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13 Nov 2023

PEM 制氢催化剂及膜电极的降"铱"之路

Reducing Iridium in Catalyst & Membrane Electrode Assemblies for PEM Water Electrolyzers

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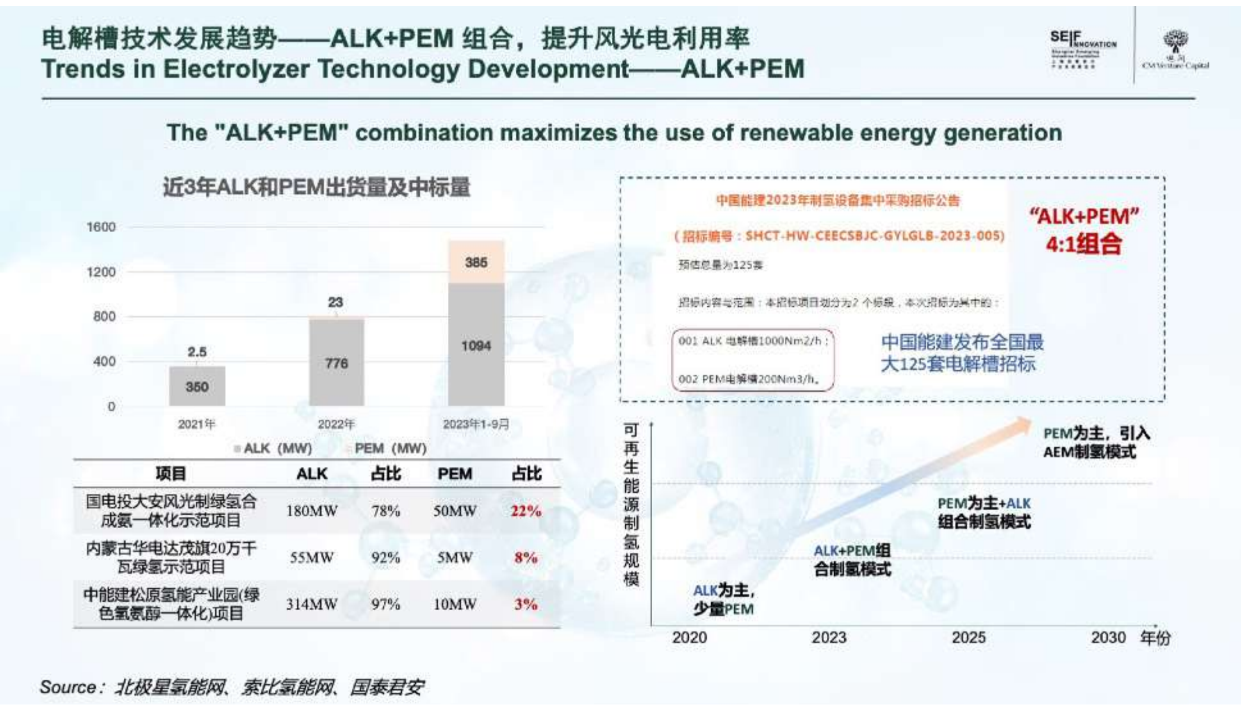
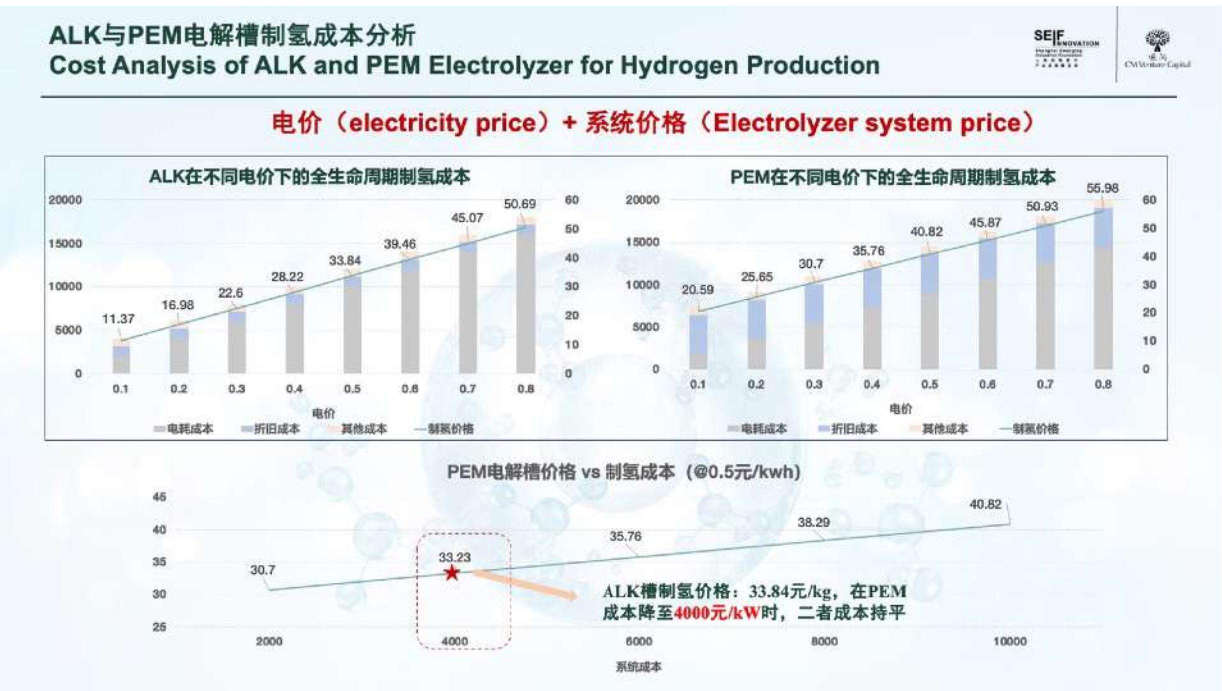


This slide, titled "Trends in Electrolyzer Technology Development — ALK+PEM," discusses the integration and advancements in electrolyzer technologies, particularly focusing on the combination of Alkaline (ALK) and Proton Exchange Membrane (PEM) systems for hydrogen production.

Here's a detailed explanation:

- The main header indicates that this is an analysis of the current state and the development trend of electrolyzer technologies that use a combination of ALK and PEM systems.
- The subtitle states that the "ALK+PEM" combination maximizes the use of renewable energy generation.
- A bar chart shows the projected capacities of ALK and PEM technologies from 2021 to 2023. In 2021, ALK technology had a capacity of 350 MW, which is expected to rise to 776 MW in 2022 and then to 385 MW for ALK and 1094 MW for PEM by September 2023.
- There is a note on the slide highlighting the significance of the "ALK+PEM" ratio, which is 4:1 according to a specific policy document or regulation (indicated by the document number "SHCT-HW-CEEC SBJC-GYGLB-2023-005").
- The slide also includes a bullet point stating that the Chinese hydrogen economy is expected to reach a production capacity of 125 GW by 2030.
- A smaller graph or chart indicates the specific production capacities of a single ALK unit (1000 Nm³/h) and a single PEM unit (200 Nm³/h).
- The bottom right of the slide mentions the transition to PEM and Anion Exchange Membrane (AEM) electrolysis technologies, with a trend line that shows the increasing adoption of PEM and a combined approach (ALK+PEM) from 2020 to 2030.
- The source credits at the bottom suggest that the information comes from various industry reports and expert analysis.

Overall, this slide emphasizes the growing trend towards PEM technology in electrolyzers, the strategic combination of ALK and PEM systems, and the ambitious goals set by China for hydrogen production capacity. It also hints at policy directions and the evolution of technology preferences over the next decade.



Slide 3 is titled "Cost Analysis of ALK and PEM Electrolyzer for Hydrogen Production," which compares the costs associated with Alkaline (ALK) and Proton Exchange Membrane (PEM) electrolyzers used in hydrogen production.

The slide features two bar charts:

- **ALK Electrolyzer Cost**: The left chart shows the cost of hydrogen production using ALK electrolyzers across different electricity prices, ranging from 0.1 to 0.8 yuan (RMB) per kilowatt-hour (kWh). The bars indicate that as the electricity price increases, the cost of hydrogen production also rises. The highest price shown is 50.69 RMB/kg at an electricity price of 0.7 RMB/kWh.
- **PEM Electrolyzer Cost**: The right chart mirrors the left but for PEM electrolyzers. It shows a similar trend of increasing hydrogen production costs with higher electricity prices. The cost at 0.7 RMB/kWh is 55.98 RMB/kg, slightly higher than that of the ALK electrolyzer.

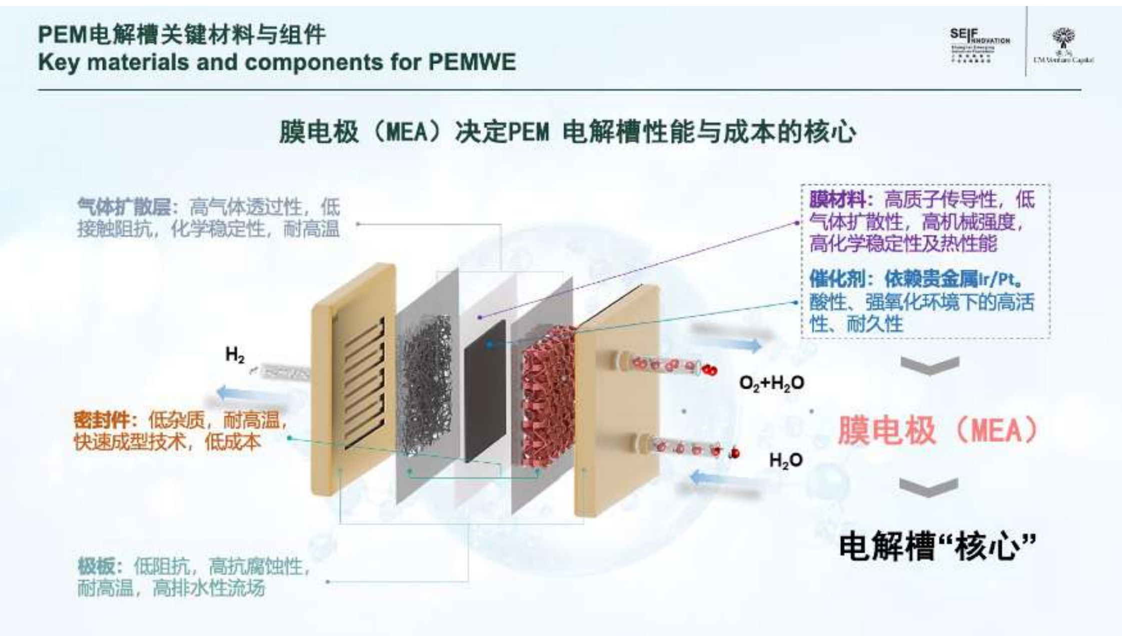
At the bottom of the slide, there's a line graph with a key insight:

- The star marker highlights a target cost reduction for ALK electrolyzers to 33.23 RMB/kg, assuming the PEM electrolyzer system price can be reduced to 4000 RMB/kW. This suggests that with technological advancements and cost reductions, the cost of hydrogen production from PEM electrolyzers could become much more competitive.

The text below the graphs states two bullet points:

- The first bullet mentions that the current cost of producing hydrogen with ALK electrolyzers is around 33.84 RMB/kg, and the future target is to reduce the PEM electrolyzer cost to 4000 RMB/kW, making it competitive with ALK technology.
- The second bullet speaks to improving current density (which likely relates to the efficiency of the electrolyzer) and reducing iridium loading (which refers to using less iridium in the catalyst), with the goal of reducing the cost of hydrogen production fivefold by 2025.

Overall, the slide presents a cost comparison and a path towards making PEM electrolyzers, which typically require expensive catalysts like iridium, more cost-effective and competitive in the hydrogen production market.



Slide 4 is focused on the key materials and components used in Proton Exchange Membrane Water Electrolysis (PEMWE). Here's a breakdown of the slide's content:

- The title "Key materials and components for PEMWE" suggests the slide will detail the critical elements required for the PEM water electrolysis process, which is used to produce hydrogen.
- The slide features a labeled diagram of a PEM electrolyzer. The diagram includes:
  - **Hydrogen side (left side)**: This is where hydrogen gas (H_2) is produced and collected.
  - **Oxygen side (right side)**: This side shows where oxygen (O_2) and water (H_2O) are expelled.
- Central to the diagram is the **Membrane Electrode Assembly (MEA)**, which is a critical component in the PEM electrolyzer. The MEA is where the actual electrolysis process happens, splitting water into hydrogen and oxygen gases.

The MEA is composed of:

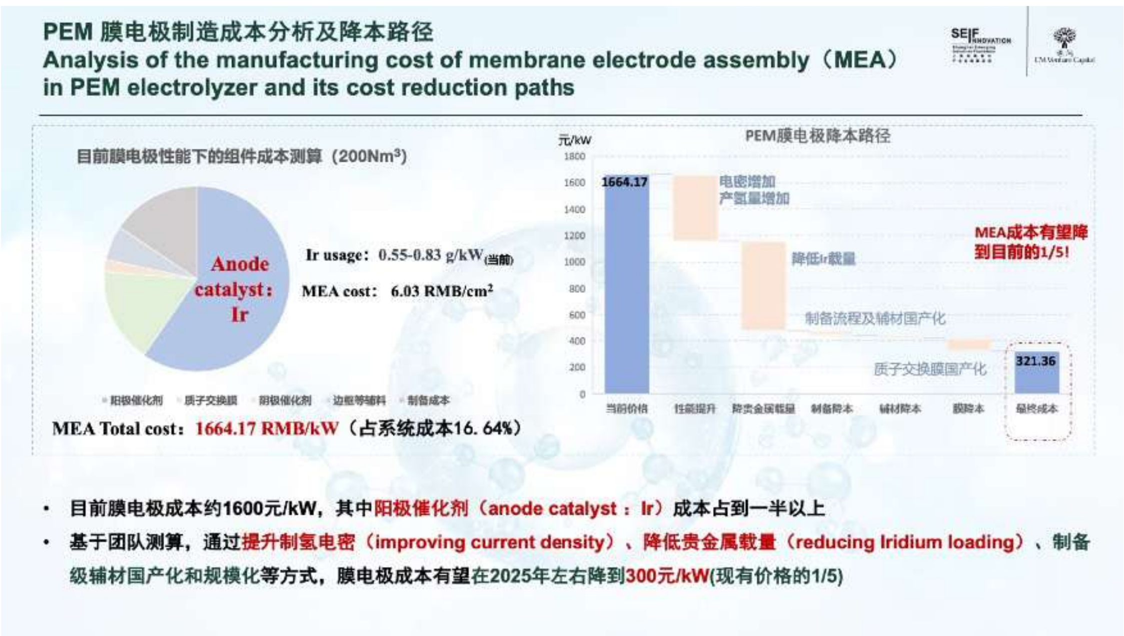
  - **Anode catalyst**: Made of iridium (Ir), which is responsible for the oxygen evolution reaction.
  - **Membrane**: The core part that conducts protons while insulating electrons.
  - **Cathode**: Usually made of platinum (Pt), which facilitates the hydrogen evolution reaction.

The slide includes notes on the efficiency and durability of the system:

  - **Efficiency**: Outlined improvements such as larger stacks, better manufacturing, and quality control.
  - **Operational expenditure (OPEX)**: Related to the ongoing costs of running the electrolyzer, with suggestions for improvements like using thinner membranes and more active catalysts.
  - **Capital expenditure (CAPEX)**: Related to the initial costs of the electrolyzer, with a note on the trade-off between durability and cost.
  - **Durability**: Notes the importance of high-pressure operation, reduced maintenance, and lower water quality.

The bottom of the slide states that the development of low-iridium catalysts and high-performance MEA is the "heart" of the hydrogen production process, emphasizing the importance of these components in efficient and sustainable hydrogen energy production.

Overall, the slide provides an overview of the components and materials that are essential for PEM electrolyzers, highlighting the need for innovation in catalyst and membrane technology to improve performance and reduce costs.



Slide 5 presents an analysis of the manufacturing cost of Membrane Electrode Assembly (MEA) in PEM electrolyzers and discusses potential pathways for cost reduction.

Here's a detailed explanation:

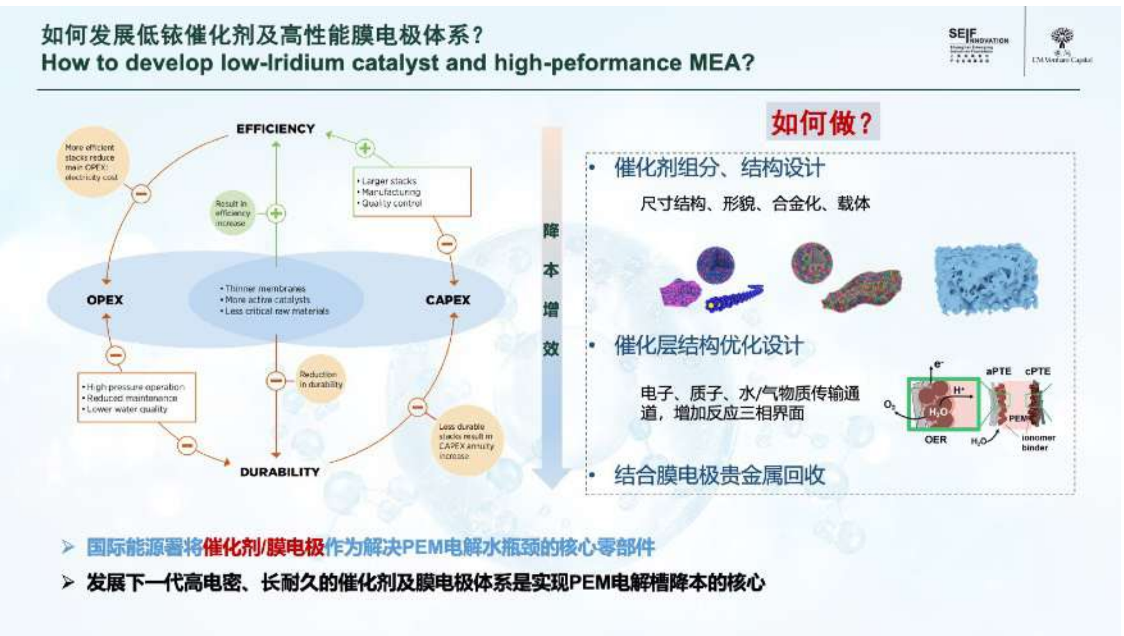
- The title of the slide, "Analysis of the manufacturing cost of membrane electrode assembly (MEA) in PEM electrolyzer and its cost reduction paths," suggests a focus on understanding and reducing the costs associated with producing MEAs, a critical component in PEM electrolyzers.
- A pie chart shows the cost distribution for manufacturing MEA, with a significant portion attributed to the anode catalyst, which includes iridium (Ir), a very expensive material.
- The slide includes specific figures such as iridium usage at 0.55-0.83 grams per kilowatt (g/kW) and the MEA cost at 6.03 RMB/cm².
- The total cost of MEA is given as 1664.17 RMB/kW, which accounts for 16.64% of the total electrolyzer cost.

Below the chart, there are bullet points highlighting that:

  - The goal is to reduce the cost of MEA to below 1600 RMB/kW and significantly reduce iridium usage.
  - There are efforts to improve current density (which would enhance efficiency) and to reduce iridium loading (which would lower costs). The target is to reduce the MEA cost to 300 RMB/kW by 2025, which would be roughly one-fifth of the current cost.

- The bar graph on the right shows the current cost of MEA and projects significant cost reductions over time, with a final target cost of 321.36 RMB/kW.
- The slide suggests that reaching these cost reduction targets will be crucial for making hydrogen production via PEM electrolyzers more economically viable and scalable.

Overall, the slide conveys the importance of reducing the cost of key components in PEM electrolyzers to make green hydrogen a more competitive energy source. It highlights the specific challenge of reducing the use of iridium, which is a major cost driver due to its scarcity and price.



Slide 6 appears to be focused on the development strategies for low-iridium catalysts and high-performance Membrane Electrode Assemblies (MEAs) for Proton Exchange Membrane (PEM) electrolyzers. The slide is divided into several sections, each addressing different aspects of the development process.

Here's a detailed explanation:

The title of the slide is "How to develop low-iridium catalyst and high-performance MEA?", indicating the slide's focus on reducing the use of the rare and expensive metal iridium in catalysts while still achieving high performance in MEAs.

The slide has a central diagram that connects four key areas: Efficiency, OPEX (Operational Expenditure), CAPEX (Capital Expenditure), and Durability. These areas are interrelated in the development of MEAs:

- **Efficiency**: Larger stacks, improved manufacturing, and quality control can result in efficiency increases.
- **OPEX**: Proposes using thinner membranes, more active catalysts, and less critical raw materials to reduce the main operational costs, which are largely due to electricity.
- **CAPEX**: Initially, less durable stacks might lead to higher capital expenditure over time due to the need for more frequent replacements or maintenance.
- **Durability**: High-pressure operation, reduced maintenance, and the use of lower water quality can impact the durability of the systems.

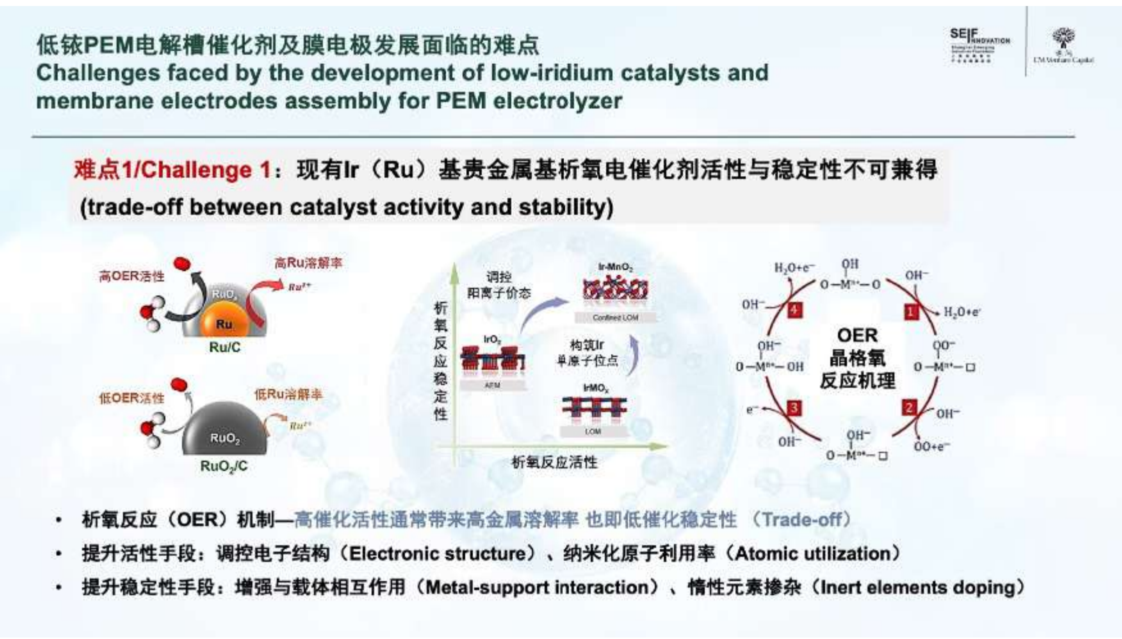
On the right side, there's a box with text and images related to catalyst development:

- It mentions key properties such as activity, stability, selectivity, and conductivity that are important for catalyst performance.
- There are images of different catalyst structures, suggesting a focus on the molecular or nano-scale engineering of catalyst materials.
- The schematic at the bottom of this box appears to show the components of an MEA, including the anode and cathode catalyst layers, and the proton exchange membrane. It also references the Oxygen Evolution Reaction (OER), which is critical for water electrolysis.

The bottom of the slide lists two bullet points:

- The first bullet point suggests a strategy for reducing the cost of MEA production for PEM electrolyzers, which might involve new materials or processes that use less iridium.
- The second bullet point proposes setting a new standard in the industry for these components, likely related to performance and cost.

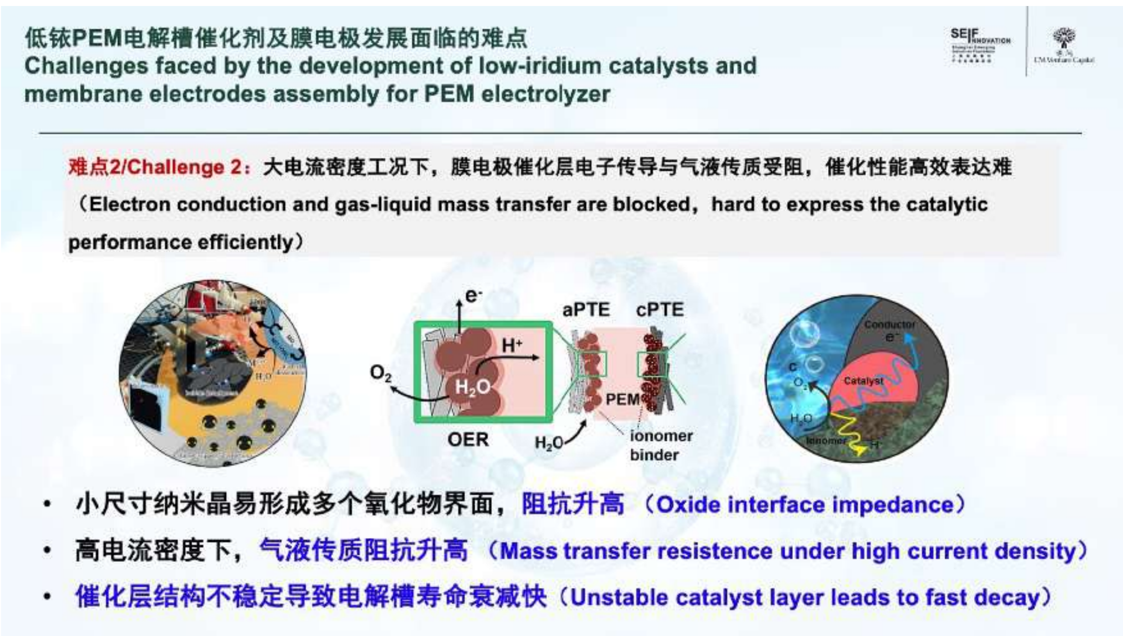
Overall, this slide outlines the considerations and challenges in developing MEA technology for PEM electrolyzers, emphasizing the need to balance cost, efficiency, and durability, especially in the context of using less iridium, which is a scarce resource.



Slide 7 appears to address one of the challenges in developing low-iridium catalysts for Proton Exchange Membrane (PEM) electrolyzers. Let's break down the information provided:

- The title of the slide is "Challenges faced by the development of low-iridium catalysts and membrane electrodes assembly for PEM electrolyzer."
- **Challenge 1, as listed on the slide, is the "trade-off between catalyst activity and stability," specifically when using iridium (Ir) or ruthenium (Ru). This challenge refers to the difficulty of achieving both high activity and high stability in the catalyst materials used in the electrolysis process.**
- The slide features a diagram explaining the Oxygen Evolution Reaction (OER) at the anode side of the electrolysis process, which involves multiple steps where water molecules are split into oxygen, protons, and electrons.
- **There are images depicting different catalysts:**
  - One set shows the OER process with a ruthenium-based catalyst, with a transition from Ru to RuOx states.
  - The other set shows a layered structure with an iridium-based catalyst, transitioning between IrOx states.
- **Below the diagrams, there are bullet points:**
  - The first point discusses the Oxygen Evolution Reaction (OER) and the importance of the electronic structure and the atomic utilization of the catalyst.
  - The second point talks about the metal-support interaction and doping with inert elements to improve the catalyst's performance.
- On the right side, there's a chemical cycle diagram illustrating the steps (1 to 4) of the OER, showing the intermediates and the release of oxygen gas.

Overall, the slide presents the complex nature of designing catalysts that are both active enough to catalyze the oxygen evolution reaction efficiently and stable enough to last a long time without degradation. It also suggests strategies for optimizing these catalysts, such as adjusting their electronic structure and adding inert elements, to improve their overall performance in PEM electrolyzers.



Slide 8 addresses the second challenge in developing low-iridium catalysts for PEM electrolyzers, focusing on issues related to electron conduction and mass transfer.

Here's an explanation of the slide:

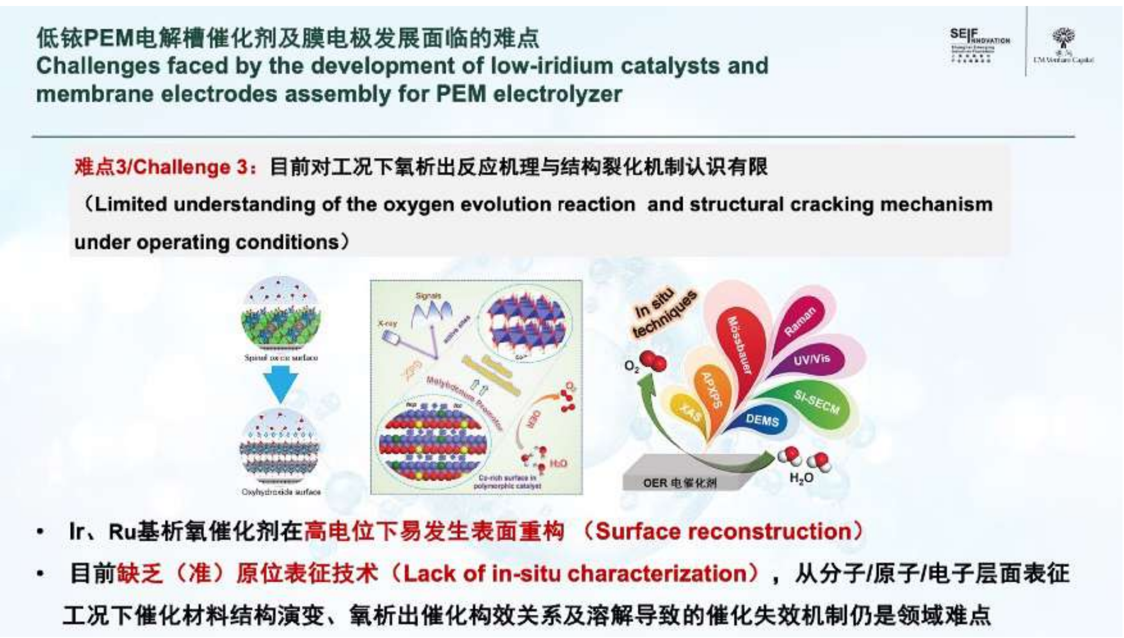
- The title of the slide is "Challenges faced by the development of low-iridium catalysts and membrane electrodes assembly for PEM electrolyzer."
- Challenge 2 is described as difficulties with electron conduction and gas-liquid mass transfer. Specifically, these processes can be blocked, making it hard to express the catalytic performance efficiently.
- The slide features a diagram illustrating the Oxygen Evolution Reaction (OER) occurring at the anode side of a PEM electrolyzer. It highlights the path of oxygen gas (O2), water (H2O), protons (H+), and electrons (e-).

There are three main bullet points discussing the specific challenges:

  - **Oxide interface impedance**: This refers to resistance at the interface where the catalyst interacts with the oxide, hindering electron flow.
  - **Mass transfer resistance under high current density**: As the current density increases, the resistance to the movement of molecules (mass transfer) can also increase, impeding the efficiency of the reaction.
  - **Unstable catalyst layer leading to fast decay**: If the catalyst layer is not stable, it can degrade quickly, reducing the lifespan and performance of the electrolyzer.

- The diagram to the right side appears to show a close-up view of a catalyst within an electrolyzer, with an ionomer binder, catalyst particles, and the conductor. It visually represents where electron conduction and gas-liquid mass transfer take place.

Overall, this slide suggests that improving the stability and efficiency of catalyst layers, as well as enhancing electron and mass transfer processes, are critical areas of focus to overcome the challenges in developing effective low-iridium PEM electrolyzers.



Slide 9 addresses the third challenge in the development of low-iridium catalysts for PEM electrolyzers, specifically related to the Oxygen Evolution Reaction (OER) and the catalyst's structural integrity.

Here's a detailed explanation:

- The title of the slide is "Challenges faced by the development of low-iridium catalysts and membrane electrodes assembly for PEM electrolyzer."
- Challenge 3 is identified as "Limited understanding of the oxygen evolution reaction and structural cracking mechanism under operating conditions." This suggests a need for deeper knowledge about how the OER functions and how the catalyst structures respond during operation, which is crucial for improving catalyst design and stability.

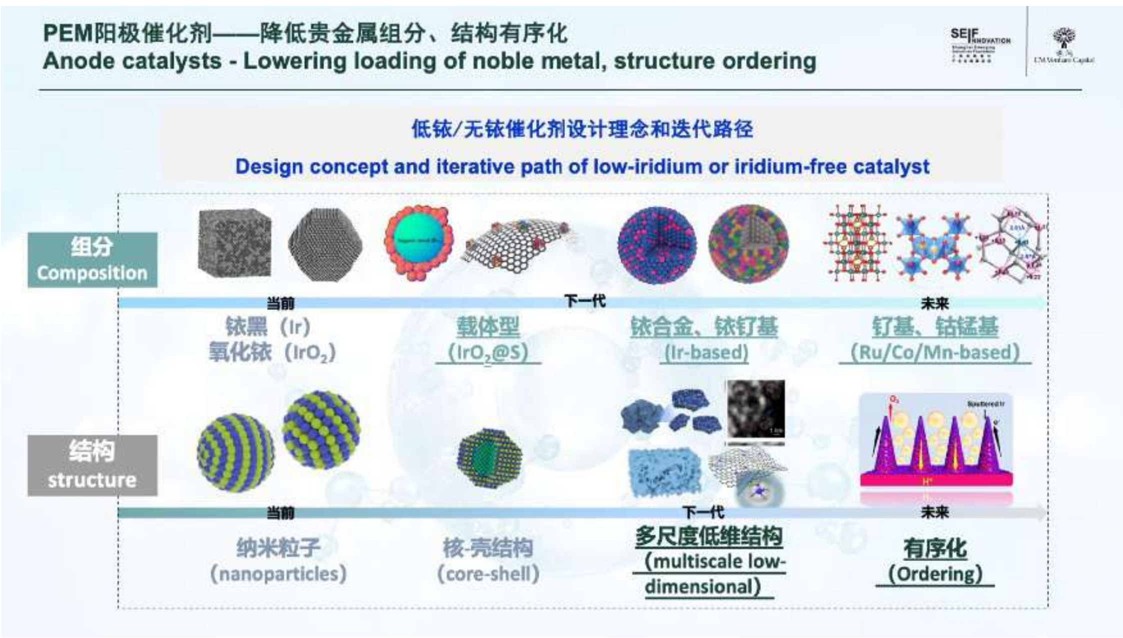
The slide features two main diagrams:

- On the left, there's an illustration of a spinel oxide surface transforming into an oxyhydroxide surface, which is likely a representation of the catalyst surface undergoing changes during the OER. The text below mentions iridium (Ir) and ruthenium (Ru) and discusses surface reconstruction, which affects the catalyst's performance.
- On the right, there's a graphic showing various in situ characterization techniques like X-ray Absorption Fine Structure (XAFS), Raman spectroscopy, and Differential Electrochemical Mass Spectrometry (DEMS). These techniques are used to study the catalysts' behavior during the OER in real-time, which is crucial for understanding and improving their performance.

The bullet points below the diagrams discuss:

- The surface reconstruction of iridium and ruthenium catalysts and the implications for their activity and durability.
- The lack of in situ characterization, meaning that there isn't enough real-time analysis of these catalysts under actual operating conditions, which makes it challenging to understand and optimize their performance.

Overall, the slide conveys the importance of understanding the OER at a fundamental level and the need for real-time analysis of catalyst behavior to overcome the challenges of developing efficient, durable, and low-iridium catalysts for PEM electrolysis.



Slide 10 appears to explore the design and development of anode catalysts for PEM electrolyzers with an emphasis on reducing the use of expensive noble metals like iridium and enhancing the structure ordering of the catalysts.

Here's a detailed explanation:

- The title of the slide suggests a focus on "Anode Catalysts - Lowering loading of noble metal, structure ordering."
- The subtitle "Design concept and iterative path of low-iridium or iridium-free catalyst" indicates that the slide will outline the strategies and progressions in catalyst design that aim to minimize or eliminate the use of iridium.

The slide presents a visual progression of catalyst development, showcasing various stages:

  - **Composition**: Starting with pure iridium (Ir) and its oxide form (IrO2), which are traditional catalyst materials.
  - **Structure**: Moving on to nanoparticles and core-shell structures, which are advanced forms where the catalyst material is engineered at the nano-scale to improve performance and reduce material usage.
  - **Multiscale low-dimensional**: Further advancement to multiscale low-dimensional structures that optimize the surface area and reactivity.
  - **Ordering**: The final stage shows ordered structures that maximize the efficiency and stability of the catalyst.

- To the right, there is a reference to alternative materials, such as those based on ruthenium (Ru), cobalt (Co), and manganese (Mn), which may be used to either supplement or replace iridium in the catalyst composition.
- The images and diagrams in the slide illustrate the different catalyst structures and their evolution from simple particles to more complex, engineered structures.
- There are also mentions of in situ techniques and advanced characterization methods that are likely used to study and optimize these catalysts.

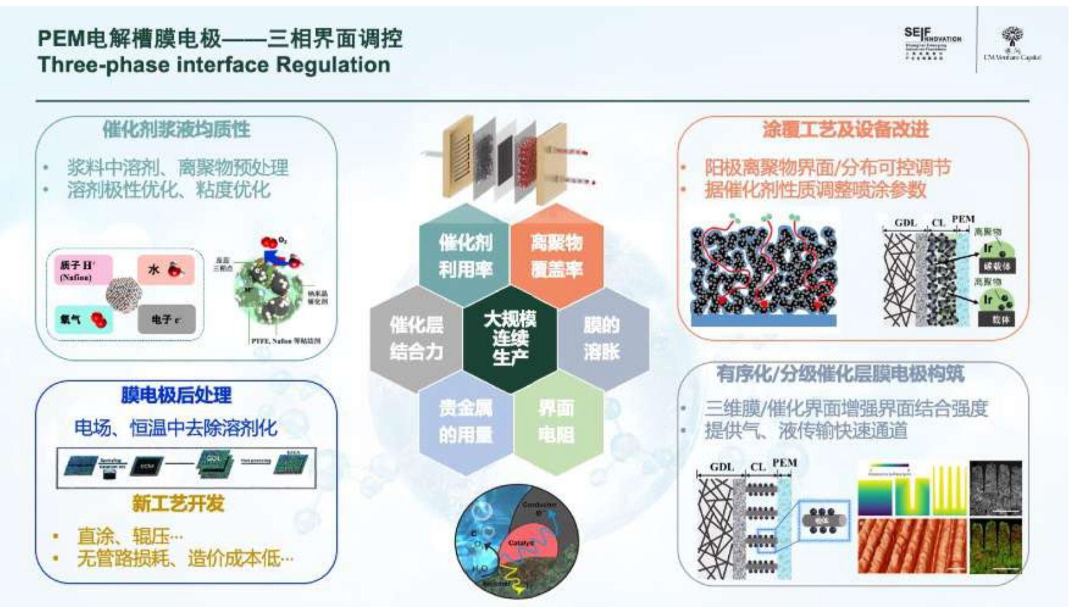
Overall, the slide emphasizes the ongoing innovation in catalyst development for PEM electrolysis, specifically targeting the reduction in the use of iridium, which is a scarce and expensive resource. By improving the catalyst structure and exploring alternative materials, the goal is to create more sustainable and cost-effective solutions for hydrogen production.

Slide 11 seems to delve into the design strategy and mechanisms of anode catalysts for PEM electrolyzers, with a focus on overcoming certain limitations and enhancing the structure of the catalysts.

Here's a detailed explanation:

- The title of the slide, "Design strategy and mechanism of anode catalysts," indicates a focus on the approach to designing anode catalysts for PEM electrolyzers and the mechanisms by which they operate.
- The section labeled "Limitations" likely outlines the current challenges or shortcomings in the design of anode catalysts.
- There are three main categories outlined in the slide that describe different types of catalysts and strategies for their development:
  - **Supported Type**: This category probably discusses catalysts that are supported on a substrate to improve their activity and stability. The accompanying images may show catalyst particles on a support material, and the text may discuss the advantages of this type of structure.
  - **Alloyed Type**: This type involves alloying different metals to create a catalyst with improved properties. The text and images might detail how alloying can enhance the performance of the catalyst and show examples of alloyed nanoparticles.
  - **Multi-scale micro/nano ordered structure design**: This section likely describes the design of catalysts at multiple scales, from micro to nano, to create highly ordered structures that improve catalytic activity. The images may illustrate the sophisticated architecture of these catalysts.
- Each section seems to have bullet points detailing the properties and benefits of each catalyst type, such as high activity, enhanced stability, and improved mass transfer.
- The right side of the slide shows microscopy images of catalysts, providing visual evidence of the nanostructures and possibly the results of in-situ characterization techniques that reveal the detailed architecture of the catalysts.
- The bottom right corner shows an illustration of a catalyst layer within a PEM electrolyzer, providing a schematic representation of how these catalysts function within the electrolyzer environment.

Overall, this slide emphasizes the innovation in catalyst design for PEM electrolyzers, highlighting different strategies to optimize the catalysts' performance while addressing their limitations. It underscores the importance of material science and engineering in developing more efficient and durable catalysts for hydrogen production.



Slide 12 appears to discuss the regulation of the three-phase interface in PEM electrolyzers, which is crucial for efficient catalyst function and overall electrolyzer performance.

Here's a detailed explanation:

- The title of the slide, "Three-phase interface Regulation," suggests a focus on managing the interactions at the point where the catalyst, electrolyte, and reactants (gas and liquid phases) meet.

There are two main sections on the slide:

  - **Left Section**: This part likely explains the importance of optimizing the interface where the electrolysis reaction occurs. It mentions the proton (H+), water (H2O), and oxygen (O2) molecules and shows a diagram of a catalyst particle, with a focus on enhancing catalyst activity and stability. The text may also reference Nafion, a common proton exchange membrane material, and its integration with the catalyst.
  - **Right Section**: This section seems to discuss the challenges of in-situ characterization, which is essential for understanding how the catalyst behaves under real operating conditions. It emphasizes the importance of directly observing the catalyst's function within the membrane electrode assembly (MEA).

The central hexagons outline various aspects related to the three-phase interface, such as catalyst activity, mass transfer, charge transfer, and structural stability. These factors are critical in determining the efficiency and durability of the electrolyzer.

- There are visual aids, including microscopy images and diagrams, that provide insight into the microstructure of the catalysts and the MEA. These images show the actual materials and layers involved in the electrolysis process.
- The bottom of the slide includes bullet points that likely highlight the key design considerations and the desired outcomes of this regulation strategy. It may mention specific techniques or improvements, such as surface area enhancement or nanostructuring, to optimize the three-phase interface.

Overall, the slide emphasizes the complexity of the three-phase interface in PEM electrolyzers and the need for precise control and understanding of this region to improve the performance and longevity of the electrolysis system.

Slide 13 appears to describe the use of in-situ electrochemical spectroscopy to monitor various aspects of catalyst behavior in PEM electrolyzers.

Here's a detailed explanation:

- The title of the slide, "In-situ electrochemical spectroscopy," suggests that the slide will discuss a method for observing and analyzing catalysts during operation.
- The subtitle "To monitor surface reconstruction, dissolution process, and dynamic evolution of oxygen species" indicates that the in-situ spectroscopy is used to study changes in the catalyst's surface, how it dissolves, and how oxygen-related molecules behave dynamically during the reaction.

The slide features two diagrams:

  - On the left, there's a setup showing an in-situ spectroscopy instrument attached to a PEM electrolyzer, highlighting the OER happening on the catalyst's surface.
  - On the right, there's an illustration of a spectroscopy probe analyzing a catalyst layer within an electrolyzer, with a focus on the reaction zone where oxygen evolves.

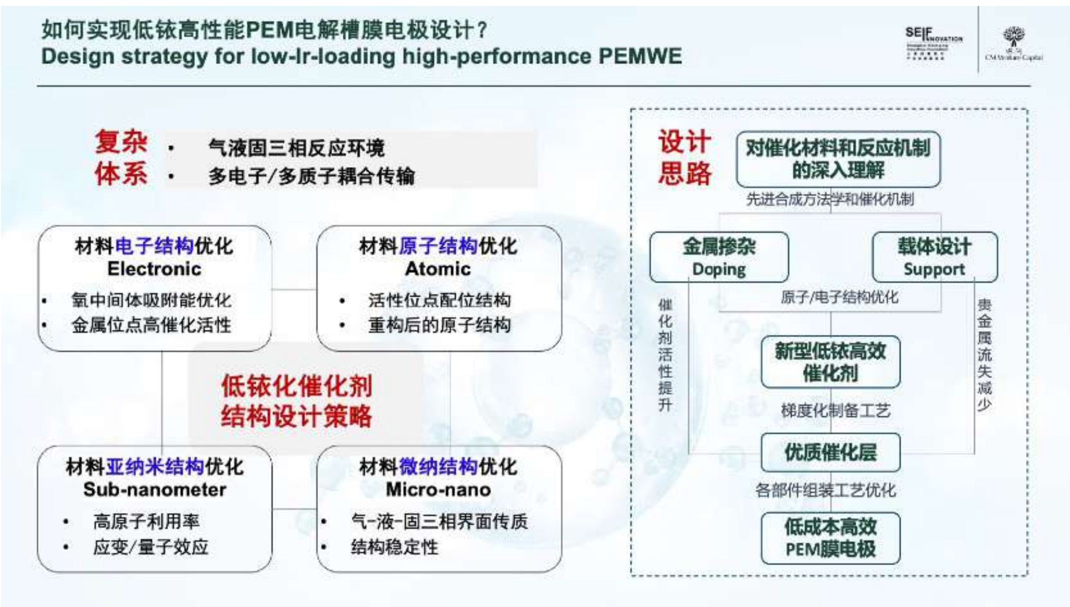
There are bullet points on the left and right sides of the slide, which likely list the advantages and insights gained from using in-situ electrochemical spectroscopy, such as:

  - Understanding the mechanisms at the atomic or molecular level.
  - Detecting changes in the catalyst's structure as it operates.
  - Observing how the catalyst interacts with the membrane and the reactants in real-time.

The bullet points might also mention the types of spectroscopy used, such as X-ray absorption spectroscopy or Raman spectroscopy, and how these techniques contribute to better catalyst design.

- The bottom of the slide shows additional images related to the spectroscopy methods and the detailed analysis they provide, such as surface images of the catalysts and spectral data.

Overall, this slide emphasizes the importance of using advanced in-situ characterization techniques to gain a deeper understanding of catalyst behavior during the electrolysis process. This information is crucial for the development of more efficient and durable catalysts for hydrogen production.



Slide 14 outlines a design strategy for developing low-iridium-loading, high-performance Proton Exchange Membrane Water Electrolyzers (PEMWE).

Here's a detailed explanation:

- The title suggests a focus on strategies to reduce the amount of iridium, a scarce and expensive metal, used in the catalysts of PEM electrolyzers while still achieving high performance.

The slide is divided into two main sections:

Left Section (Design Aspects): It outlines different scales at which catalysts can be designed and optimized:

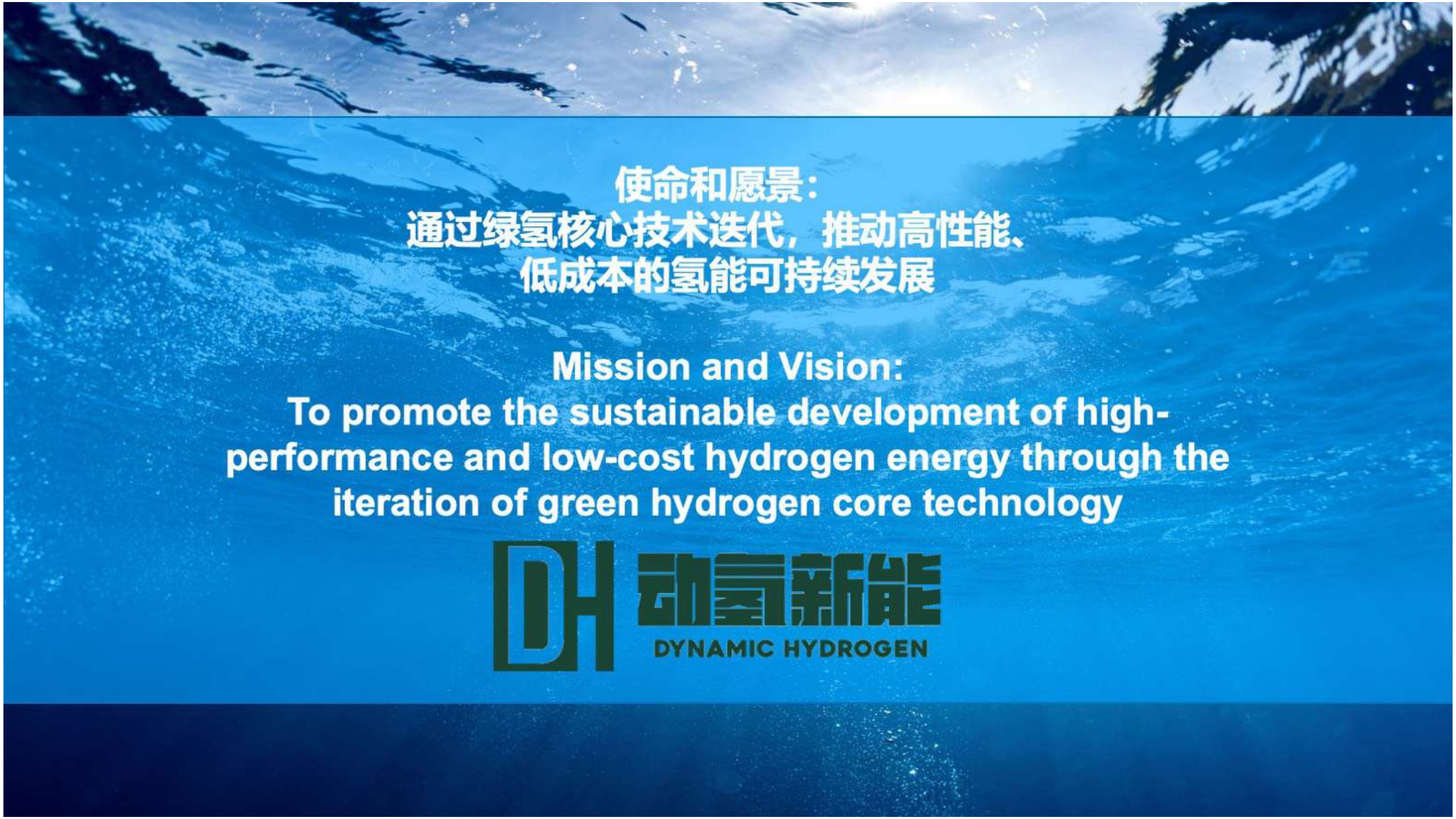
- **Electronic**: Adjusting the electronic structure for improved catalytic activity and stability.
- **Atomic**: Fine-tuning at the atomic level to enhance activity and achieve better atom utilization.
- **Sub-nanometer**: Designing structures smaller than a nanometer to optimize surface area and reactivity.
- **Micro-nano**: Combining micro and nano approaches to create an overall design that maximizes performance.

Right Section (Design Techniques): This section lists the techniques used to implement the design aspects on the left:

- **Doping**: Incorporating other elements at the atomic level to improve the catalyst's electronic structure and activity.
- **Support**: Using a support material to enhance the catalyst's stability and dispersion.

- Additionally, there are a few more specific methods mentioned for doping and support, such as using transition metal carbides or oxides.
- The slide emphasizes that optimizing at different scales and using various techniques are crucial for enhancing the performance of PEMWE catalysts while minimizing iridium usage.
- The visual elements in the slide, such as diagrams and microscopic images, likely showcase examples of catalyst structures and the mechanisms by which they operate more effectively.

Overall, this slide conveys the comprehensive approach needed to innovate in catalyst design, considering electronic, atomic, and material aspects to achieve a high-performing and cost-effective PEM electrolyzer.


使命和愿景：
通过绿氢核心技术迭代，推动高性能、
低成本的氢能可持续发展
Mission and Vision:
To promote the sustainable development of high-
performance and low-cost hydrogen energy through the
iteration of green hydrogen core technology
DH 动氢新能
DYNAMIC HYDROGEN

Slide 16 presents a comparative analysis of the performance of various membrane electrode assemblies (MEAs) with a focus on iridium (Ir) loading, a key factor in the cost and sustainability of Proton Exchange Membrane Water Electrolyzers (PEMWE).

The title suggests that "Dynamic Hydrogen" has achieved super-low iridium loading in their MEAs, indicating significant progress in their design strategy for cost-effective and efficient hydrogen production.

Here's a breakdown of the table and the key points:

- The table compares the performance characteristics of four different types of MEAs at a current density of 2A/cm², a common operational metric for these devices.

The key performance metrics compared include:

  - **Voltage**: The operational voltage required to achieve the specified current density, with lower values indicating higher efficiency.
  - **Iridium loading on the anode side (mg/cm²)**: The amount of iridium used in the catalyst layer on the anode side.
  - **Iridium loading on the cathode side (mg/cm²)**: The amount of iridium used on the cathode side.
  - **Membrane Thickness (µm)**: The thickness of the proton exchange membrane.
  - **Operation Temperature (°C)**: The temperature at which the MEA operates optimally.

- The MEA types listed include three with varying iridium loadings and one Anion Exchange Membrane (AEM) type with zero iridium loading.
- The slide highlights the "Advantages of DM," suggesting that the MEAs developed by Dynamic Hydrogen offer superior performance, particularly in reducing the voltage and iridium loading.
- The bottom of the slide has a statement which likely emphasizes the significance of Dynamic Hydrogen's achievements in developing advanced MEAs and their contribution to the PEM electrolyzer field.
- The statement is supported by bullet points that mention specific advantages, such as achieving operational voltages below 1.88V at a current density of 2A/cm² and significantly reducing the iridium loading to as low as 0.3 mg/cm² on the anode and 0.5 mg/cm² on the cathode.

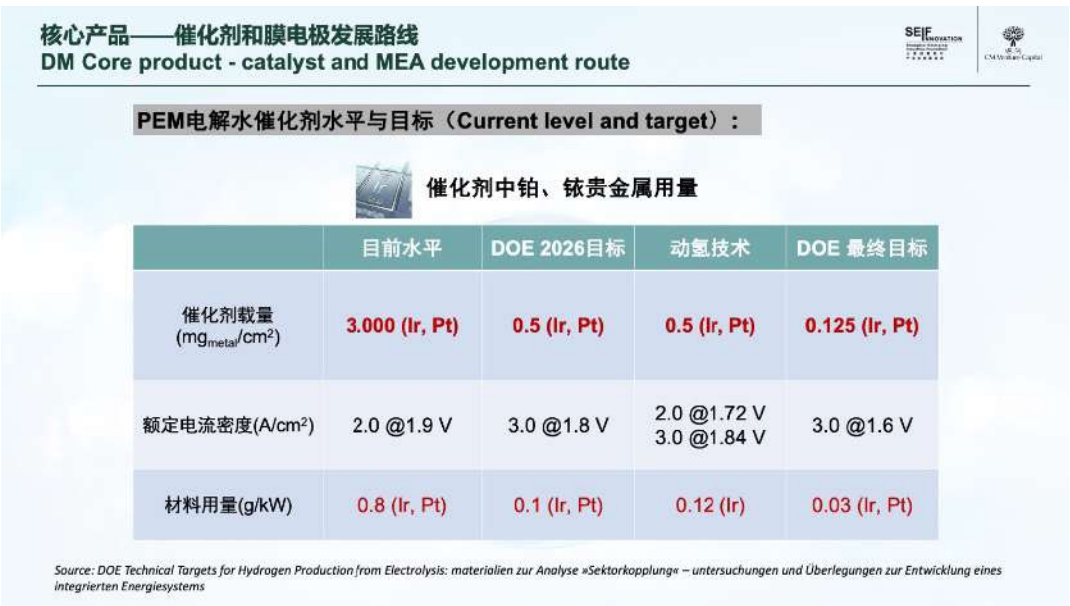
Overall, the slide positions Dynamic Hydrogen's MEAs as highly efficient and cost-effective due to their low iridium content, which can make hydrogen production more sustainable and commercially viable.

Slide 17 seems to detail the development route for Dynamic Hydrogen's core product: their catalyst and Membrane Electrode Assembly (MEA) for Proton Exchange Membrane Water Electrolyzers (PEMWE).

The slide includes several sections that cover different aspects of the product development:

- **Comparison Table**: There is a table that compares the iridium content in catalysts from different suppliers. The table lists the catalyst activity (at 1.55V) and the iridium loading in milligrams per gram of catalyst (mg/g). Dynamic Hydrogen's catalyst shows a significantly lower iridium content compared to other suppliers, which is highlighted in red.
- **Iridium Loading and Performance**: A graph and accompanying text likely discuss the reduction of iridium loading to 0.12 g Ir/kW, which is lower than the typical range of 0.5-0.75 g Ir/kW. This achievement points towards an improved catalyst with lower costs and potentially higher sustainability.
- **Product Images and Data**: The slide showcases images of the MEA and catalysts, along with performance data. This includes operational voltages, such as 1.846 V @ 3 A/cm² for PEM and 1.78 V @ 2 A/cm² for AEM, which are measures of the energy efficiency of the electrolyzer.
- **Durability Testing**: There are charts that show the durability of the MEA under operational conditions, indicating that the product can sustain a current density of 1 A/cm² for 1000 hours without significant loss of performance.
- **Novel Catalyst Development**: The slide also introduces a new catalyst designated as "DQ高活性催化剂-001" and "DQ无铱催化剂Ru-001," which likely signifies a high-activity catalyst and a ruthenium-based catalyst without iridium, respectively.
- **Key Features**: The text boxes highlight features such as rapid start-up times (less than 1 minute to reach stable operation) and low voltage increases over time (less than 200 mV after 40 hours of operation), which suggest quick activation and stable performance.
- **Bottom Text**: The bottom of the slide contains a statement that might summarize the performance goals for PEM electrolyzers and Dynamic Hydrogen's achievements in catalyst and MEA development.

Overall, this slide emphasizes the innovation in reducing iridium usage while maintaining or enhancing the performance and durability of MEAs for PEM electrolyzers. It positions Dynamic Hydrogen's products as competitive and forward-thinking in the field of hydrogen energy technology.



Slide 18 outlines the development goals for Proton Exchange Membrane (PEM) electrolyzers, specifically focusing on the catalyst and MEA (Membrane Electrode Assembly) development route with a comparison to the targets set by the U.S. Department of Energy (DOE) for 2026.

Key aspects of the slide include:

- **Iridium and Platinum Loading**: The "催化剂载量 (mg/metal/cm²)" row indicates the loading amount of iridium or platinum in the catalyst per square centimeter. The current level is at 3.000 mg/cm², with a DOE 2026 target of 0.5 mg/cm², and a further reduced ultimate target of 0.125 mg/cm².
- **Operational Current Density**: The "额定电流密度 (A/cm²)" row shows the current density at which the electrolyzer operates. The current operational level is at 2.0 A/cm² at 1.9V, with the DOE's 2026 target at 3.0 A/cm² at 1.8V, and an even higher performance goal at the same current density but a lower voltage of 1.72V and 1.6V respectively.
- **Catalyst Cost**: The "催化剂量 (g/KW)" row lists the amount of catalyst used per kilowatt of energy produced. The current cost is 0.8 g/KW, with a DOE target of 0.1 g/KW, and an ambitious goal to reduce this further to 0.03 g/KW.

This slide demonstrates the industry's push towards more efficient and less costly electrolyzers by reducing the amount of precious metals like iridium and platinum, lowering operational voltages, and therefore enhancing the overall sustainability and commercial viability of hydrogen production. The DOE targets are presented as benchmarks for the industry, guiding the development of new technologies that Dynamic Hydrogen aims to meet or exceed.

Slide 19 illustrates the research and development technology route for Dynamic Hydrogen's core products in the field of PEM electrolyzers, from catalyst research to volume production.

Here's a breakdown of the slide's key points:

- **Catalyst Research & Development**: This section emphasizes the innovation in catalyst technology, likely discussing the various elements that contribute to a catalyst's performance, such as activity, stability, and durability. This may include advancements in Oxygen Evolution Reaction (OER) catalysts.
- **MEA Control Technology**: The slide points to the development of Membrane Electrode Assembly (MEA) technology, focusing on optimizing the interface and interactions between the membrane and the catalyst. It suggests that the MEA design is tailored for efficient operation and longevity.
- **Volume Production**: The final stage involves scaling up the production of these advanced catalysts and MEAs. This includes establishing manufacturing processes that are both consistent and cost-effective, ensuring that the technology can be made available for wide-scale use.

The visual elements include:

- A diagram showing the integration of different components and technologies into the MEA.
- Images of MEA components and assembly.
- A flow from left to right that indicates the progression from research and development to mass production.

The bottom section of the slide contains a text box that likely lists various catalysts and technologies that are part of Dynamic Hydrogen's research and development process, possibly including advanced iridium-based catalysts, anion exchange membrane (AEM) technologies, and other proprietary materials or methods they have developed.

The rightmost part of the slide includes images of the production equipment and an explanation of how the MEA is integrated into a complete electrolyzer system, highlighting the practical application of the research and development work in producing hydrogen fuel.

Overall, the slide aims to demonstrate Dynamic Hydrogen's comprehensive approach to developing and manufacturing high-performance, cost-effective components for PEM electrolyzers.