3M Science. Applied to Life.™

▶ 3M™ Dyneon™ Fluoropolymers

Supporting the energy and e-mobility demands of the future.

Alternative Energy: Storage and Conversion.

Alternative Energy Storage and Conversion.

Currently many industries are facing the same challenge globally: they need to find ways to reduce CO_2 and NO_x emissions to stop global warming and improve air quality. Two long-term activities which are derived from this challenge are the electrification of vehicles and the use of renewable energies. This brochure will demonstrate how 3M™ Dyneon™ Fluoropolymers will be fundamental in solving this great global challenge, by illustrating some of their features and attributes essential in electrifying vehicles and implementing renewable energies.

Vehicle Electrification

Global car manufacturers have programs for vehicle electrification in place. Some of them have already commercialized vehicles which are no longer powered by a gasoline or diesel engine, but by electric motors getting their energy from fuel cells or batteries.

The trend in the automotive industry shows that for small distances, for example commuting in urban settings, a battery-powered car is likely to be used, as currently only short distances can be achieved with a battery's capacity.

For longer distances fuel cell powered cars might be the preferred solution, as refueling is comparable to a gasoline or diesel powered car, but without any harmful emissions.

These scenarios will be especially relevant if the use of renewable energies becomes more common in the energy production and plays a larger role in energy and hydrogen infrastructure.

Renewable Energies

To reduce emissions and to improve our air quality, the energy production must become environmentally more sustainable. Rather than producing energy from nuclear power or coal, harmful emissions reduction can be achieved by solar, wind or other forms of renewable energy production.

The use of these renewable solutions relates to the ability to store energy as it is often being produced when demand is low. Options to store the energy are batteries (electrical energy) or via electrolysis in hydrogen (chemical energy).

Both technologies support a reduction of harmful emissions and would help to implement the infrastructure for electrified vehicles.

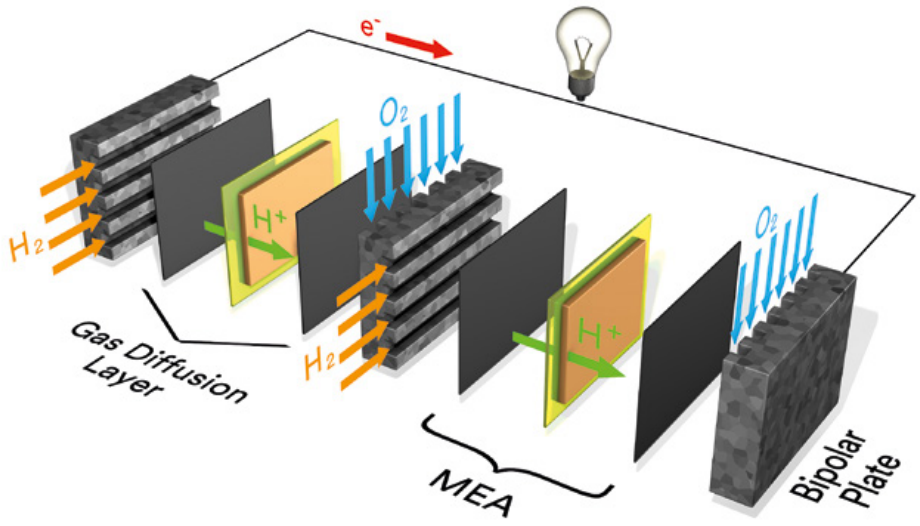
Fuel Cell Applications.

Overview

Fuel cells are electrochemical cells that convert the chemical energy from continuously fed-in fuel and oxidant into electrical energy and heat in an isothermal process. Fuel cell technology offers advantages over conventional energy conversion technologies thanks to their higher efficiency and harmful emissions.

3M™ Dyneon™ Fluoropolymers are key to enabling fuel cells to achieve high performance and long lifetimes. The main fuel cell components benefit from the fluoropolymers' chemical and electro-chemical properties.

Overview of materials used in fuel cells:



Gas Diffusion Layer:	Paper, non-woven coated with Polytetrafluoroethylene (PTFE)
Membrane / Electrolyte:	PFSA Ionomer
Bipolar Plate:	Metal, Graphite with FP binder
Sealing:	Fluoroelastomer (FKM), Silicone Rubber, Ethylene Propylene Diene Rubber

Membrane / Electrode Ink

3M offers 3M™ Dyneon™ Fluoroionomers for membrane and electrode ink applications in Proton Exchange Membrane Fuel Cells (PEM FC).

These Fluoroionomers are copolymers of tetrafluoroethylene (TFE) and perfluorobutanesulfonylfluoride vinyl ether. The short side chain of the 3M Dyneon Fluoroionomers without the pending -CF_3 group offers a variety of advantages compared to standard PFSA ionomers:

- It allows a higher degree of crystallinity at a given equivalent weight (EW)
- Equivalent weights at 725 and above are stable in boiling water
- Performance and durability of the membrane can be optimized by varying EW, thickness, additive loading
- Performance and durability can be improved based on raw material building blocks

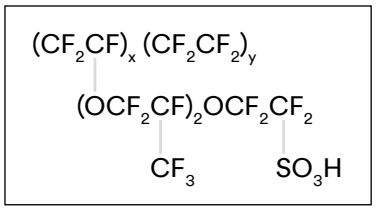
In addition to the above, Dyneon Fluoroionomers offer the following key features that the membrane, electrode inks and other electrochemical applications benefit from:

- High purity
- High conductivity at low relative humidity
- Low hydrogen cross-over
- Good mechanical strength at high relative humidity
- High thermal stability
- High chemical resistance

The Dyneon Fluoroionomers are offered in two different equivalent weights: 725 and 800. The products are available as powder as well as Dispersions of water/ethanol (20 % solids) and water (15 % solids).

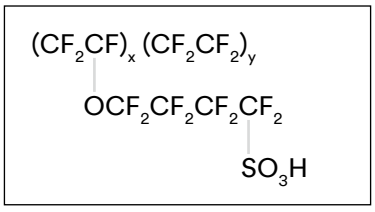
Chemical Composition of Ionomers

Standard Composition



Standard Fluoroionomers

Higher Value Composition



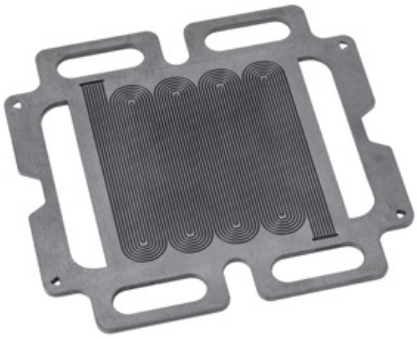
3M™ Dyneon™ Fluoroionomers

Bipolar Plate

The bipolar plate (BPP) is a key component of the fuel cell. In Proton Exchange Membrane Fuel Cells, it is usually made from metal; in Phosphoric Acid Fuel Cells (PAFC) it is usually made from graphite and a binder.

3M offers a fluorothermoplastic binder based on FEP to improve chemical resistance and durability of the BPP. The key features of 3M™ Dyneon™ Fluoroplastic FEP 6322PZ, besides the excellent chemical resistance are its high thermal stability, fine particle size and ease of dispersing into graphite powders. The properties of Dyneon FEP 6322PZ are listed in the table below.

Property	Test Method	Value
Melt Flow Index (372° C / 5kg)	ASTM D1238	22 g / 10 min
Specific Gravity	ASTM D792	2.15 g / cm³
Melting Point	ASTM D4591	252° C
Tensile Strength at Break (23° C)	ASTM D638	20 MPa
Elongation at Break (23° C)	ASTM D638	300%
Flexural Modulus	ASTM D790	580 MPa
Limiting Oxygen Index	ASTM D2863	> 95%
Median Particle Size		5 µm



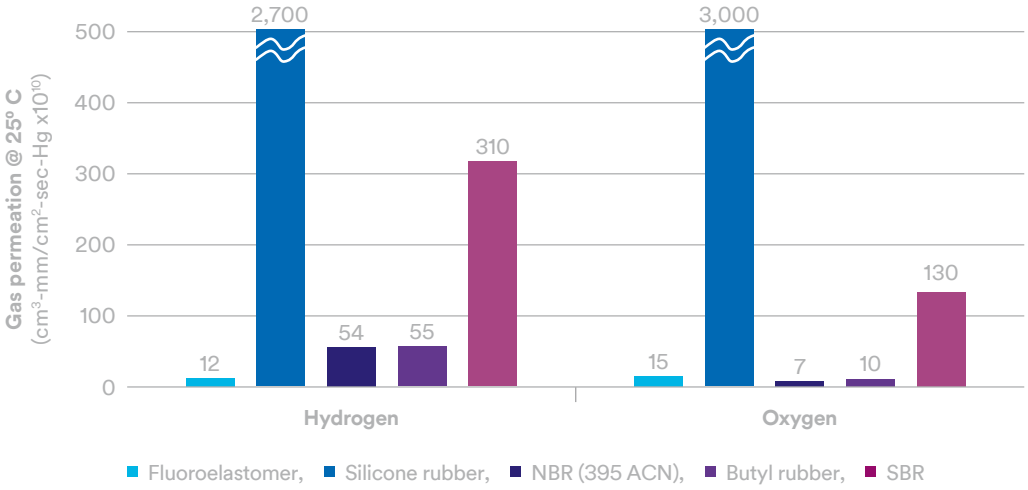
Sealings

Although the operating temperature of PEM Fuel Cells is rather low (80 to 120° C), nonetheless they can benefit from reliable fluoroelastomer seals as hydrogen and oxygen permeation is much lower than with currently used silicone seals.

In Phosphoric Acid Fuel Cells the operating temperature is between 180 to 220° C, which makes a fluoroelastomer seal even more desirable for this application.

Temperature resistance, oxygen and hydrogen permeation are not the only tough requirements in the fuel cell environment. A great challenge for sealing materials is the lifetime requirement. For automotive and stationary fuel cells, it is critical to last as long as possible. To ensure this, a 3M™ Dyneon™ Fluoroelastomer is the optimal choice.

Gas Permeation Comparison of Elastomers



Depending on the application and processing needs, 3M offers a variety of peroxide curable fluoroelastomers that suits the requirements of fuel cell sealing due to their high chemical resistance. This includes ultra-low viscosity and low temperature fluoroelastomers such as 3M™ Dyneon™ Fluoroelastomers FPO 3600ULV, FPO 3520 and 3M™ Dyneon™ Fluoroelastomer LTFE 6320.

All products can be directly processed through dispensing or injection molding onto the bipolar plate, which improves plate handling and stack assembly. Due to the excellent material flow the shapes of seals can be very complex. In addition, these products provide:

- Easy processing
- 100 % solids
- Low temperature curing

3M™ Dyneon™ Fluoroelastomers, Peroxide Curable for sealing applications

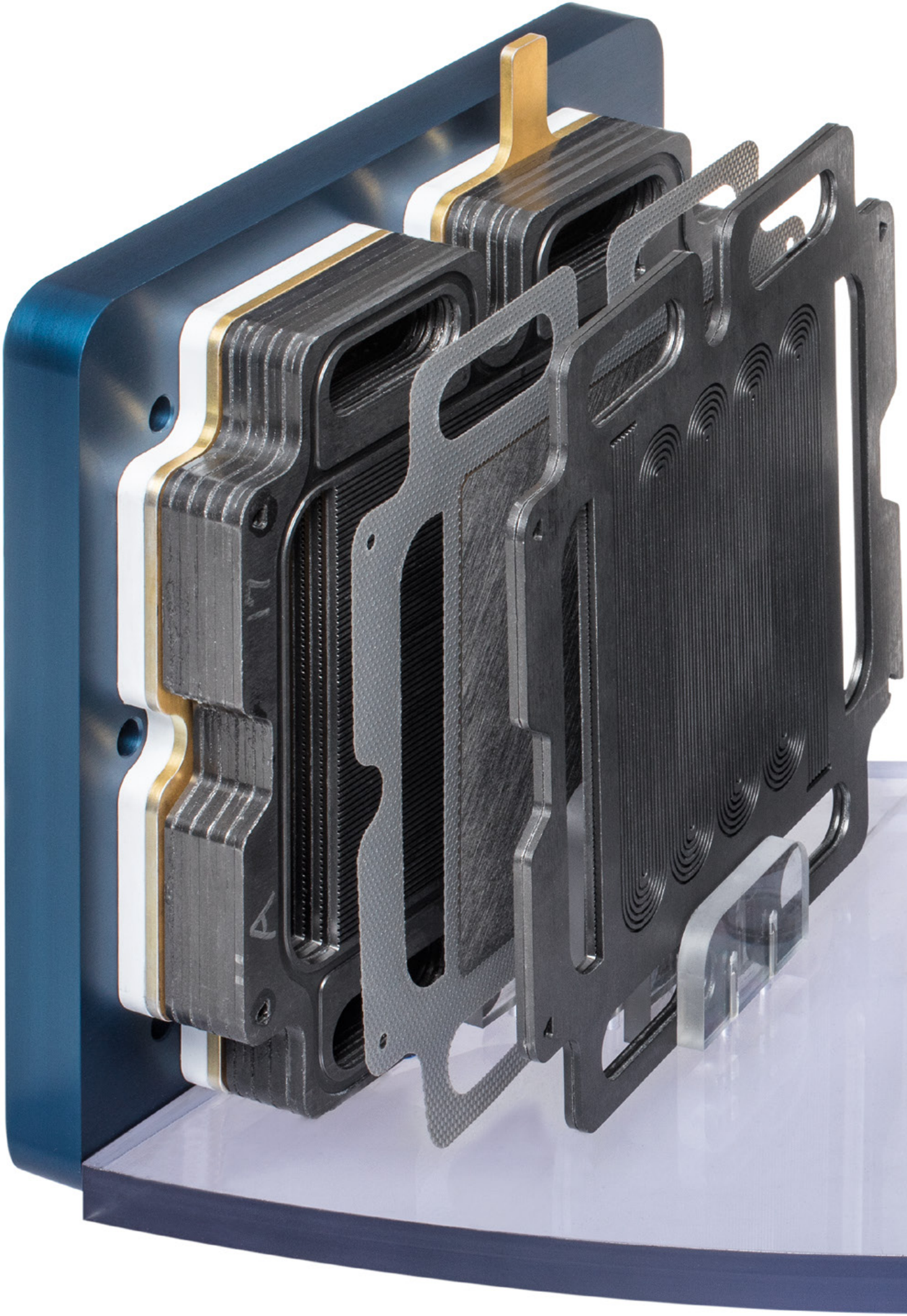
Property	Unit	FPO 3520	FPO 3600ULV	LTFE 6320Z
Fluroine Content %	%	65.2	65.9	64.3
Mooney Viscosity ML 1 + 10 @ 121 ° C	Mooney Unit	25	3.5	20
TR10 (ASTM D1329)	° C	-20	-19	-30
Tensile Strength	MPa	19.3	17.7	21.2
Elongation at Break	%	204	252	230
100 % Modulus	MPa	5.8	4.1	4.2
Compression Set (70 h @ 200° C)	%	32	46	20

Product Overview by applications

In summary, the 3M product offerings for the above applications in fuel cells are presented in the table below.

3M AdMD Fuel Cell Product Portfolio

3M™ Dyneon™ Fluoroionomers	→	PEM Membrane, Electrode Inks
3M™ Dyneon™ Fluoroplastic FEP 6322PZ	→	Binder for graphite Bipolar Plates
3M™ Dyneon™ Fluoroelastomers	→	Sealing Materials
3M™ Dyneon™ PTFE Dispersion	→	Gas Diffusion Layer (GDL) Coating

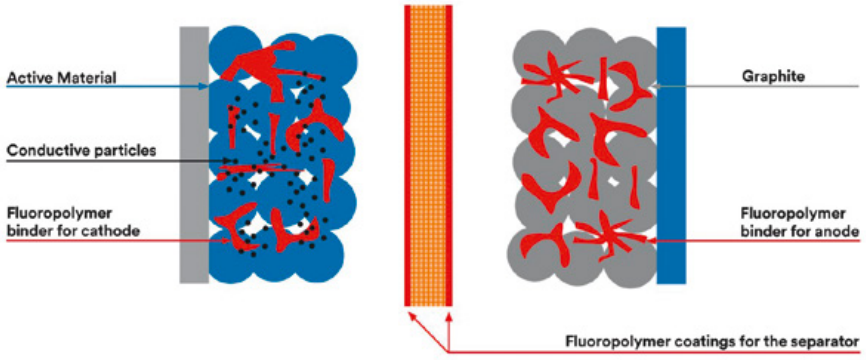


Battery Applications.

Overview

With the need for higher capacities, voltages and current densities the material requirements within the battery cell become more demanding. Additionally, the manufacturing of cells will be more challenging with new environmental standards being implemented in Europe or the United States. 3M™ Dyneon™ Fluoropolymer solutions for batteries support these scenarios with the following applications:

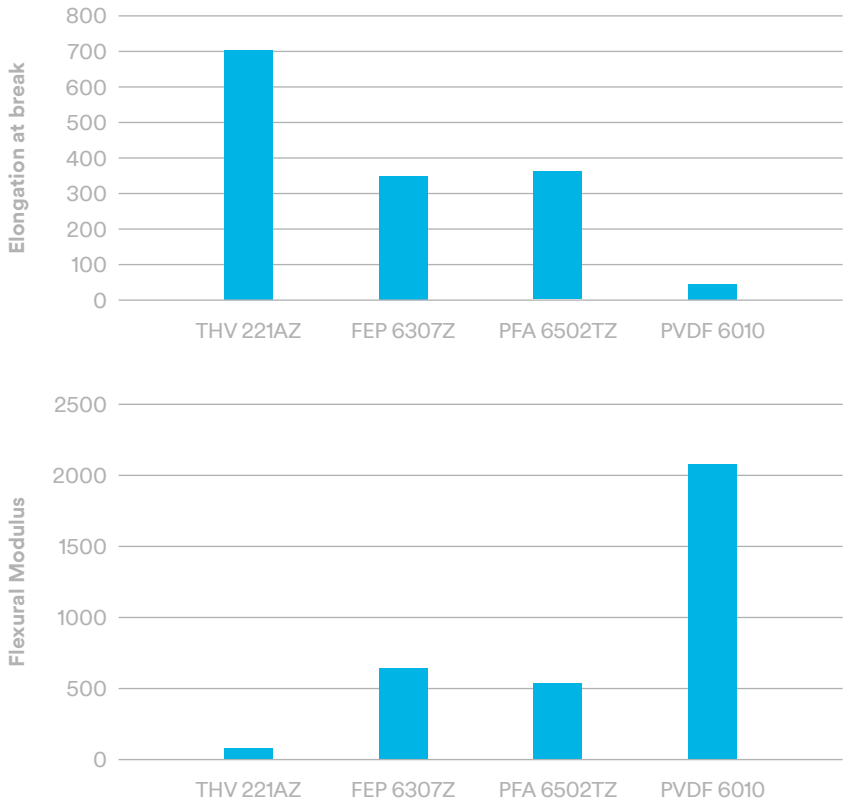
Overview / crosscut of a battery:



Cathode and Anode Binder

3M™ Dyneon™ Fluoropolymers, such as Dyneon THV, Dyneon FEP, or Dyneon PFA, are well suited for aggressive battery applications. Such as those environments in Lithium Ion batteries, where compatibility with carbonate electrolytes or newer electrolytes is essential. This means that the fluoropolymer must be chemically resistant to the electrolyte or any degradation products that may arise through the charging/discharging cycles. Furthermore, these fluoropolymers demonstrate excellent oxidative resistance, as is critical for cathode binders, due to their chemical nature of having very strong carbon-fluorine bonds. The flexibility and high extensional properties of these fluoropolymers, see table on next page, also make them well equipped as binders, where through the cycles of lithiation and de-lithiation of the active materials, mechanical stresses are generated on the system. Fluoropolymers can absorb these mechanical stresses due to their excellent mechanical properties. Coatings on separators with these fluoropolymers can allow for increased oxidative stability while improving processing and performance.

Mechanical properties of THV, FEP and PFA in comparison to PVDF



3M™ Dyneon™ Fluoropolymers such as Dyneon THV, Dyneon FEP, or Dyneon PFA, can be used in these applications in a variety of forms. Some of these fluoropolymers are soluble in common solvents to facilitate low temperature processing. Since however, there is a desire to move to solvent-free processing, these fluoropolymers can also be offered as aqueous dispersions.

Technical Information and Test Data

Technical information, test data, and advice provided by Dyneon personnel are based on information and tests we believe are reliable and are intended for persons with knowledge and technical skills sufficient to analyse test types and conditions, and to handle and use raw polymers and related compounding ingredients. No license under any Dyneon or third party intellectual rights is granted or implied by virtue of this information.

General recommendations on health and safety in processing, on work hygiene and on measures to be taken in the event of accident are detailed in our material safety data sheets.

You will find further notes on the safe handling of fluoropolymers in the brochure “Guide for the safe handling of Fluoropolymers Resins” by PlasticsEurope, Box 3, B-1160 Brussels, Tel. +32 (2) 676 17 32.

The present edition replaces all previous versions. Please make sure and inquire if in doubt whether you have the latest edition.

Important Notice

All information set forth herein is based on our present state of knowledge and is intended to provide general notes regarding products and their uses. It should not therefore be construed as a guarantee of specific properties of the products described or their suitability for a particular application. Because conditions of product use are outside Dyneon’s control and vary widely, user must evaluate and determine whether a Dyneon product will be suitable for user’s intended application before using it. The quality of our products is warranted under our General Terms and Conditions of Sale as now are or hereafter may be in force.

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