Economic and Environmental Improvements with Versatile Membranes

How Ion Exchange Membranes
Can Benefit Our World

Executive Summary

Ion exchange materials (IXMs) have many uses that can positively impact our world's economy and environment. Their versatility enables growth in new applications and more sustainable business practices across the globe. This paper discusses a range of IXMs, with a narrower focus on ion exchange membranes (IEMs). In production across many industries, IEMs can help reduce carbon emissions and offer more efficient ways to manage worldly resources, such as hydrogen and electricity.

Cleaner and More Cost-Effective Processes Can Improve Our World

Efficiency and cost savings have always been production and operation goals of every business; but, in the last few decades, sustainability has grown just as important. Practicing all three means reducing the emissions and waste from production and ensuring processes are cost-effective and repeatable for the long run.

Sometimes, the materials purchased for use in production or operations can help businesses accomplish these goals. However, it's difficult to imagine a product that helps improve efficiency, cost savings, and sustainability for more than one industry. But, such versatile and adaptable products do exist in the form of ion exchange materials (IXMs).

These ionically conductive materials make appealing concepts, like the hydrogen economy, possible. The hydrogen economy[1] is a state where hydrogen replaces hydrocarbons and is used to produce clean energy, support energy storage, and enable efficient distribution. However, energy is only one of many industries that IXMs stand to improve. Overall, the versatility of IXMs could enable many economic and environmental improvements for our world.

[1]Source: https://www.weforum.org/agenda/2018/11/this-is-the-potential-of-the-hydrogen-economy

Different Ion Exchange Materials: Membranes, Dispersions, and Resins

All IXMs must be chemically resistant and durable in the environment they are used, if they are to perform well. However, IXMs come in several useful forms for different uses. These forms include:

Membranes

Ion exchange membranes (IEMs) act as a separator and solid electrolyte in electrochemical cells, where the membrane allows cations and/or anions across the cell junction. They can be used to produce hydrogen, energy, and sodium hydroxide or for energy storage using flow batteries.

Reinforced Membranes

IEMs can be further reinforced with strong and durable materials, offering mechanical stabilization of the polymer. This helps reduce degradation, enhance durability, allow broader operating ranges, and extend the useful life of the membrane. Reinforced membranes are beneficial and/or necessary in some applications, such as Chlor Alkali and fuel cells.

Dispersions

A dispersion is a system in which distributed particles of one material are dispersed in a continuous phase of another material. Polymer dispersions are typically used to fabricate thin films and coating formulations for fuel cell membranes, catalyst coatings, and a variety of electrochemical applications. When used in fuel cells, some dispersions can reduce the amount of platinum needed as a catalyst.

Resins

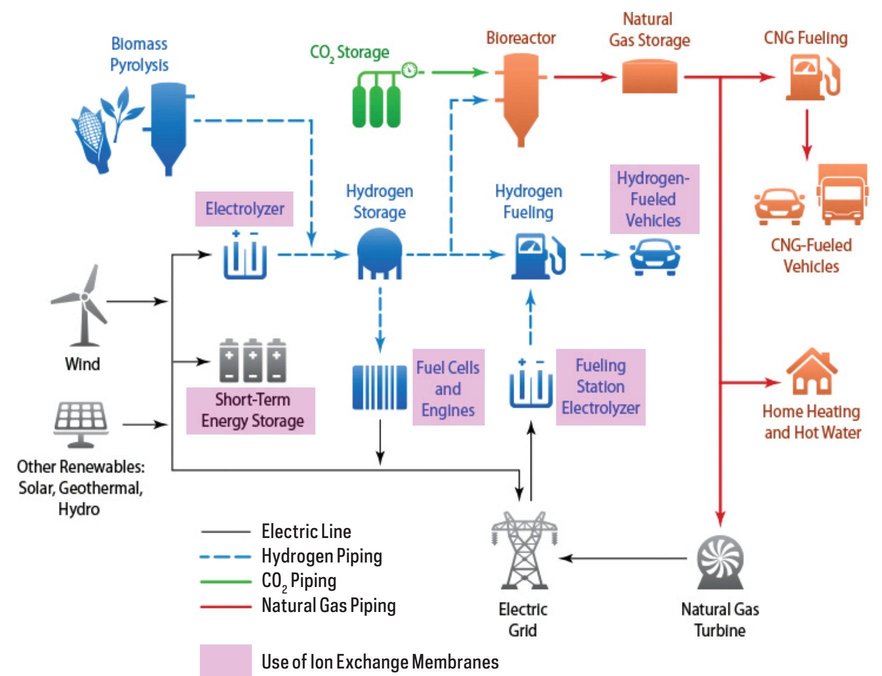
Resins act as a support structure and medium for ion exchange. There are multiple types of ion-exchange resins. Most commercial resins are widely used in different separation, purification, and decontamination processes, such as water softening and purification.

Great Market Potential for Ion Exchange Membranes

Ion exchange via membranes can make many desirable products, depending on the application in which they are used. IEMs are most commonly used in the chlor-alkali process and fuel cells. However, there is significant opportunity in new and growing applications such as fuel cells, water electrolysis and energy storage.

Applications where IEMs have the greatest potential include:

- **Energy Production** – when used in fuel cells to convert hydrogen to electricity
- **Hydrogen Production** – when used in water electrolysis to convert water into hydrogen and oxygen
- **Energy Storage** – when used to enable renewable energy storage in flow batteries and electrolysis-hydrogen from excess electricity of renewable energy sources[2]
- **Electrochemical Processes** – when used to produce specialty electrochemicals; one example is the chlor-alkali process
- **Water Purification** – when used in desalination by electrodialysis



[2]Source: https://www.sme.org/technologies/articles/2018/december/fuel-cells-lithium-ion-batteries-are-stand-out-candidates-for-energy-storage

A Closer Look at the Many Uses of Ion Exchange Membranes

IEMs can be designed to operate under different conditions and retain their properties over time. This flexibility allows designers and engineers to match the properties of the membrane (such as membrane thickness) to their application, optimizing process efficiency and product quality.

Depending on how they are modified, IEMs can improve efficiency, cost savings, and sustainability in the following applications:

Energy Production

Many industries are adopting clean energy production methods, like fuel cells, to eliminate carbon emissions.[3] When fuel cells use hydrogen as fuel, they produce electricity while emitting only heat and water. They use an IEM called a proton exchange membrane to selectively exchange hydrogen protons and force electrons through an external circuit, which generates the electricity. Fuel cells can produce energy so long as they're fed fuel and do not require a separate charging step like batteries.

In the future, fuel cells may be the main choice to power transportation. Hydrogen-powered buses, trucks, cars, trains, airplanes, and freight ships may eventually replace those powered by fossil fuel. This energy solution offers the best combination of sustainability and efficiency available.

Hydrogen Production

More global regulations are demanding reductions in emissions[4] and have made desires for a hydrogen economy more prevalent.[5] While the traditional methods used to generate hydrogen—steam or oil reforming and coal gasification—are more efficient and sustainable than using fossil fuels directly, they still emit significant amounts of greenhouse gases.

However, water electrolysis is a process that can produce hydrogen without any harmful emissions, so long as the power used comes from a renewable source.[6] During the process, an electrolyzer uses an IEM to convert electricity and water into hydrogen and oxygen, which can be stored for later use. This stored hydrogen can then be converted to electricity, which can supplement energy grids during peak demand.

Large-scale electrolysis systems are becoming more economically and commercially viable through improvements in membrane technology and, therefore, easier to adopt for future use.

[3]Source: https://www.energy.gov/eere/fuelcells/early-adoption-fuel-cell-technologies

[4]Source: https://afdc.energy.gov/fuels/laws/HY?state=US

[5]Source: https://afdc.energy.gov/fuels/hydrogen_benefits.html

[6]Source: http://www.sciencenter.org/climatechange/d/cart_activity_guide_energetic_electrolysis.pdf

Energy Storage

Efficient and effective energy storage is critical to global power supply and energy infrastructures, as it can solve some of the biggest problems associated with utility-scale renewable energy production.

For instance, the peak production times of wind and solar energy don't often match peak demand because they produce intermittently. Similarly, excess energy from base electricity production can go to waste during low demand times. In either, energy can be stored in a flow battery and delivered when energy is needed.[7] Using flow batteries this way maximizes renewable energy production without destabilizing utility grids.

Flow batteries are rechargeable batteries attached to two tanks with liquid electrolyte solutions. These electrolytes can be converted to electricity when passed through a power producing stack with the electrodes separated by an IEM. This system decouples energy stored from the power generated, allowing for more flexibility compared to other batteries. One example is capacity; flow batteries could potentially be applied across a wide range of energy storage applications, from kW-hour to MW-hour capacity. Ultimately, they offer economical, safe, and low environmental footprint solutions to store electrical energy.[8]

[7]Source: https://www.sciencemag.org/news/2018/10/new-generation-flow-batteries-could-eventually-sustain-grid-powered-sun-and-wind

[8]Source: https://www.sciencedirect.com/topics/chemistry/redox-flow-battery

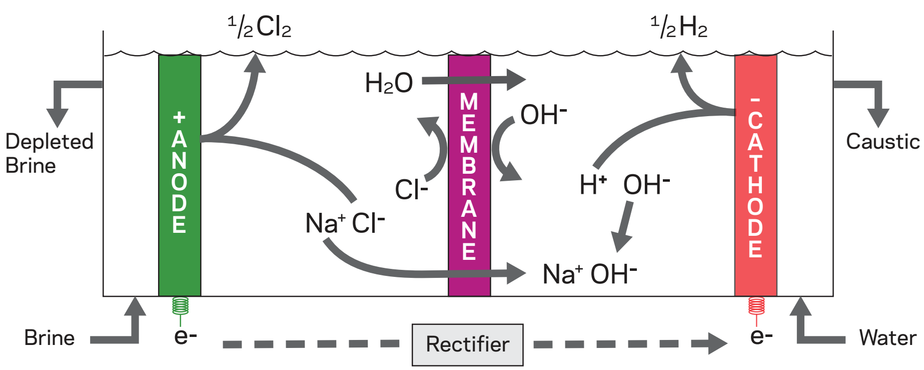
Chlor-alkali Process

Nearly half of the world's chemicals depend on the two primary products of the chlor-alkali process: sodium hydroxide, also known as caustic soda or lye, and chlorine.[9] Chlorine alone is used to make polyvinyl chloride (PVC) building materials and many other chemical intermediates. Sodium hydroxide alone is used to manufacture many staple products, such as paper, aluminum, commercial drain and oven cleaners, soap, and detergents. Chlorine bleach is made from both chemicals.

Past production techniques for chlorine and caustic sodium hydroxide have been dangerous for workers, as well as energy consuming and damaging to the environment. Modern and safer production methods use an IEM between half-cells to electrolyze brine into chlorine and sodium hydroxide. IEMs enable the chlor-alkali process to consume less energy and have a much smaller impact on the environment.

Nafion™ Membrane in Chlor-alkali Electrolysis

$$NaCl + H_2O \longrightarrow \tfrac{1}{2}Cl_2 + \tfrac{1}{2}H_2 + NaOH$$



Seawater Desalination

Freshwater comprises about 3% of the world's water supply and two-thirds of that is frozen in glaciers or otherwise inaccessible.[10] Additionally, nearly 1.1 billion people worldwide lack access to potable drinking water.[11] Unfortunately, rapidly growing urban areas will exacerbate water scarcity, and climate change will amplify the demand for freshwater.[12]

Traditional desalination processes, which remove salts and minerals from seawater for human consumption or irrigation, are costly and consume a lot of energy. A more practical and less expensive alternative is using IEMs for electrodialysis. Electrodialysis transports salt ions from one solution through an IEM to another solution by applying an electric potential difference.

This IEM-based solution could play a vital role in meeting freshwater demands around the globe, as well as generating clean water for agricultural, medical, and chemical industries.

[9]Source: https://www.marketwatch.com/press-release/chlor-alkali-market-research-reports-2019-global-industry-size-share-emerging-trends-growth-boosted-by-demand-and-advanced-technology-till-2022-mrfr-2019-07-08

[10]Source: https://www.usgs.gov/faqs/how-much-earths-water-stored-glaciers?qt-news_science_products=0#qt-news_science_products

[11]Source: https://www.worldwatercouncil.org/en/water-supply-sanitation

[12]Source: https://www.unwater.org/water-facts/climate-change

Making Worldly Resources More Abundant and Accessible to All

IEMs stand to play a significant role in today's modern world, powering the future of energy production, energy storage, electrochemical processing, and water purification. To work effectively, IEMs need the right ion transport properties for the cell in which they reside. Some of these properties include:

- High conductivity
- Resistance to chemical attack
- High operating temperature range
- Low permeability
- Balanced durability and performance

These are all areas where Nafion™ membranes excel.

Nafion™ membranes have received a considerable amount of attention as a proton conductor for proton exchange membrane (PEM) fuel cells because of its excellent chemical, thermal, and mechanical stability. Nafion™ membranes also offer durability and performance, which makes them the solution of choice when engineers are designing new systems or existing processes that require IEMs.

Reinventing the Energy Market with Nafion™ Membranes

With over 50 years of experience, the Nafion™ membranes and dispersions team has the knowledge to lead the energy industry on the journey toward a safer, cleaner world. Nafion™ ion exchange membranes have been the products of choice for chlor-alkali electrolysis, providing unparalleled performance and durability. Today, Nafion™ membranes also offer leading-edge solutions for energy storage, fuel cells, water electrolysis, ultrahigh purity chemical production, and other specialty applications.

Nafion™ membranes by Chemours deliver:

Superior chemical stability and proton conductivity

The structure of Nafion™ membranes consists of a flexible, hydrophobic backbone that provides excellent mechanical and chemical stability, while its pendent groups deliver high proton conductivity.

Adaptability for alternative electrolyte systems

Built from Chemours' strong knowledge base and industry experience, Nafion™ membrane properties—like ion conductivity and crossover—are tunable at various levels using monomer, polymer, and membrane processing techniques.

Proven performance from industry-leading field experience

Nafion™ ion exchange membranes have served as the benchmark material across several industries.

It's time to let the future in. Won't you join us?

Visit **Nafion.com** or call one of our technical experts:

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Asia Pacific – North .... +86 400 8056 528
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Europe/Middle East/Africa .... +41 22 719 1500
Brazil 0800 110 728
Mexico .... 1 800 737 5623 or +55 55 5125 4907(DF)

More Benefits of Nafion™ Membranes for Electrolysis Applications

- Durable
- Deliver high performance
- Operate in caustic and low voltage environments
- Retain their properties over time
- Well suited to applications where intermittent renewable energy is used

Nafion™

Chemours™

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