

Carbon corrosion in polymer electrolyte membrane fuel cell (PEMFC) catalysts is a significant issue affecting the durability and efficiency of power generation systems. Here is a summary of the main points associated with this topic:

## 1. Introduction to carbon corrosion

- Definition of carbon corrosion and its role in catalysts.
- Importance of carbon-based catalysts in fuel cells.

Introduction to carbon corrosion, particularly in the context of polymer electrolyte membrane fuel cell (PEMFC) catalysts, is essential to understand the challenges related to the sustainability and performance of these energy systems.

### What is carbon corrosion?



Carbon corrosion refers to the degradation of carbonaceous materials, often used as supports in catalysts, under the influence of specific environmental conditions and electrochemical reactions. In the case of PEMFCs, carbon is used to support platinum catalyst nanoparticles, which is essential for hydrogen oxidation and reduction reactions.

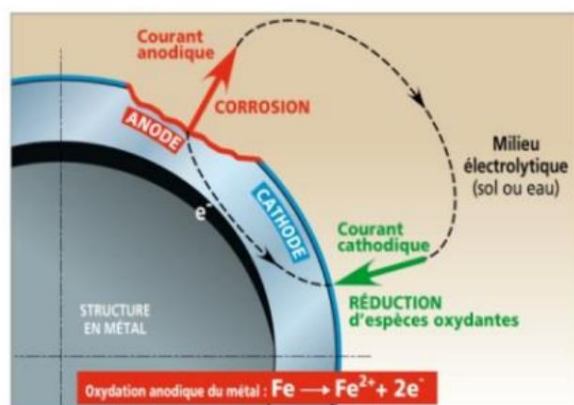
### Role of carbon in PEMFCs

- **Catalytic support** : Carbon provides a large specific surface area, allowing uniform distribution of the platinum catalyst and thus improving the efficiency of electrochemical reactions.
- **Electrical conductivity** : Carbon has excellent conductive properties, facilitating the transfer of electrons during reactions in the hydrogen fuel cell.

### Corrosion mechanisms

Carbon corrosion in PEMFCs can be caused by several mechanisms:

1. **Oxidation** : At high temperatures and in oxidizing environments, carbon can oxidize, resulting in the formation of CO<sub>2</sub> or CO and loss of active surface area.
2. **Humidity conditions** : A lack of humidity can exacerbate the reaction of corrosion, because adequate humidity is necessary to ensure maximum water redistribution and avoid dehydration of the catalytic layers.
3. **Degradation products** : Products generated by carbon oxidation can interfere with the operation of catalysts and reduce their overall efficiency.



### Importance of the study of carbon corrosion

Carbon corrosion is a critical factor that can compromise the longevity and performance of PEMFCs. Analyzing corrosion mechanisms and developing mitigation strategies is crucial to:

- **Improve the durability of fuel cells** : Better resistance to corrosion will lead to an increase in the operational life of the systems.
- **Optimize energy performance** : By reducing corrosion, we can maintain higher efficiency levels in converting hydrogen into electricity.

## 2. Corrosion mechanisms

- Description of the electrochemical processes leading to the degradation of carbon.
- Influencing factors: operating conditions, temperature, humidity, and interactions with other materials.

### How does corrosion form?

Corrosion, a chemical process, **occurs when metal encounters oxygen and moisture**. This contact transforms it into an electrochemical "battery." One area of the metal becomes the anode, losing electrons and oxidizing, while the cathode remains intact. **The loss of electrons at the anode forms metal oxide, or rust.** Water and oxygen in

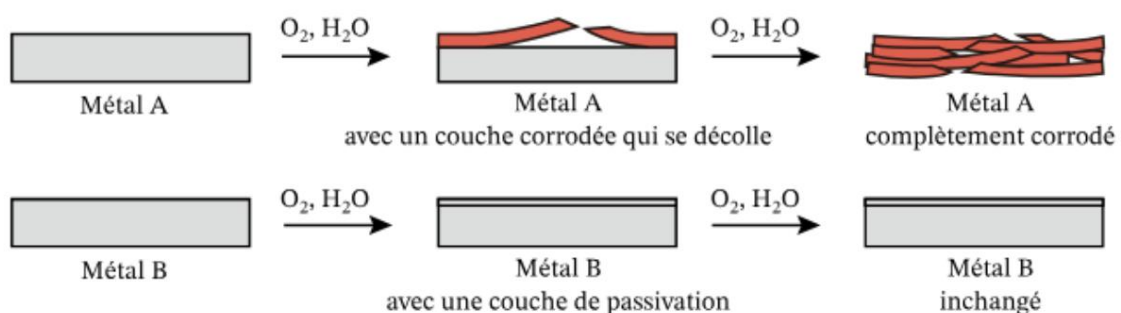
Air promotes this process, pollution and temperature variations can amplify it, thus accelerating corrosion. The reason is that airborne contaminants such as particulate matter are born as a result of chemical reactions between liquids and solids. These same liquids and solids, including salt and black carbon, can interact with molecules contained in metals and accelerate disintegration.

Although the word "corrosion" is used to describe the disintegration of metals, all natural and synthetic materials are subject to degradation.



*Where does corrosion come from? (It's not rocket science)*

### The different types of corrosion



### Pitting corrosion

It focuses on tiny areas, where it **creates deep cavities or holes**. This insidious type of corrosion is particularly dangerous because it can cause

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significant damage to metal structures, often without being immediately visible or detectable.

### Uniform corrosion

It is distributed evenly throughout the metal. It is easy to see and measure. This equality simplifies repair or replacement decisions. Decision-makers can therefore act quickly to preserve the integrity of structures.

### Crevice corrosion

It acts like pitting but on larger areas, deeper. **It forms cavities under the metal.** These damaged areas seriously threaten the structure. Their early detection is essential to avoid significant damage and maintain safety.

### Galvanic corrosion

When two different metals come into contact in an electrolyte (minerals that carry an electrical charge when dissolved in a liquid: sodium, potassium, etc.), **the more anodic metal corrodes, protecting the cathodic one.** This phenomenon is common in mixed structures.

### Stress corrosion cracking

It **mainly threatens stainless steels**, especially in the presence of chloride ions. It weakens components under low stresses, well before reaching their elastic limit.

Chloride ions aggravate cracks, accelerating degradation. Often undetectable at first, this corrosion can cause unexpected component failure, posing a serious risk of sudden failure.

### Atmospheric corrosion

It is the result of the interaction between materials and air, influenced by oxygen, carbon dioxide, humidity and pollutants such as **sulfur** and chlorine. Climatic variations complicate this phenomenon, which varies according to the region and the weather.

### Atmospheric corrosion study provides additional information

A recent study on atmospheric corrosion provided a better understanding of how airborne pollutants directly affect metals in an urban environment.

The researchers put forward a first thesis according to which atmospheric corrosion of metals and their alloys is very frequent in industrial cities due to the

high concentration of corrosive pollutants in the air. Air pollution in a large city would accelerate the corrosion process and contribute to the degradation of metals more quickly than if the pollution were at a lower level.

To test this theory, the researchers exposed several metal samples to an industrial urban environment for 12 months to determine the effect of airborne particles on the corrosion rate. They chose a heavily polluted area in the test city.

**The study found that metal corrosion was much faster in winter, when pollution levels were at their highest.**

This increase in pollution is due to increased emissions from nearby power plants and heating plants, as well as vehicle emissions and heating furnaces used extensively due to the cold.

Sulfur dioxide, carbon dioxide, **dust** and moisture were the most common pollutants that accelerated corrosion.

### **Marine corrosion**

In seawater, **salt ions intensify corrosion**, representing a significant problem for maritime infrastructures and vessels. This acceleration of salt corrosion requires protective measures (**air filtration in the marine environment**) reinforced to preserve the durability and safety of buildings and boats exposed to this aggressive environment.

### **Corrosion of metals**

Each metal has its own vulnerabilities to corrosion, requiring specific strategies for its protection.

### **Corrosion of aluminum**

Although corrosion resistant, aluminum can suffer from galvanic corrosion in the presence of other metals.

### What are the signs of corrosion?

Visible signs of corrosion, such as **unusual stains** and rust ranging from reddish-brown to orange, signal the deterioration of metals. **Changes in color** (from black to green) also indicate corrosion. Identifying these signs early is essential to act before the damage becomes irreparable. Regular monitoring helps preserve the durability and safety of metal structures, allowing targeted preventive or corrective interventions to maintain the integrity of the materials.

### Effects and challenges of corrosion

Corrosion specialists have identified **sulfur dioxide (SO<sub>2</sub>)** produced by **power plant** emissions and vehicles as one of the main factors of corrosion.

#### On the environment

Corrosion releases heavy metals into the environment, **increasing pollution and damaging ecosystems.** This release of toxic substances affects water and soil quality, threatening biodiversity and the health of natural habitats.

High concentrations of sulfur dioxide can harm trees and plants by destroying their foliage and stunting their growth. A recent study by Greenpeace (**ranking global SO<sub>2</sub> air pollution hotspots**) also indicates that high concentrations of sulfur dioxide can seriously pollute the air and lead to premature deaths.

#### On the goods

Corrosion does not only affect man-made monuments. It also affects objects close to homes, such as vehicles, barbecues, outdoor furniture and household appliances. In addition, corrosion can damage data centers, industrial process control facilities, as well as sensitive production sites and historical cultural sites. For all these applications, it is necessary to measure corrosion.

Corrosion also degrades important infrastructure such as reinforced steel highways, electricity pylons, parking lots and bridges.

Corrosion, which degrades material assets, **increases maintenance costs and reduces the lifespan of infrastructures.** It generates significant additional costs and requires frequent interventions to preserve the integrity of the affected structures.

*“ We know that many commercial industries such as oil and gas, construction and electronics are vulnerable to the effects of corrosion ,” said **Cam fil USA's Molecular Filtration segment manager.** “ Without control methods, equipment and structural failure will likely occur with potentially catastrophic consequences. That's why molecular filtration is so critical to removing corrosive agents from the air and ensuring structural integrity. ”*

### 3. Impact on catalysts

- Degradation of catalytic performance due to loss of active surface area.
- Consequences on the energy efficiency and longevity of PEMFCs.

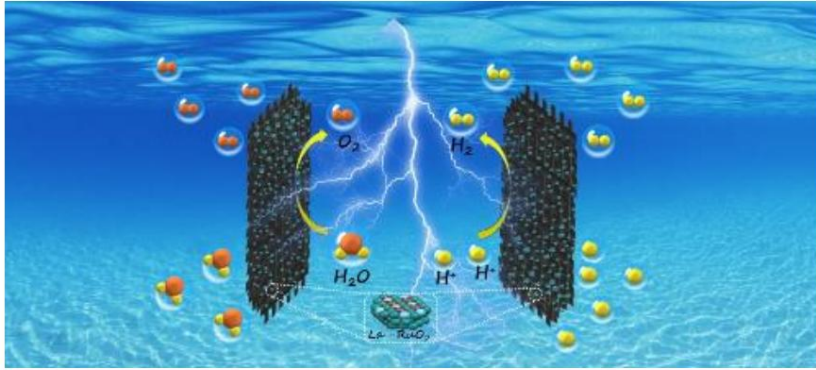
If the catalytic converter can no longer filter the gases properly, they can escape and invade the interior of the vehicle. Finally, if you notice an increase in fuel consumption or a loss of power in your vehicle, this can also be a sign of a faulty catalytic converter.

Removing the catalyst changes the flow of exhaust gases, which can affect engine sound and power.

Degradation of catalytic performance due to loss of active surface area is a major issue in the field of proton exchange membrane hydrogen fuel cells (PEMFC - Here is an overview of the causes, consequences and implications for the energy efficiency and longevity of PEMFCs:

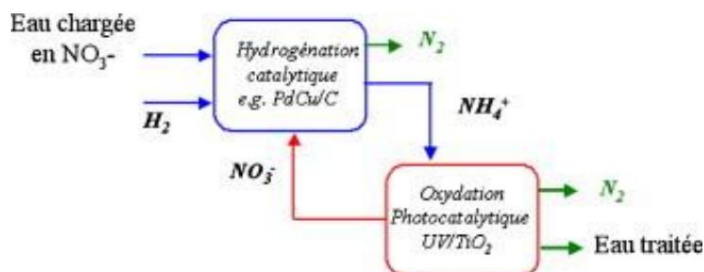
#### Degradation of catalytic performance

1. **Loss of active surface area** : Catalysts, often platinum-based, can suffer a loss of active surface area due to various mechanisms, such as:
  - o **Nanoparticle osmosis** : Small catalyst particles can cluster or agglomerate, reducing the surface area available for reactions.
  - o **Fouling** : The accumulation of contaminants, such as dirt hydrogen or reaction products, can clog the catalytic sites.
  - o **Corrosion** : Prolonged exposure to aggressive environments can cause corrosion of the catalytic particles, reducing their effectiveness.



### Consequences for energy efficiency

1. **Decreased hydrogen production** : A loss of active surface area means fewer sites for the hydrogen oxidation reaction, leading to less electricity production for the same amount of hydrogen.
2. **Increased Ohmic Losses** : Degradation also affects the internal impedance of the battery, resulting in increased Ohmic losses. This increases the energy requirement to maintain the same output, hence decreasing the overall energy efficiency.
3. **Decreased power density** : The ability to generate electricity per unit volume or weight (power density) decreases, making PEMFCs less competitive compared to other energy technologies.



### Implications for PEMFC longevity

1. **Reduced Lifetime** : Degradation of catalytic performance reduces the effective life of PEMFCs. With significant performance losses, systems require more frequent replacement or maintenance, resulting in higher costs.
2. **Reliability** : Erratic performance caused by degradation can compromise the reliability of hydrogen fuel cells, especially in critical applications such as hydrogen vehicles or energy storage systems.
3. **Hydrogen supply austerity** : Decreased energy efficiency may result in increased consumption of hydrogen to achieve desired performance levels, raising questions about the sustainability of hydrogen supply.

#### 4. Mitigation strategies

- **Modification of cathode materials** : Use of new supports or protective coatings.
- **Optimization of operating conditions** : Control of temperature and humidity to limit corrosion.
- **Diagnostic techniques** : Continuous monitoring and evaluation to detect the corrosion.
- **Research into new catalysts** : Development of catalytic materials alternatives less sensitive to corrosion.



Strategies to mitigate catalyst degradation in proton exchange membrane fuel cells (PEMFCs) are essential to improve their performance, energy efficiency, and longevity. Here is a detailed overview of the strategies you mentioned:

##### 1. Modification of cathode materials

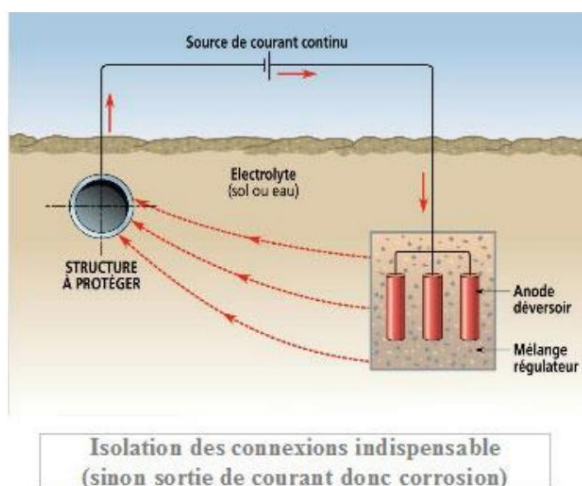
###### *Using new media:*

- **Innovative supports** : The use of carbon or material supports  
Composites can improve the stability of catalysts. Porous and lightweight structures promote better hydrogen distribution and improved active surface area.
- **Nanoporous materials** : These materials can provide a larger active surface area while maintaining good conductivity, which can enhance the efficiency of reactions.

###### *Protective coatings:*

- **Anti-corrosion coatings** : Apply protective coatings to the catalysts can reduce their exposure to corrosive environments, thereby extending their service life.

- **Protective layers** : The use of thin layers of metal oxides or polymers can help block corrosive agents while allowing the diffusion of reagents.



Système de protection par courant imposé

## 2. Optimization of operating conditions

### Temperature control:

- **Thermal management** : Maintaining optimal temperatures for reactions electrochemical is crucial. Proper regulation helps avoid extreme variations that can lead to accelerated degradation.

### Humidity control:

- **Moisture balance** : Accurate control of moisture in the cell is vital to prevent excess water build-up, which can lead to corrosion conditions. Moisture management systems can be incorporated to maintain adequate levels.

## 3. Diagnostic techniques

### Continuous monitoring:

- **Advanced sensors** : Installing sensors to monitor the conditions of PEMFC operation (temperature, humidity, voltage, current) allows for rapid detection of anomalies and anticipation of corrosion problems.

***Regular assessment:***

- **Non-destructive testing** : The use of methods such as spectroscopy or tomography can provide information on the condition of the catalyst and its integrity, allowing preventive interventions.

**4. Search for new catalysts*****Development of alternative catalytic materials:***

- **Non-precious catalysts** : The search for catalysts based on materials Abundant and less expensive catalysts, such as nickel or iron, could offer an alternative to platinum catalysts which are susceptible to corrosion.
- **Nanomaterials** : Research is underway into composite nanomaterials or alloy structures that could improve corrosion resistance without sacrificing efficiency.

***Innovations in electrocatalysis:***

- **Improved performance catalysts** : The development of novel composites or multidimensional layered catalysts is a promising approach to increase the active surface area while reducing corrosion sensitivity.

**Conclusion**

The combination of these strategies can play a key role in improving the performance of PEMFCs while extending their lifetime. Continued research and innovation in these areas are needed to overcome current challenges and maximize the potential of hydrogen fuel cells as a clean and sustainable energy source.

**5. Conclusion and future prospects**

- Importance of continuing research to improve the sustainability of PEMFCs.
- Potential of new technologies to improve corrosion resistance of carbon.

The sustainability of proton exchange membrane fuel cells (PEMFCs) is a critical issue for the widespread adoption of this technology as a clean and renewable energy source. Catalyst degradation, particularly surface area loss and material corrosion, represents a significant challenge that requires continued attention and innovation. Here are some key points highlighting the importance of research and future perspectives:

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### *Importance of continuing research*

1. **Continuous performance improvement** : Research should focus on developing more robust and efficient PEMFC systems. This includes research into new materials, understanding degradation mechanisms, and optimizing control systems.
2. **Environmental sustainability** : By improving the sustainability and efficiency of PEMFCs, the overall environmental impact of this technology can be reduced. This also contributes to energy transition goals and the fight against climate change.
3. **Cost reduction** : Optimizing materials and processes can help reduce the cost of PEMFCs, making the technology more accessible and commercially viable, which is essential for applications in transportation, industry and power generation.
4. **Interdisciplinary collaboration** : Research integrating diverse disciplines, such as chemistry, materials science and engineering, is crucial to address the complex challenges related to the sustainability of PEMFCs. Collaboration between research institutes, industry and governments can accelerate innovations.

### *Potential of new technologies*

1. **Nanotechnologies and new materials** : The development of advanced nanomaterials or composites, specifically designed to resist corrosion, could revolutionize the durability of PEMFCs. These materials can offer an improved combination of mechanical and chemical resistance.
2. **Innovative coatings** : Exploring new coating techniques, such as self-curing functional coatings or hybrid coatings, can help to protect carbon surfaces and improve corrosion resistance.
3. **Advanced management systems** : The integration of diagnostic and Real-time monitoring for operating condition control can help detect corrosion early and adjust operating parameters to reduce its impact.
4. **Alternative materials** : Research into non-precious or precious-based catalysts abundant materials with better resistance to corrosion and degradation are promising. These options could establish a more sustainable basis for the development of PEMFCs, enabling their large-scale use.

### **General conclusion**

In conclusion, for PEMFCs to realize their full potential as a sustainable energy solution, continued research focused on improving their durability and overcoming the challenges associated with corrosion is essential. With current and future technological advances, we have the opportunity to transform PEMFCs into a key technology in the transition to cleaner and more efficient energy systems.

The combination of materials innovation, optimized management strategies and the integration of new technologies will pave the way for a future where PEMFCs could play a leading role in the global energy landscape.