Chemours™

Nafion™

Sustainable Nafion(TM): Opportunities in Recycling & Re-use of Membranes and Ionomers

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Manufacturing Automation and Recycling for Clean Hydrogen Technologies Experts Meeting

May 26th, 2022

An Introduction:
The Chemours Company and Its Sustainability Goals

Chemours™

Industry Leader in safe production and manufacture of performance chemicals, combining leading products, applications expertise, and market-shaping chemistry

Our Goal

Is to achieve Net Zero Operations Greenhouse Gas Emissions by 2050

2030

Achieve 60% absolute reduction of CO_2 emissions from operations

Our strengthened climate goal

- Aligns with Paris 1.5◦C rule
- Sets a science-based target
- Will be realized by process emissions reductions, energy efficiency, renewable energy

Commitment to achieve net-zero CO_2 emission from operations by 2050

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Translating Words to Action: Responsible Manufacturing

By 2030, we aim to reduce air and water process emissions of fluorinated organic chemicals by 99% or greater.

- In 2020, we successfully deployed our thermal oxidizer at our Fayetteville Works facility which eliminates 99.999% of PFAS emissions and represents a $100 million investment in emissions control technology
- At our Dordrecht facility in the Netherlands, we're investing €75 million in emissions control technology to achieve our 2030 goal to reduce all PFAS emissions by more than 99% compared to 2018 baseline levels.

Nafion™ Polymer Chemistry: Unique Polymer for Proton Conduction

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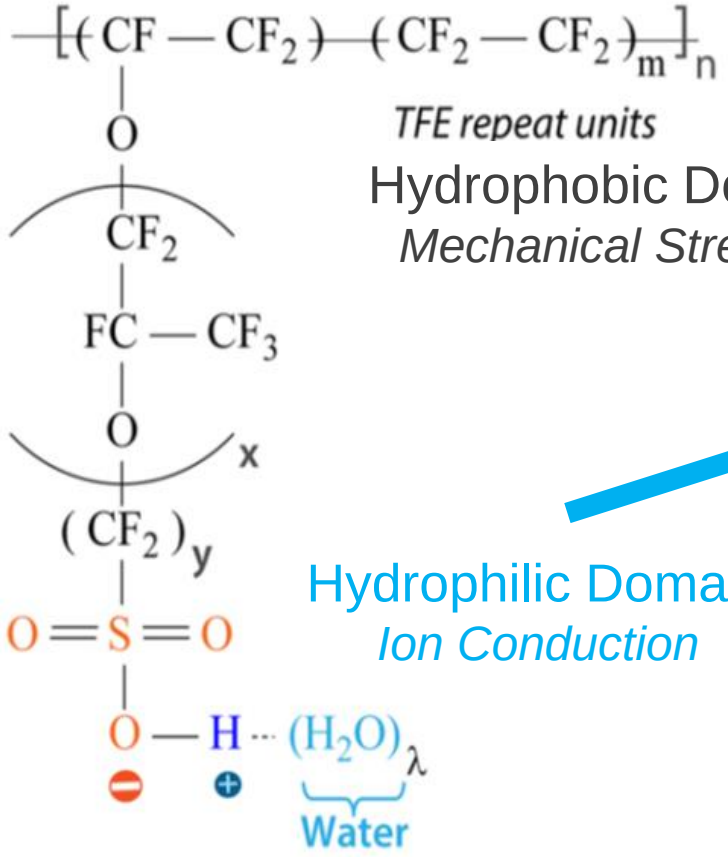
Backbone



TFE repeat units

Hydrophobic Domain
Mechanical Strength

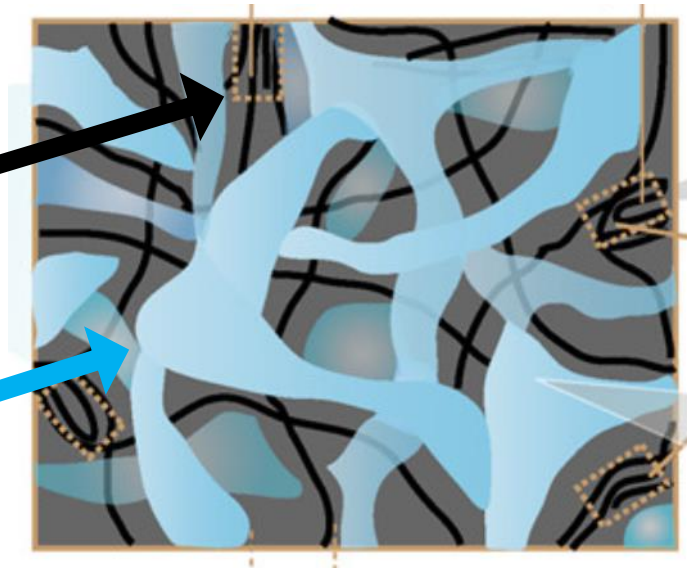
Side Chains

Ionic Group

Hydrophilic Domain
Ion Conduction

Water

Nafion™ at the Nanoscale: Phase Separated Morphology



- ***Nafion™ is a proton conducting polymer electrolyte***
- ***Hydrophobic domains provide a durable, mechanically reinforcing "backbone"***
- ***Hydrophilic domains enable a proton conducting "highway" throughout the polymer matrix***

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Images adapted from: Kusoglu and Weber, Chem Rev. 2017, 117, 987-1104

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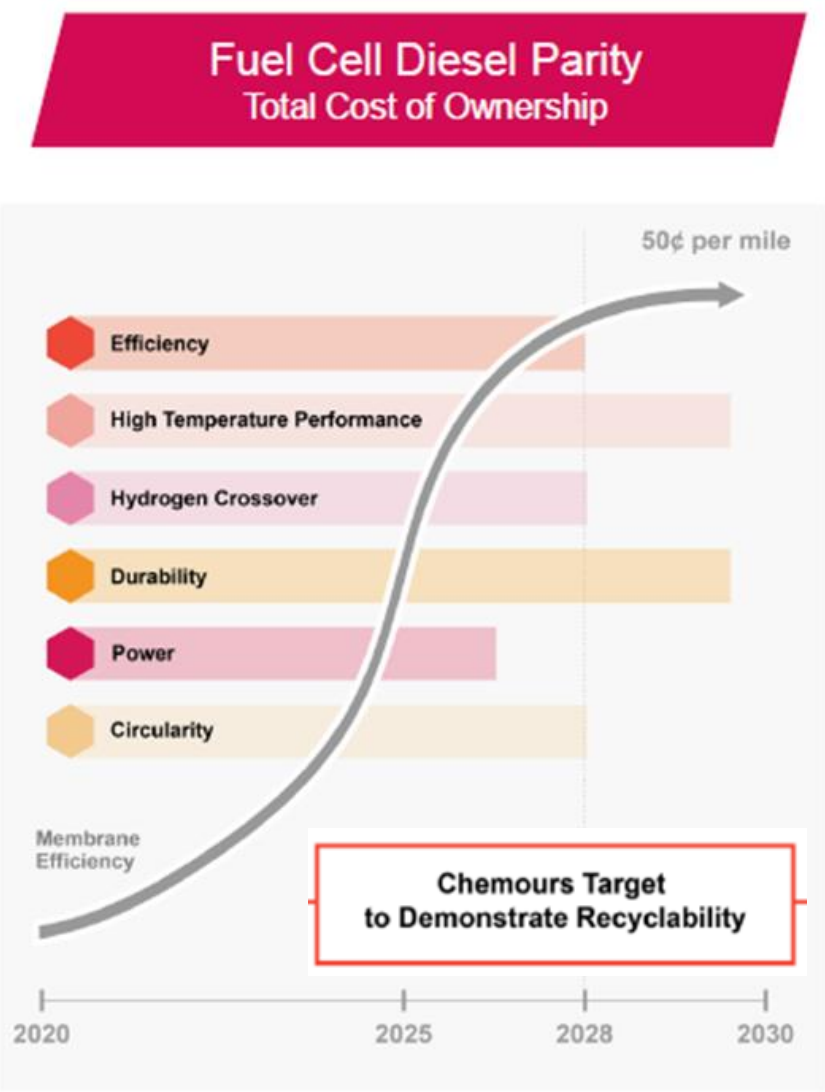
Nafion™ Supply Chain: Enabling the Hydrogen Economy

Chemours is **backward integrated** in the manufacture of Nafion™ membranes and dispersions.

Chemours has the **polymer capacity** to manufacture Nafion™ membranes in large scale.

Raw Materials → **Monomers** → **Polymer Resins** → **Nafion™ Membranes and Dispersions**

- Chemours has >50 years' experience in the commercial manufacture of Nafion™ ion exchange materials
- Chemours has established a Global Venture Team solely focused on the development of materials used in the Hydrogen Economy, enabling our customers to achieve their business objectives.
- Multiple new product development programs in progress for membranes and dispersions in hydrogen applications



Nafion™ Research Activity and Collaborations: Sustainable Ionomer

- Chemours has recently completed the Chemours Discovery Hub - a 312,000 sq ft facility dedicated to R&D in Newark, DE.
  - Unifies >300 scientists and engineers under one roof
- Chemours believes using Nafion™ sustainably is a critical component to a hydrogen economy at-scale.
- Chemours has kicked off an internal team dedicated to exploring how to most effectively incorporate used Nafion™ into recycled components
- Chemours intends to be a leader in this space and is open to partnering with interested parties in upcoming funding opportunities.

A Second Life for Nafion™ Ionomers: Four Possibilities

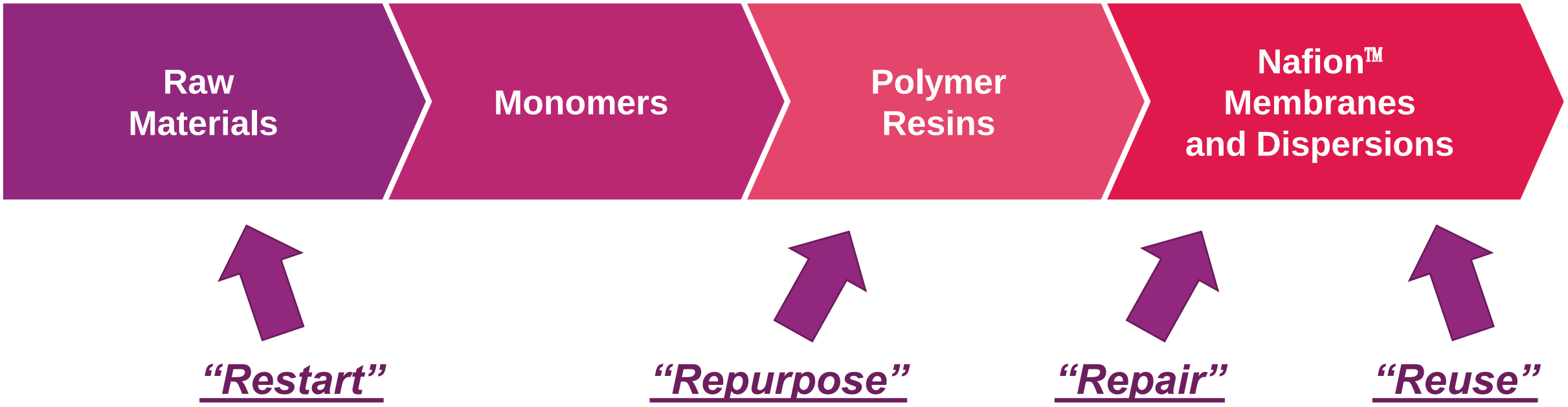
1. ***Reuse:*** Ionomer is recaptured at end of device lifetime, converted into new ionomer products with no loss in performance/durability

2. ***Repair***: Any damaged ionomer regions “healed” by chemical treatment at end of life

3. ***Repurpose:*** Ionomer is recaptured, but “wear and tear” or conversion challenges restrict usage to secondary, alternative markets for ionomers

4. ***Restart:*** Ionomer broken down into elemental constituents and used as recycled fluorine in manufacturing of Nafion™

Reincorporation of Nafion™ in Ionomer Supply Chain



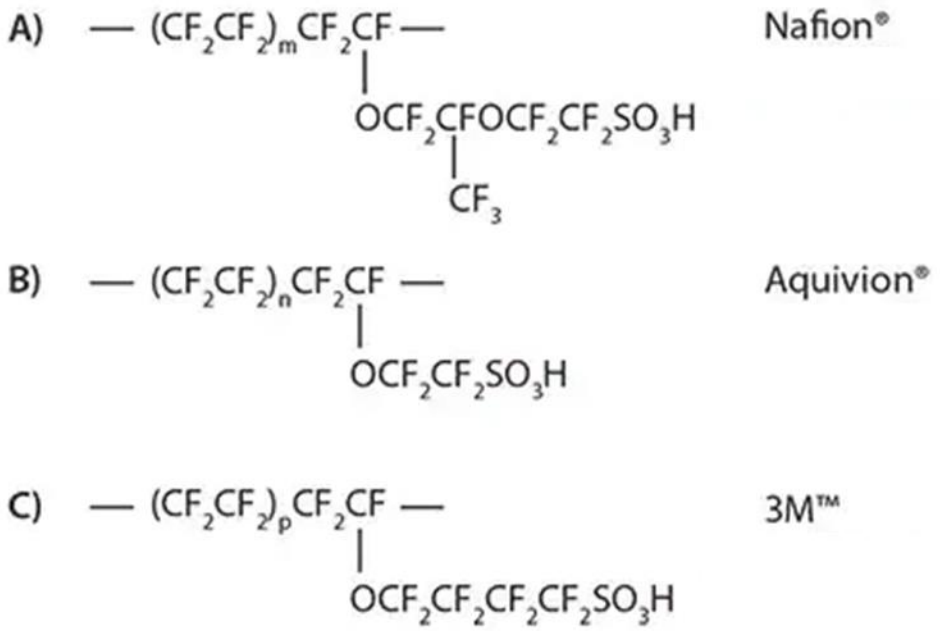
- Backwards integration in Nafion™ supply chain enables efficient recycling of Nafion™ ionomer in multiple steps in value chain

- No matter which path is determined to be most viable, there is value in each

Considerations in Ionomer Sustainability: Different Ionomers

- Several different chemistries exist within ionomer market for PEM materials
- Unlike PGM metals, recovering “pure” ionomer material would require segregating spent MEA material by ionomer type
  - Different ionomers also possible within MEA (i.e., catalyst layer vs membrane)
- “Blending” several types of spent ionomer carries several obvious challenges:
  - Performance of multiple ionomers in composite structure has not been studied
  - Uncertain legal/regulatory framework

Example Ionomer Chemistries



Adapted from: Perfluorosulfonic Acid Membranes for Fuel Cell and Electrolyser Applications. Deborah Jones

Considerations in Ionomer Sustainability: Perspective and Targets

- Recycling of ionomer is in its infancy – significant progress in fundamental R&D is necessary before demonstration is possible

- Recycling ionomer is beneficial not only for reusing end-of-life materials, but also repurposing early-stage ionomer yield loss (i.e. in-process scrap)

- Topics to explore include:
  - Efficient separation of electrodes (PGM) and ionomer materials without necessarily destroying ionomer component
  - Evaluating end-of-life ionomer composition
  - Engineering optimized pathways to incorporate recycled material
  - Answering questions around how to deal with multiple ionomers in MEA

- Early-stage targets should be demonstration projects (Go-No/Go on process); quantified targets should be dependent on established pathways

Sustainable Nafion™: Summary and Conclusions

- Recycling of ionomers is a critical component to ensuring a sustainable hydrogen economy.
- Chemours is eager to lead ionomer recycling efforts based on historical strength/competency in Nafion™ manufacturing and backwards integrated supply chain
- Several questions, both philosophical and technical, must be answered in short order to ensure strategic alignment within hydrogen economy on ionomer recycling

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Thank You!