2015): Ramin Amin-Sanayei, Wensheng He, Advanced Fluoride-Based Materials for Energy Conversion, Chapter 10 - Application of Polyvinylidene Fluoride Binders in Lithium-Ion Battery, 2015, 225-235.
https://www.sciencedirect.com/science/article/pii/B9780128006795000105

Despotopoulou, Burchill (2002): Marina Despotopoulou, Michael T Burchill, Coatings for electrochemical applications, Progress in Organic Coatings, 45 (2)-(3), 2002, 119-126.
https://www.sciencedirect.com/science/article/pii/S0300944002001054

Inaba et al (2013): The 54th Battery Symposium, Yusakua Inaba, Tamito Igarashi, Yasuhiro Suzuki, 3F21, p46 (2013).

KKS (2021): Kikan Kagaku Sosetsu, 49, 2001, 136-145. [in Japanese]

Kurihara, Nagai (1998):The 39th Battery Symposium, Azusa Kurihara, Aisaku Nagai, 3C09、p309（1998）.

Nagai (2009): Nagai Aisaku, Applications of Polyvinylidene Fluoride-related materials for Lithium-Ion Batteries, Lithium-Ion Batteries, Springer, 155–161 (2009).

Yoshino (2010): Akira Yoshino, *Next Generation Lithium Battery and Polymer Materials*, Journal of the Japan Society of Polymer Processing, 22, (6), 274-278 (2010) (in Japanese).

Watanabe (2021): Tatsuya Watanabe, Kouji Hirai, Fuma Ando, Shoudai Kurosumi, Shinsaku Ugawa, Hojin Lee, Yuta Irii, Fumihiko Maki, Takao Gunji, Jianfei Wu, Takeo Ohsaka, Futoshi Matsumoto, Surface Double Coating of LiNiaCobAl1-a-bO2（a > 0.85）Cathode with TiOx and Li2CO3 to Apply a Water-Based Hybrid Polymer Binder to Li-Ion Batteries' Preparation, RSC Advances, 10, 13642-13654 (2020).

c. The number of companies in the sector estimated to be affected by the restriction.

A-1, A-2, A-3

In the EU

(1) Manufacturers | Binder

2

(2) Lithium-ion battery manufacturers（Gigafactories） (Walker 2022)

7 (2022), 27 (2030)

(3) Electric vehicle manufacturers

10 （major European car manufacturing groups） (BSC 2021)

(4) Battery Supply Chain and EV Supply Chain

The number of companies is unknown.

The current working population is 14.6 million. (FURUYA 2021, ACEA 2020)

References

ACEA (2020): Facts about the automobile industry, The automobile industry: the engine of Europe, The European Automobile Manufacturers' Association (AECA), 2020. https://www.acea.auto/fact/facts-about-the-automobile-industry/ (last accessed 24.04.2023)

BSC (2021): 2021 (Europe): Top Car Makers Electric Vehicle Readiness Index - Car Sales Statistics, best-selling-cars.com (BSC), 2021. https://www.best-selling-cars.com/electric/2021-europe-top-car-makers-electric-vehicle-readiness-index/ (last accessed 23.04.2023)

Furuya (2021): Shota Furuya, How much jobs will be lost in the automotive industry due to the transition to electric vehicles?, Energy Shift, 2021. https://energy-shift.com/news/93eb91ad-37a7-46d7-959c-5f5eb55ec505, 2021（last accessed 17.04.2023）

Walker (2022): Michael Walker, The battery market in Europe is growing: in 2030 production of

789.2 GWh, US-JPRI, 2022. https://www.us-jpri.org/the-battery-market-in-europe-is-growing-in-2030-production-of-789-2-gwh/ (last accessed 23.04.2023)

d. The availability, technical and economic feasibility, hazards and risks of alternatives for the relevant use, including information on the extent (in terms of market shares) to which alternative-based products are already offered on the EU market and whether any shortages in the supply of relevant alternatives are expected.

A-1, A-2, A-3

Alternative(s) to LIB

Nickel Metal Hydride Battery (**NiMH)**

In Japan, it is manufactured and sold for use in vehicles. Compared to LIB, it is inferior in some performances such as battery capacity.

Sales volume in Japan: 435M cells (2022)

Alkali (NiMH): 434,573 (Unit: 10^3 cells)

LIB: 1,191,771 (Vehicle 898,393; Others 293,378) (Unit: 10^3 cells)

(BAJ 2023)

References

BAJ (2023): December Battery Sales Results (Ministry of Economy, Trade and Industry Machinery Statistics), Jan.-Dec.,2022., Secondary batteries, Monthly newspaper "Denchi", March, 2023, Battery Manufacturers Association of Japan (BAJ).
https://www.baj.or.jp/public_relations/denchi/gu58lf0000000bbo-att/denchi2303a.pdf (last accessed 27.04.2023)

Alternative(s) to EV

Internal combustion engine (ICE) Vehicle (Gasoline engine car, Hybrid car with NiMH etc.)

(a) Gasoline Engine Car

It is still used all over the world today. There are also reports that CO2 emissions are about the same as LIB-equipped EVs. (Yasukawa 2020, Kawamoto et al 2019)

(b) Hybrid car

It is still used all over the world today. There are also reports that CO2 emissions are about the same as LIB-equipped EVs.

Vehicles equipped with NiMH batteries are limited to hybrid vehicles from the viewpoint of energy capacity. This battery is inferior in performance to LIB. (BAJ 2023)

References

BAJ (2023): December Battery Sales Results (Ministry of Economy, Trade and Industry Machinery Statistics), Jan.-Dec.,2022., Secondary batteries, Monthly newspaper "Denchi", March, 2023, Battery Manufacturers Association of Japan (BAJ).

https://www.baj.or.jp/public_relations/denchi/gu58lf0000000bbo-att/denchi2303a.pdf (last accessed 27.04.2023)

Kawamoto et al (2019): Ryuji Kawamoto, Hideo Mochizuki, Yoshihisa Moriguchi, Takahiro Nakano, Masayuki Motohashi, Estimation of CO2 Emissions of Internal Combustion Engine Vehicle and Battery Electric Vehicle Using LCA", Yuji Sakai, Atsushi Inaba, Sustainability 2019, *11*(9), 2690. https://doi.org/10.3390/su11092690

Yasukawa (2020): Hiroshi Yasukawa, Do EVs release more emissions than ICE vehicles across their lifespan? – I examine the "Well To Wheel" analysis by Mazda, 2020. https://blog.evsmart.net/english-content/do-evs-release-more-emissions-than-ice-vehicles-across-their-lifespan/ (last accessed 19.04.2023)

g. For cases in which substitution is not technically or economically feasible, information on what the socio-economic impacts would be for companies, consumers, and other affected actors. If available, please provide the annual value of EU sales and profits of the relevant sector, and employment numbers for the sector.

A-1, A-2, A-3

Alternatives to PVDF binder for LIBs:

(a) No alternative binder for lithium metal oxide cathode materials

In general, LIB binders use PVDF for the positive electrode, and styrene-butadiene rubber (SBR)/carboxymethylcellulose (CMC) and acrylic resin for the negative electrode. An organic solvent (N-methyl pyrrolidone, NMP) and water are used as solvents for electrode slurries for coating with these binders, respectively.

An electrode slurry is prepared by mixing a lithium metal oxide, a conductive carbon material, a binder and a solvent as an electrode material.

A coated electrode is obtained by coating the slurry on a metal foil and volatilizing the solvent. The binder binds the members together in the electrode. A cell consists of a positive electrode, a negative electrode, a separator, an electrolyte, and a container (metal can, aluminum pouch, etc.).

SBR (Styrene Butadiene Rubber) and acrylic resins can be dissolved or dispersed in an organic solvent to prepare a slurry, which is then applied to a current collector foil and dried to prepare an electrode. However, in the battery, electrochemical oxidative decomposition occurs on the surface of the positive electrode to generate gas, etc., and the battery performance deteriorates, making it impossible to maintain the initial performance. (Kurihara, Nagai 1998, Inaba et al 2013) In addition, since alkaline components (such as LiOH) derived from the raw materials remain in the positive electrode material, there is also the problem of corrosion of the aluminum current collector when the electrode is coated with a water-based slurry. (Watanabe 2021)

A carbon material with a large specific surface area is used for the conductive agent, and because it is generally fine particles and hydrophobic, it is difficult to disperse it evenly in an aqueous slurry. This impairs the manufacturing process and product functionality. (Kondo, Ohnishi 2014)

Therefore, it cannot be replaced with the non-fluorinated resin binders used in current water-based slurries.
CMC cannot be used because it is insoluble in organic solvents. Cellulosic resins such as hydroxypropyl cellulose (HPC) are soluble in organic solvents and are effective in imparting viscosity to slurries. However, it dissolves in the organic solvent of the electrolyte in the cell, so that the binding function as a binder cannot be maintained, and the SEI function on the surface of the positive electrode material cannot be imparted. Therefore, cellulosic resins cannot be used in organic solvent slurry systems.
In organic solvent-based slurries, even if slurries and electrodes can be manufactured, no binder other than PVDF has been found that satisfies the requirements for electrochemical stability in cells, battery life characteristics, and safety.

Even if a substitute is found, it is necessary to reconsider an electrode coating device and a solvent recovery system. Commercially produced in 1991, and subsequent developments have not found a better oxide cathode material than the PVDF binder. Therefore, it will take a long time (probably more than 5 years) to confirm the suitability of cathode materials, formulations, manufacturing processes, development, etc., and further verification (battery functions, safety and life) and facility construction. It is expected that it will take 10 years or more.

Many LIB storage batteries are installed in electric vehicles such as EVs and PHEVs and have a proven record of accomplishment as automotive batteries. However, since the alternative battery has no record of accomplishment in small equipment applications, it is necessary to confirm safety and reliability after completing the development of materials and processes for automotive applications. Therefore, it is expected that demonstration tests for another 5 to 10 years will be required.

(b) Improvement of LIB cathode material

Appropriate methods and materials need to be developed, such as a coating technology that suppresses oxidative decomposition of the organic material on the material surface by allowing Li ions to enter and leave the surface of the metal oxide of the positive electrode material. Coated electrodes and LIBs are highly complete systems, so if one key component is changed, it will have a significant impact on various parts such as LIB materials, manufacturing processes, battery performance, and quality control. This means that it cannot be changed easily.

As mentioned above, no substitutes for PVDF binders currently exist.

References

Inaba et al (2013): The 54th Battery Symposium, Yusakua Inaba, Tamito Igarashi, Yasuhiro Suzuki, 3F21, p46, 2013.

Kondo, Ohnishi (2014): Mitsuo Kondo, Noriyuki Ohnishi, Development of Lithium-ion Secondary

Battery Cell using Water-based Electrode Slurry", Yamaha Motor Technical Review, 12 (50), 2014. https://global.yamaha-motor.com/jp/design_technology/technical/presentation/pdf/browse/50gs05.pdf (last accessed 10.05.2023) (in Japanese)

Kurihara, Nagai (1998):The 39th Battery Symposium, Azusa Kurihara, Aisaku Nagai, 3C09、p309, 1998.

Watanabe (2021): Tatsuya Watanabe, Kouji Hirai, Fuma Ando, Shoudai Kurosumi, Shinsaku Ugawa, Hojin Lee, Yuta Irii, Fumihiko Maki, Takao Gunji, Jianfei Wu, Takeo Ohsaka, Futoshi Matsumoto, Surface Double Coating of LiNiaCobAl1-a-bO2（a > 0.85）Cathode with TiOx and Li2CO3 to Apply a Water-Based Hybrid Polymer Binder to Li-Ion Batteries' Preparation, RSC Advances, 10, 13642-13654 (2020).

(c) Polyfluorovinyl（Polyvinyl fluoride, PVF）, –(-CH2CHF-)-

Not a substitute.

Regulation XV proposes PVF as an alternative to PVDF.
The reason is that the polymer structure does not fit the definition of PFAS. It is not known whether it can be used or not. Since it is FP, there are no particular differences in terms of safety, biotoxicity, environmental sustainability, etc. It may be an example of the proposed regulation lacking scientific grounds.

PVF has a high melting point of 180°C, which is higher than PVDF. In addition, it does not dissolve in organic solvents. Therefore, molding is performed by mixing an organic solvent, which is a latent solvent, with a plasticizer. Due to its excellent durability and weather resistance, the material is formed into films and sheets, and is used for the outer walls of buildings and the front and back sheets of solar panels. (Ebnesajjad 2012)

DuPont is the manufacturer of PVF and its fabrication as we know it today. (DuPont 2023) When using a battery binder, the binder is dissolved in an organic solvent, mixed with each part of the electrode to form a slurry, then applied to the metal foil of the current collector and dried. Generally, NMP is used as an organic solvent, and it is recovered in the drying process and reused.

Due to the excellent solvent resistance of PVF (Dupont 2021), it is considered difficult to coat it with the current solvent N-methyl pyrrolidone (NMP) when manufacturing electrodes for LIBs. In addition, there is likely to be concern that dehydrohalogenation reaction occurs in PVF due to the strong base of impurities in NMP.

The electrochemical oxidation resistance of PVF has been found to be inferior to that of PVDF. (Inaba et al 2013, Inaba 2023)

Switching to PVF presents many challenges, such as searching for a suitable solvent for the coated electrode system of ordinary LIBs and confirming cell performance.

References

DuPont (2021): Chemical Resistance of Tedlar® PVF Film, DuPont, 2021. https://www.dupont.com/content/dam/dupont/amer/us/en/tedlar-pvf-films/public/documents/DuPont-Technical-Bulletin_Chemical-Resistance-of-Tedlar.pdf (last accessed 11.05.2023)

DuPont (2023): DuPont™ Tedlar® surface protection film provides superior surface protection for a variety of materials and industries, DuPont. https://www.dupont.com/brands/tedlar.html (last accessed 11.05.2023)

Ebnesajjad (2012): Sina Ebnesajjad, Polyvinyl Fluoride: Technology and Applications of PVF, Plastics Design Library, 1st Ed., William Andrew, 2012.

Inaba et al (2013): The 54th Battery Symposium, Yusakua Inaba, Tamito Igarashi, Yasuhiro Suzuki, 2013, 3F21, p46.

Inaba (2023): Yusakua Inaba, Inteenal data. Oxidation potential of PFV, by molecular orbital calculation: PVF 6.11V vs PVDF 6.48V.

Alternatives to LIB with PVDF binder

All-solid-state batteries and others

Excellent materials for all-solid-state batteries have been found, but it will take a considerable amount of time to achieve a substitute, such as mass production technology and price of materials, manufacturing methods and life characteristics of cells, and verification tests for automotive batteries. (Yaku 2023)

The cost of materials is still high, and there is still a long way to go before it can be put to practical use, including technology development for mass production and the construction of facilities. The price of solid electrolytes is about 50 to 200 times the price of electrolytes (based on reagent prices: Sigma 2023; TESHIMA 2023).

Concerns about high LIB voltages (Zackrisson and Schellenberger 2020) can be addressed by various safety standards for traditional industrial products, passenger cars and aircraft.

References

Sigma (2023): Solid electrolyte price information, Lithium-ion battery materials, Sigma Aldrich,

2023. https://www.sigmaaldrich.com/JP/ja/technical-documents/technical-article/materials-science-and-engineering/batteries-supercapacitors-and-fuel-cells/lithium-ion-batteries (last accessed 27.04.2023)

TESHIMA (2023): Solid electrolyte price information, TESHIMA CORPORATION Electrode Materials and Electrolytes,【Synthesis and Materials】, Product Information, Reagents, FUJIFILM Wako Pure Chemical, 2023. https://labchem-wako.fujifilm.com/jp/category/00234.html (last accessed 27.04.2023)

Yaku (2023): Fumie Yaku, All-solid-state batteries are "the best after practical application" Tokyo Tech Specially Appointed Professor Kanno, Nikkei Business, 2023. https://www.nikkei.com/article/DGXZQOUC174M50X10C23A1000000/ (last accessed 10.05.2023)

Zackrisson and Schellenberger (2020): *Toxicity of lithium ion battery chemicals -overview with focus on recycling*, Mats Zackrisson, Steffen Schellenberger, Research Institutes of Sweden, 06.18.2020.

Alternatives to EV equipped with LIB:
Internal combustion engine automobiles and hybrid vehicles

If LIBs cannot be used, vehicles will have to be equipped with internal combustion engines permanently or until alternative batteries are available. (EP 2022, Kawamoto et al 2019) With the insistence of some countries such as Germany, only the synthetic fuel, “e-Fuel”, is allowed to be used in internal combustion engines. (Reuters 2023) Italian biofuels were not allowed. (Pascal 2023) Regarding alternative batteries as well, it is necessary to coordinate with regulations on internal combustion engine passenger cars based on environmental policies such as CN and zero emissions of the EU and governments of other countries. Some HEV models use nickel-metal hydride secondary batteries (NiMH). Both alternatives are realistic because they are easy to maintain or partially replace, and social confusion is less.

References

EP (2022): EU ban on the sale of new petrol and diesel cars from 2035 explained, European Parliament, 2022. https://www.europarl.europa.eu/news/en/headlines/economy/20221019STO44572/eu-ban-on-sale-of-new-petrol-and-diesel-cars-from-2035-explained (Accessed 20230424)

Kawamoto et al (2019): Ryuji Kawamoto, Hideo Mochizuki, Yoshihisa Moriguchi, Takahiro Nakano, Masayuki Motohashi, Estimation of CO2 Emissions of Internal Combustion Engine Vehicle and Battery Electric Vehicle Using LCA”, Yuji Sakai, and Atsushi Inaba, Sustainability 2019, *11*(9), 2690. https://doi.org/10.3390/su11092690

Pascal (2023): Federica Pascale, Italian MP slams EU plan on e-fuel combustion cars, regrets treatment of biofuels, EURACTIV, 2023. https://www.euractiv.com/section/politics/news/italian-mp-slams-eu-plan-on-e-fuel-combustion-cars-regrets-treatment-of-biofuels/ (last accessed 27.04.2023)

Reuters (2023): EU-German deal to map path for e-fuel cars after 2035, Reuters, 2023. https://www.reuters.com/business/autos-transportation/eu-german-deal-maps-legal-path-e-fuel-cars-after-2035-document-2023-03-27/ (last accessed 27.04.2023)

Yasukawa (2020): Hiroshi Yasukawa, Do EVs release more emissions than ICE vehicles across their lifespan? – I examine the "Well To Wheel" analysis by Mazda, 2020. https://blog.evsmart.net/english-content/do-evs-release-more-emissions-than-ice-vehicles-across-their-lifespan/ (last accessed 19.04.2023)

Advantages of lithium-ion batteries using PVDF as the positive electrode binder

The performance and quality of LIBs vary widely among manufacturers. Since 2010, more than 600,000 units of Nissan Motor's EV Leaf have been sold. Nonetheless, there have been zero serious battery accidents, such as fires, for over a decade. (ELECTRIC LIF 2023, Tepco 2022)

Since some companies have already achieved a high degree of safety, other companies can also be expected to be able to sufficiently avoid accidents by establishing public safety standards and improving their own technology.

References

ELECTRIC LIF (2022): LEAF batteries without major accidents for more than 10 years, ELECTRICLIFE, 2022. https://electriclife.jp/leafsafebattery/ (last accessed 23.04.2023)

Tepco (2022): Solving the Problem of Used EV Batteries at the Forefront of "Battery Reuse", Tepco, 2022. https://evdays.tepco.co.jp/entry/2022/04/28/tepco_13, 20220428, (last accessed 23.04.2023)

Socio-economic impact

Major countries within the EU have decided to ban the sale of new passenger cars with internal combustion engines by 2035 or 2040, and shift to electric vehicles (EVs) entirely. (EP 2022)

If the draft PFAS regulations are implemented as they are, PVDF cannot be used for LIBs by 2027 at the earliest, and EVs equipped with LIBs cannot be manufactured, imported, or sold.

PVDF is currently used as a binder for oxide cathode electrode of LIBs, but no substitutes for this material or manufacturing method have been found yet. Considering the search and development of alternative materials and technologies, demonstration tests, and the time required for commercialization, the transition to EVs in 2035 will be extremely difficult.

Although it cannot be deployed to EV, at the same time, most internal combustion engine vehicles will be abolished. Therefore, it affects many companies and a tremendous number of employees who manufacture internal combustion engine vehicles, batteries and EVs. (Furuya 2021, ACEA 2020)
In addition, the impact will not be limited to the countries within the EU, and the global impact on related industries (materials, batteries, vehicles, resources, etc.) and the economy will be enormous.

In the EU, large-scale factories called Gigafactories are used in some countries to manufacture LIB batteries for EVs. Those factories have started production, are under construction, or are considering investment. Globally, these are expected to be 4,000 GWh of LIB (2040) and 900 million EVs (2040). (JRC 2018) If the manufacture, sale, and use of LIBs were to be banned in the EU, the production and introduction of EVs into the market could become economically and socially unstable, and there is great concern that they would cause human disasters. There are concerns about the impact not only within the EU but on a global scale. Activities to secure resources, delays in promoting carbon neutral (CN) policies, economic stagnation and social unrest are expected to spread. In addition, countries outside the EU will similarly be concerned about political, economic, social and international trade instability. In particular, the impact on resource-producing countries could be enormous.

If there is an alternative material to PVDF for the positive electrode material of the battery, it will involve major changes in the manufacturing system and battery design. Therefore, satisfying the product specifications of LIBs installed in EVs, in other words, development, confirmation and verification of safety, reliability and long life as EVs, requires a prolonged period, changes in manufacturing facilities, and significant costs.

We used LIBs for EVs as an example, but mobile electronic devices such as smartphones, tablets, and laptops are also equipped with LIBs. LIB has permeated every field, including communications, business, education, medical care, and social safety. We must avoid a situation where the FP regulation will not allow LIBs to be manufactured or used.

Impact on the supply chain producing LIBs and EVs.

Performance, product life and economy
The lifespan of current LIBs is about 2-3 years for small devices, about 10 years for vehicles, and 20-30 years for stationary storage batteries.
Even if alternative materials and processes could be used, it would be difficult to achieve the same

level of safety and life characteristics as current batteries.
Poorly designed and manufactured LIBs have inferior performance and short lifetimes of less than 5 years. There is also concern that fires may occur frequently during charging or use. If EVs use batteries with performance inferior to current LIBs for 10 years, the frequency of battery replacement will increase, and battery costs and Well-to-Wheel (WtoW) CO2 emissions will nearly double.
Lithium-ion battery capacity is estimated at 1,100 GWh in the EU (FARADAY 2022b), equivalent to USD 165 billion in economic terms based on current lithium-ion battery prices of USD 150/kWh (BNEF 2023). However, this economic scale is based on research and will vary depending on economic conditions and policies. (Lukas et al 2021, McKinsey 2023)

Impact of CO2 emissions

Well-to-Wheel (WtoW) vehicle CO2 emissions are equivalent to those of EVs and gasoline vehicles after driving 80,000 to 90,000km. Of course, there are some differences depending on the power generation system of the area to be used. (Yasukawa 2020, Kawamoto et al 2019)
However, if the battery deteriorates after driving 100,000 km, replacing it will result in an increase in CO2 emissions due to the battery manufacturing process. By using PFAS-regulated alternative materials, if the alternative battery had half the life performance, EVs would always emit more CO2 than gasoline vehicles. Further improvement of battery performance cannot be expected at present. Therefore, in the case of LIB/EV applications, the total CO2 emissions increase over the life of the vehicle, rather than being reduced, leading to a situation of putting the cart before the horse.
For this reason, ECHA's PFAS regulation poses a major problem regarding environmental policies such as CN and carbon zero emissions, especially with respect to zero sales of new ICE vehicles in 2035. The EU and regional governments and industries will need to coordinate their environmental and energy policies and goals. The same is true of social and economic impacts.

Employment

The automobile industry and battery industry are in a situation where they have to develop new human resources who will be involved in the development and manufacturing of EVs and LIBs in preparation for the complete conversion to EVs by 2035. (EP 2022) In addition to human resources, it is also necessary to invest money and time in research and development associated with alternative materials such as LIB binders and the development of new batteries.
EV, LIB, and battery supply chains in the EU employ 14,600,000 people, and 3,700,000 in manufacturing (Bhutada 2022). Based on our estimates based on UK data (FARADAY 2022b), the number of supply chain workers in the EU is expected to reach 2,100,000 in 2030. (Appendix B: Estimation)
ECHA regulation XV presents an unexpectedly large problem that these industries and their employees will have to solve, and large-scale social disruption may be inevitable.

The "correctness" of policies and regulations, and the "judgment" of their content and timing of implementation, require scientific grounds, consistency with economic and environmental policies, and agreement with relevant parties. Drafting and submitting regulatory proposals will need to be rationally rethought, or at least postponed. Based on the above-mentioned PFAS definition and the case of LIB-equipped EVs, it will be necessary to exclude PVDF from the substances and applications to be regulated. As in the case with PVDF, we also believe that at least Polymeric PFASs deserve to be exempted from the proposed regulation, as they are widely prevalent and safely used in so many different applications in society.

The above comments do not include impacts on supply chains outside the EU, extraction of resources, recovery of materials and products, etc. It is thought that the impact of the regulation will extend to a wide area around the world.

References

ACEA (2020): Facts about the automobile industry, The automobile industry: the engine of Europe, The European Automobile Manufacturers' Association (AECA), 2020. https://www.acea.auto/fact/facts-about-the-automobile-industry/ (last accessed 24.04.2023)

(BNEF 2023): Lithium-ion Battery Pack Prices Rise for First Time to an Average of $151/kWh, Bloomberg NEF. https://about.bnef.com/blog/lithium-ion-battery-pack-prices-rise-for-first-time-to-an-average-of-151-kwh/ (last accessed 18.05.2023)

Bhutada (2022): Govind Bhutada, Mapped: EV Battery Manufacturing Capacity, by Region, 2022. https://www.visualcapitalist.com/sp/mapped-ev-battery-manufacturing-capacity-by-region/ (last accessed 10.04.2023)

EP (2022): EU ban on the sale of new petrol and diesel cars from 2035 explained, European Parliament, 2022. https://www.europarl.europa.eu/news/en/headlines/economy/20221019STO44572/eu-ban-on-sale-of-new-petrol-and-diesel-cars-from-2035-explained (Accessed 20230424)

FARADAY (2022a): Growing optimism for the UK battery manufacturing industry but redoubling of efforts needed to keep pace with investments across Europe, The Faraday Institution, 2022. https://www.faraday.ac.uk/ev-economics-study-2022/ (last accessed 21.04.2023)

FARADAY (2022b): *UK electric vehicle and battery production potential to 2040*, THE FARADAY INSTITUTION UK GIGAFACTORY OUTLOOK (JUNE 2022), THE FARADAY INSTITUTION, 2022. https://www.faraday.ac.uk/wp-content/uploads/2022/06/2040-Gigafactory-Report_2022_Final_spreads.pdf (last accessed 21.04.2023)

Furuya (2021): Shota Furuya, How much jobs will be lost in the automotive industry due to the transition to electric vehicles?, Energy Shift, 2021. https://energy-shift.com/news/93eb91ad-37a7-46d7-959c-5f5eb55ec505 (last accessed 17.04.2023)

Gifford (2022c): Stephen Gifford, The Gigafactory Boom: The Demand for Battery Manufacturing in the UK, FARADAY INSIGHTS - ISSUE 2 UPDATE: JULY 2022. https://www.faraday.ac.uk/wp-content/uploads/2022/07/Faraday_Insights_2_update_July_2022_FINAL.pdf (last accessed 21.04.2023)

JRC (2018): Lithium-ion batteries for mobility and stationary storage applications: Scenarios for costs and market growth. Joint Research Centre (JRC), European Commission. https://visitors-centre.jrc.ec.europa.eu/sites/default/files/poster_flyer/jrc114616_li-ion_batteries_two-pager_final.pdf (last accessed 29.12.2022)

(Lukas et al 2021): Lukas Mauler, Fabian Duffner, Wolfgang G. Zeier, Jens Leker, Battery cost forecasting: a review of methods and results with an outlook to 2050, Energy Environ. Sci., 2021, 14, 4712-4739. https://pubs.rsc.org/en/content/articlehtml/2021/ee/d1ee01530c (last accessed 18.05.2023)

(McKinsey 2023): Jakob Fleischmann, Patrick Schaufuss, Martin Linder, Mikael Hanicke, Evan Horetsky, Dina Ibrahim, Sören Jautelat, Lukas Torscht, Alexandre van de Rijt, Battery demand is growing—and so is the need for better solutions along the value chain, McKinsey & Company. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular (last accessed 18.05.2023)

Appendix B

Estimation of EV and LIB supply chain population in the EU

UK (FARADAY 2020a, b, Gifford 2022)

Gigafactory Capacity, GWh	200 (2040)
EV Workforce	170,000 (2040)
Gigafactory Workforce	35,000 (2040)
Battery Supply Chain	65,000 (2040)

EU

Gigafactory Capacity, GWh 1,100 (2030) (FARADAY 2020b)

ESTIMATTION

EV Workforce	1,600,000 (2030)
Gigafactory Workforce	198,000 (2030)
Battery Supply Chain	356,400 (2030)

Reference information

Car Industry	14,000,000 (ACEA 2020)
Car Industry, Direct Manufacturing	3,700,000 (ACEA 2020)