Fuel the Future: QIBEBT's Clean Energy Breakthroughs

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Abstract: The Qingdao Institute of Bioenergy and Bioprocess Technology (QIBEBT), under the Chinese Academy of Sciences, has emerged as a leading force in clean energy research since its establishment in 2006. This article highlights QIBEBT's significant contributions across various clean energy domains, including biomass conversion, solar energy, hydrogen production, and energy storage. Key innovations include the hydrogenation processes for biofuel production, high-solid state anaerobic digestion for biogas, perovskite solar cell technology, proton exchange membrane fuel cell systems, and deep-sea solid-state energy storage solutions. These advancements demonstrate QIBEBT's commitment to addressing global energy challenges and supporting China's transition to a sustainable energy future. The institute's success is underpinned by its integrated approach, combining fundamental research with industrial applications and fostering collaborations between academia and industry.

Keywords: technology transfer, biomass conversion, solar energy, hydrogen production, energy storage

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As the global demand for clean, renewable energy continues to rise, the urgency to reduce carbon emissions and transition from fossil fuels to sustainable energy sources has become a critical priority. In response to these global challenges and China's need for technological innovation in green energy, the Qingdao Institute of Bioenergy and Bioprocess Technology (QIBEBT) under the Chinese Academy of Sciences (CAS) was established in 2006. It was jointly initiated by CAS, the Shandong Provincial Government, and the Qingdao Municipal Government to advance research and development in clean energy technologies.

QIBEBT operates with a mission to tackle the most pressing challenges in the fields of bioenergy, solar energy, hydrogen energy, energy storage, and bio-inspired

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energy. By focusing on strategic, foundational, and cutting-edge research, the institute aims to provide innovative solutions that meet both national and global clean energy needs. The institute's work spans the entire innovation chain—from fundamental scientific research to applied technology development—ensuring its findings lead to impactful, real-world applications.

On February 5, 2024, QIBEBT received the official approval to establish the Key Laboratory for Solar Energy Photoelectric Conversion and Utilization (CAS). This laboratory focuses on developing new theories, materials, and methods for the efficient and cost-effective conversion of solar energy. It aims to address challenges such as low solar conversion efficiency, poor material stability, and limited intelligent systems. The laboratory is working to advance key technologies like next-generation thin-film batteries and solar photoelectric-biological fusion while exploring disruptive innovations in solar energy conversion.

Notably, QIBEBT has developed a robust model for collaboration and technology transfer, characterized by "industry-driven challenges, scientific validation, collaborative problem-solving, and market acceptance". To date, QIBEBT has formed substantial partnerships with over 500 enterprises, including major players like Sinopec, PetroChina and State Energy Group. These collaborations, which include joint R&D, technology licensing, and technology transfer, have fostered deep integration of industry, academia and research.

By partnering with leading enterprises, the institute ensures that its innovations are closely aligned with industry needs. Researchers are required to work with businesses on practical challenges, ensuring that the solutions developed are both innovative and market-ready. This model has successfully accelerated the transfer of cutting-edge technologies to industry while providing companies with strong technical support and innovation capacity.

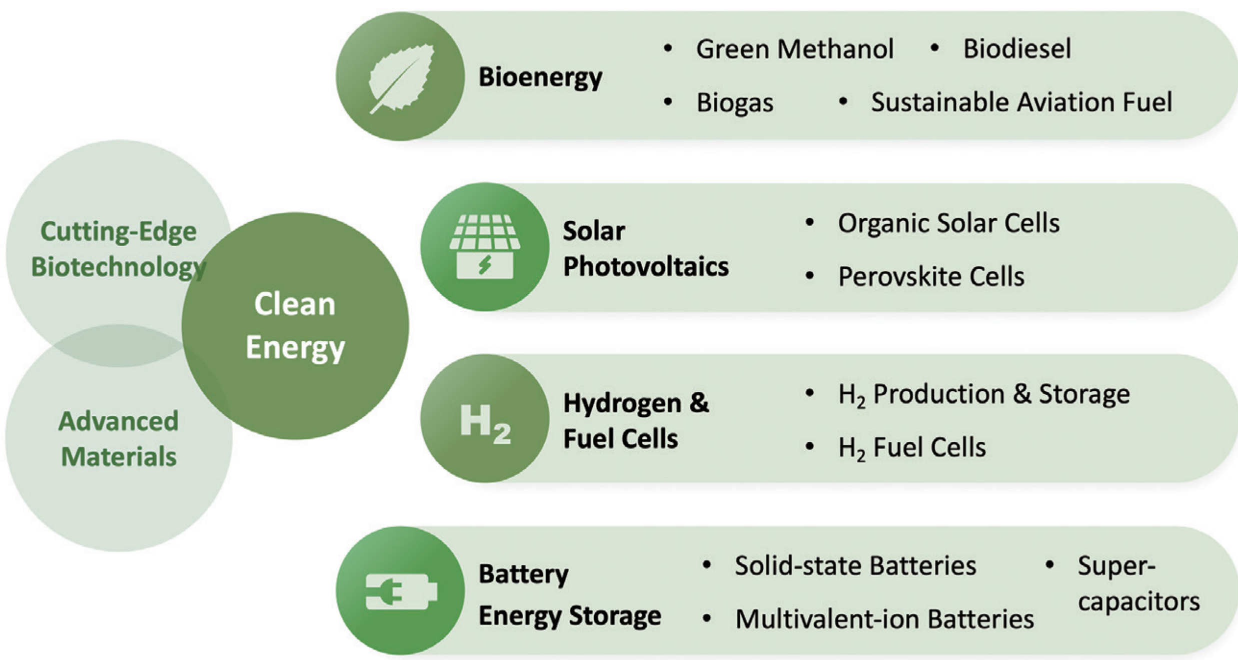
The institute's efforts have yielded several notable achievements, as outlined below.

Green Methanol from Biomass

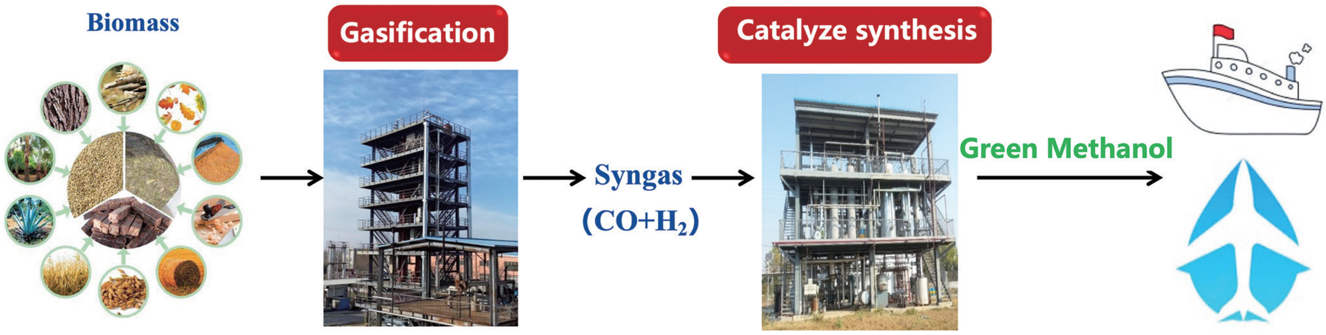
Green methanol can be used as a clean fuel to replace traditional fossil energy in the fields of transportation and industry. It is of great significance to promote China's industrial upgrading, cope with climate change and sustainable development, and meet China's carbon neutrality target. The development of green, efficient and low-cost methanol preparation technology is the key factor.

The gasification synthesis of biomass to methanol is recognized as one of the most important production methods of green methanol in the future. To further promote the industrialization of

Research layout of QIBEBT.



Graphic: YANG Xutong



Graphic: Dr. CHEN Tianju

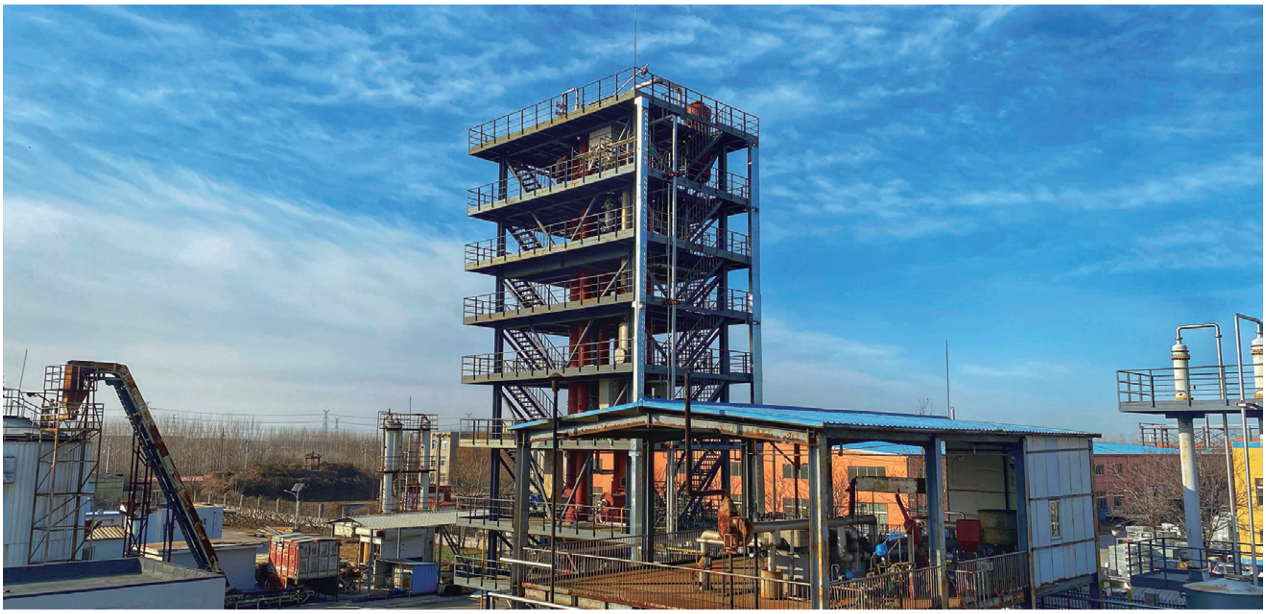
Pilot-scale experimental device for biomass chemical looping gasification at QIBEBT.

biomass gasification, scientists at the QIBEBT have developed a pilot-scale experimental device for chemical looping gasification (CLG), capable of processing 1,000 tons of biomass annually. The CLG process, which involves a gasifier reactor and an air reactor, utilizes an oxygen carrier to restore and transport lattice oxygen for partial oxidation of biomass into syngas. It is estimated that the device can produce up to 300 tons of green methanol annually.

Biomass raw materials represented by agriculture straw can be converted into green liquid fuel after gasification, which is one of the closest technical approaches to the traditional methanol manufacturing process. However, the application of this process has always been restricted by the immature biomass gasification technology and is difficult to promote. To solve the bottleneck problems of low biomass gasification efficiency and high tar content, researchers of the Thermochemical Conversion Group at QIBEBT, headed by Dr. WU Jinhu, have developed a new type of oxidation-reforming bifunctional oxygen carrier catalyst.

The efficient oxidation-reforming reaction is based on the bifunctional oxygen carrier catalyst NiO-Fe_2O_3/Al_2O_3, which includes Fe_2O_3 oxidation sites and NiO reforming sites. Syngas produced from biomass based on oxidation-reforming reactions has a

A 1,000-ton scale biomass chemical looping gasification pilot platform that produces green methanol.



Graphic: Dr. ZHANG Guoqiang

valid gas (CO, H_2) concentration of 80–85%. The valid gas yield of biomass gasification reached 1 Nm^3/kg, and the H_2/CO ratio was 1, which demonstrated that the inherent CO_2/H_2O, along with CH_4/tar species, were efficiently converted to H_2 and CO through oxidation-reforming reactions.

On January 11 and July 25, 2024, QIBEBT signed cooperation agreements on biomass CLG with the China Hydrogen Energy Co., Ltd. and the Guangdong Liquid Sunshine Green Energy Co., Ltd. respectively, which will promote the pilot-scale and industrial demonstration technology, accelerate the industrialization and commercialization of green methanol. This project is expected to build an annual output of 100,000 tons of green methanol production line in Shandong by the end of 2025, with an annual output value of about 500 million yuan, achieving near-zero carbon emissions in the methanol preparation process.

Biodiesel and SAF from Waste

In a good leap towards sustainable transportation, scientists at the QIBEBT have developed an innovative process for producing hydrocarbon-based biodiesel and sustainable aviation fuel (SAF) from waste oils and fats. This breakthrough, known as the ZKBH (an abbreviation of ZhongKe Biofuel Hydrogenation) process, effectively addresses critical challenges in the biofuel industry.

Despite the rapid progress in the electrification of common vehicles such as cars, subways, high-speed rails and bullet trains, liquid fuels, including diesel and jet fuels, are still required to drive heavy-duty vehicles and airplanes, respectively. The biofuel industry has long struggled with large-scale production of advanced fuels, such as the above-mentioned hydrocarbon-based or second-generation biodiesel, and SAF.

While waste materials like used cooking oil (UCO) are promising feedstocks, they present unique challenges. Chief among these are the high levels of impurities and the complex chemical compositions found in such waste materials because they could greatly impact the subsequent chemical reactions, and hence the biodiesel production.

The solid catalysts traditionally used in fixed-bed reactors are prone to degradation and deactivation in the reaction media. Additionally, pipeline blockages frequently occur at the high reaction temperature required for hydrogenation, leading to interruptions in production.

To overcome these limitations, a QIBEBT team led by Dr. CHEN Song developed a coupling process of suspended-bed and fixed-bed hydrogenation for second-generation biodiesel production, also named the ZKBH process, in 2020.

The key to the ZKBH process is the novel high-efficiency liquid catalysts employed for the homogeneous hydrogenation in suspended-bed reactor to dispose feedstock with high impurity, instead of solid catalysts traditionally used in fixed-bed reactor patented by several countries that had owned second-generation biodiesel technology including Finland, Italy, the United States, Denmark, and Brazil. The specific innovative liquid catalysis can ensure the stable running and high productivity of operational units. More importantly, the ZKBH process does not require pretreatment prior to hydrogenation.

The team has applied the ZKBH process to an industrial unit with the capacity of 200,000 t/a in Shijiazhuang, Hebei province in 2020. This waste-to-biodiesel process can be tailored to produce biodiesel, SAF, or both at the same time. It efficiently converts low-grade food waste oils and fats into high-value fuels, demonstrating outstanding flexibility and feedstock versatility.

This technology was further applied in commercial units in Dongying, Shandong province in 2022 and Longyan, Fujian province in 2023, respectively.

"The ZKBH process has reached the international advanced level, and further promotion and demonstration are strongly recommended," concluded an expertise evaluation panel organized by the China Petroleum and Chemical Industry Federation (CPCIF).

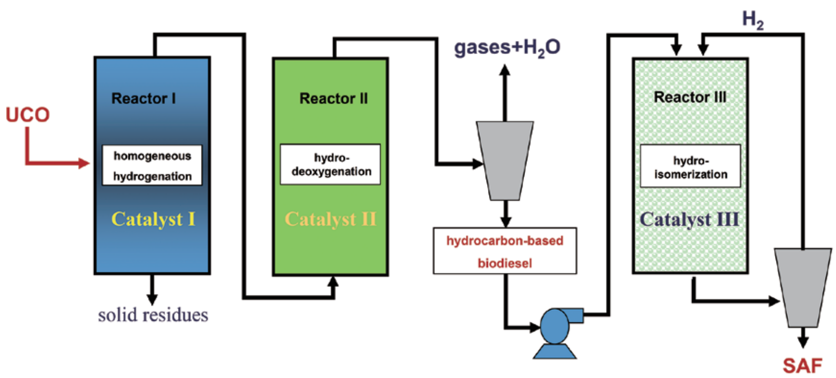
The biodiesel products have also been exported to the European Union after they were tested to meet British Standard (SB) EN 15940:2016, a European Standard that specifies the requirements and test methods for paraffinic diesel fuels from synthesis or hydrotreatment. This affordable and applicable biodiesel production system is the first technology to commercially produce second-generation biodiesel using liquid molecular catalysts in the world.

The ZKBH coupling hydrogenation process to produce second-generation biodiesel was also recommended by All-China Environment Federation (ACEF) as the "Belt and Road" Ecological Environment Governance Technologies and Products in 2022. As a patented state-of-the-art hydrocarbon-based biodiesel/SAF technology, ZKBH process addresses problems of existing industrial counterparts at home and abroad.

This waste-to-biodiesel process

Graphic: Dr. CHEN Song

The ZKBH operational units for producing hydrocarbon-based biodiesel in Shijiazhuang, Hebei.



Graphic: Dr. XIN Hongchuan

Scheme for the ZKBH processes for producing hydrocarbon-based biodiesel or/and SAF.

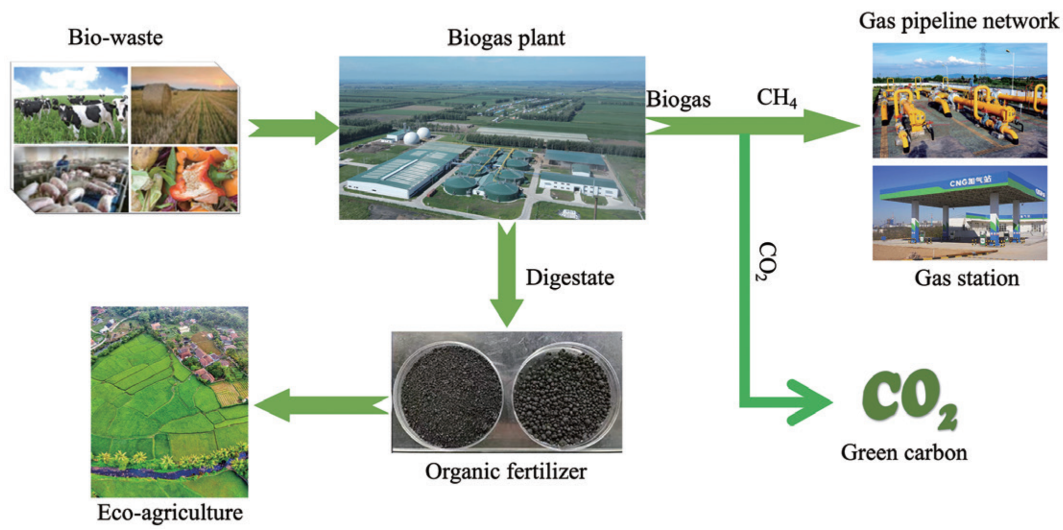
can be configured to produce either biodiesel or SAF exclusively, or both simultaneously. It effectively transforms low-quality food waste oils and fats into valuable fuels via hydrodeoxygenation or/and hydroisomerization, showcasing exceptional operational flexibility and feedstock compatibility while offering substantial social, environmental and economic benefits.

Biogas from Residues

Biogas technology utilizes agricultural straw, livestock manure, food waste or other biomass waste to produce biomethane and organic fertilizer through anaerobic digestion, making it a typical zero-carbon bioenergy technology. This plays an important role in China's efforts to achieve carbon neutrality. However, traditional biogas technology relies on low-concentration fermentation, which is mainly suitable for livestock waste. It struggles to address issues like scum crusting during fermentation, resulting in low efficiency and challenges in maintaining continuous operation, which limits the development of biogas industry.

To address these challenges, scientists from QIBEBT have made a breakthrough in biogas industrialization technology, facilitating the implementation of over 10 large-scale biogas projects. These initiatives have delivered substantial benefits to local regions.

With over a decade of effort, the Industrial Biogas Research Center, led by Dr. GUO Rongbo, has developed a high-solid state anaerobic digestion integrated reactor technology that effectively resolves the problem of straw dross encrustation. Compared with the traditional low-concentration fermentation technology, this new approach doubles both the fermentation concentration and gas production volume, greatly improves the efficiency of biogas engineering. Meanwhile, the research team has created skid mounting equipment for biogas upgrading and a closed vertical cascade composting reactor for producing fertilizer from digestate, establishing a complete tech-



Graphic: ZHAO Yuzhong

The industry chain and beneficial effects of a biogas plant.

Graphic: Dr. GUO Rongbo

The high-solid state anaerobic digestion Biogas Project for a large dairy plant in Gannan, Heilongjiang.

Graphic: Dr. GUO Rongbo

The multi-stage biomimetic solid-state anaerobic digestion industrialization demonstration project in cooperation with the China General Nuclear Power Group (Xing'an League, Inner Mongolia).

nical chain for the high-solid state anaerobic digestion industry.

Till now, the research team has promoted more than 10 large-scale biogas projects across provinces such as Heilongjiang, Shandong and Jiangsu. Among these is the large-scale dairy biogas industrial cluster project in Qiqihar city of Heilongjiang province, which produces 42 million cubic meters of biogas annually, making it the largest project of its kind in northeast China. It is also the first biomethane project to operate successfully in the region's cold climate. Additionally, the Gannan project earned zero-carbon energy certification in September 2024, showcasing significant demonstration benefits.

To continue advancing this technology, the research group has recently developed a multi-stage biomimetic solid-state anaerobic digestion approach using modular equipment. This innovation is highly conducive to industrial promotion, expanding the scope of usable substrates and improving fermentation efficiency. At present, the related industrialization demonstration has been carried out in Inner Mongolia Autonomous Region and Hebei province, in cooperation with the China General

Nuclear Power Group and the ENN Group, respectively. It is expected to become the next-generation technology leading the development of China's biogas industry.

Perovskite Solar Cells

Perovskite solar cells (PSCs) have garnered considerable attention from the academic and industrial sectors due to their ease of fabrication using a solution process. The quality of perovskite films, which act as light absorbers, is crucial to device performance. Typically, solution-processed perovskite polycrystalline films tend to exhibit pronounced roughness and pinhole structures, leading to much lower efficiencies in large modules compared to small-area devices. As a result, producing high-quality, uniform perovskite films on a large scale remains a major obstacle to PSC commercialization.

Scientists at QIBEBT have identified a novel chemical interaction between methylamine gas (MA_0) and MA-based perovskite. This interaction entails a reversible adsorption-desorption process of MA_0 within the perovskite film. Specifically, exposure of MA-based perovskite to MA_0 triggers a reaction that creates a fluid phase. When MA_0 is removed, the gas rapidly desorbs from this fluid at room temperature, regenerating a new perovskite film. Building on this finding, the research team has introduced a pioneering approach for post-healing perovskite films using MA_0 technology.

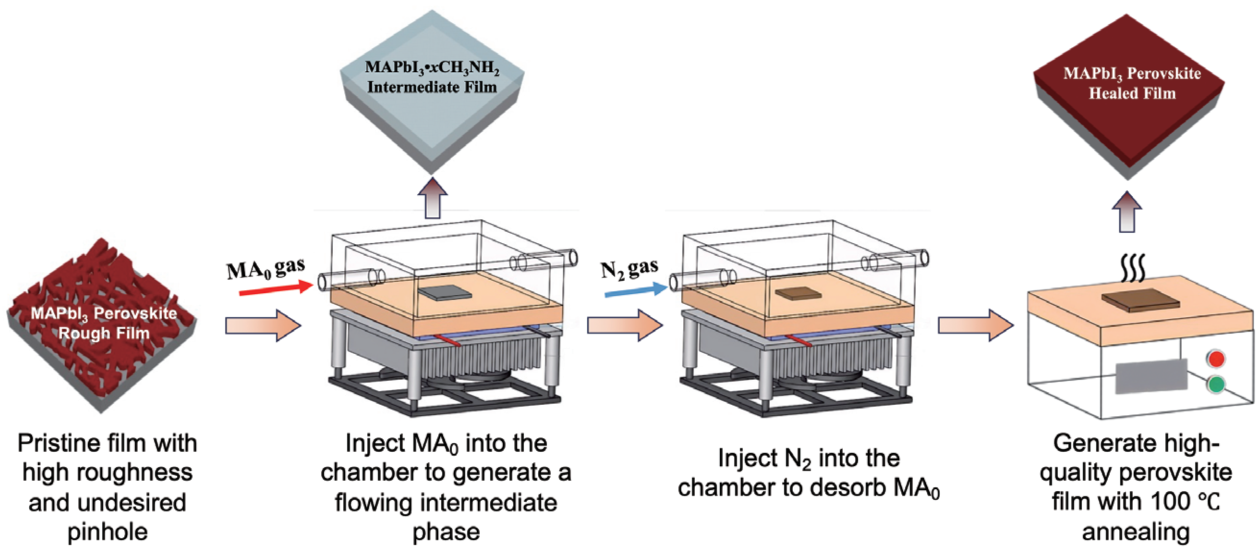
Using this new approach, researchers can transform low-quality perovskite films into high-quality ones in just a few seconds. The resulting films show enhanced crystallinity, greater uniformity, and significantly reduced surface roughness and defects, enhancing carrier transport and boosting the overall efficiency of photovoltaic devices.

This technology has been featured in the Editor's Choice section of *Science* and is recognized as an effective solution to the challenge of ensuring consistency in large-area perovskite films.

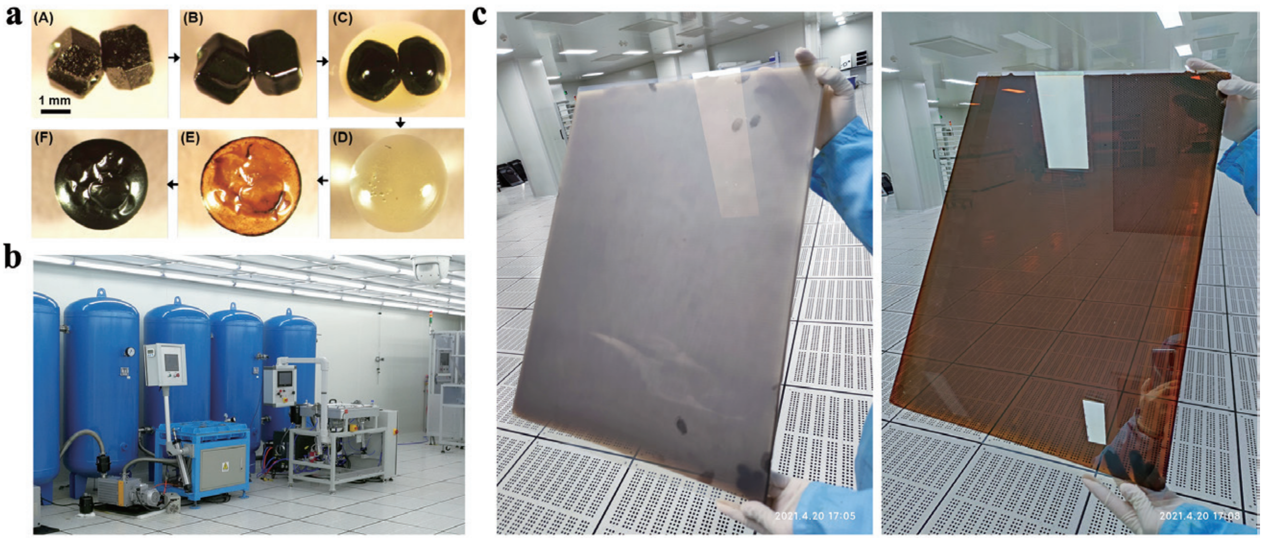
The group has partnered with the Xiamen Weihua Solar Energy Co., Ltd. to successfully develop an automated gas post-healing equipment. This technology, demonstrated to be compatible with slot-die coating, facilitates the production of high-quality, large-area perovskite films that meet photovoltaic performance standards for modules. Importantly, this technology is versatile and can be used with various substrate materials and dimensions, allowing for continuous production of large-area perovskite films.

This breakthrough technology addresses the challenges of producing perovskite films with high uniformity and consistency. Post-gas treatments, such as MA_0 for CsMA-based perovskites and the newly developed NH_3 for FA-based perovskites, have been formulated for various perovskite compositions. The post-healing technique provides easy-to-use equipment, user-friendly operation, and scalability, which are expected to accelerate the industrial development of PSCs.

Scheme for the key technologies and deep-sea applications of solid-state lithium ion batteries at QIBEBT.



Graphic: Dr. CUI Guanglei's lab



(a) *In situ* optical microscopy observed the morphological evolution of two contacting $MAPbI_3$ perovskite crystals during the adsorption and desorption of methylammonium gas. (b) Gas post-healing equipment. (c) Optical photos of perovskite films before and after post-healing.

Ion Conducting Ceramic Membranes for Stable Hydrogen Production

Hydrogen has attracted much attention due to its potential as a clean energy carrier. To date, most hydrogen is produced from fossil fuels, such as natural gas, coal and oil. Such fossil-derived hydrogen must be purified from common contaminants like CO_2, CH_4, CO, and H_2S before it can be used in fuel cells.

Fossil-derived hydrogen-assisted water splitting using dense oxygen-ion-conducting ceramic membranes is a promising technique for hydrogen purification. These membranes have 100% oxygen selectivity, allowing for the direct extraction of pure hydrogen. However, existing oxygen-conducting membranes suffer from chemical stability issues under harsh operating conditions during purification.

Researchers at QIBEBT have developed a new approach called "interface-reaction-induced reassembly" to fabricate multilayered ceramic membranes with ceria-based thin films for stable hydrogen production.

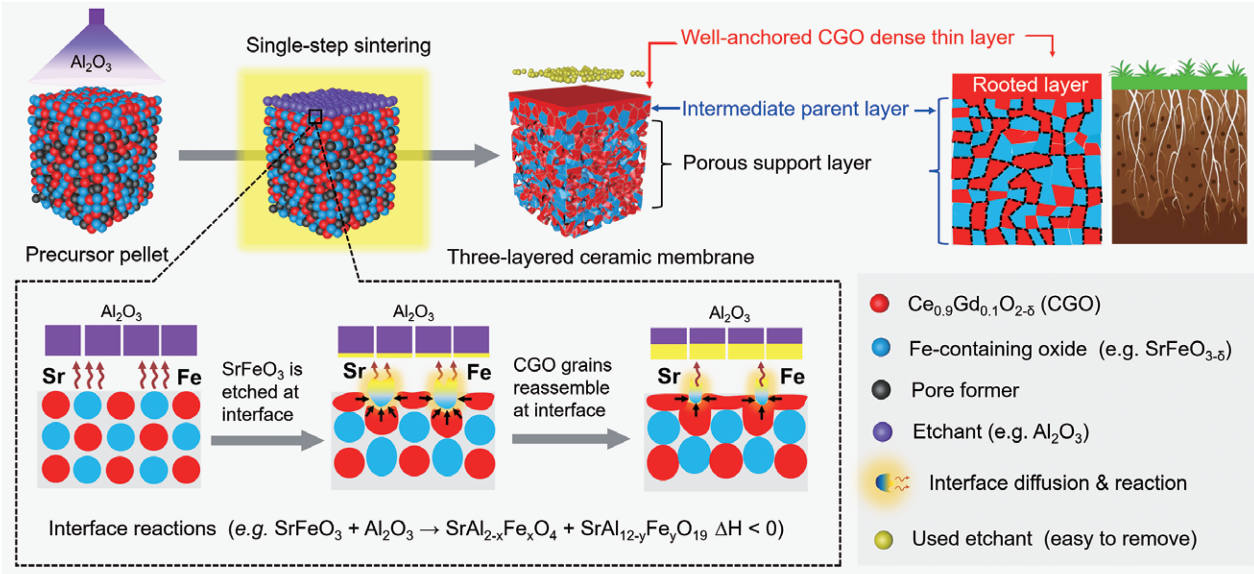
"Multilayered ceramic membranes are typically made using layer-by-layer deposition methods. However, these methods often require a serial procedure, and the thickness of the dense thin layers is commonly in the range of 10–1000 μm. In addition, the deposited thin layers often delaminate from the support layers during co-sintering," explained Professor JIANG Heqing, director of the Center of Functional Membrane and Hydrogen Energy Technology of QIBEBT.

Inspired by the structure of rooted grasses in soil, the researchers developed an interface-reaction-induced reassembly approach to create a three-layered ceramic membrane. In this design, the oxygen-conducting dense thin layer is integrated into its parent layer, achieved through a single-step sintering of dual-phase ceramic precursors.

"In this new approach, by deliberately applying an appropriate etchant (Al_2O_3), we selectively etched the surface Fe-containing grains in the pressed pellet through interface reactions at high temperatures," said Professor HE Guanghu from QIBEBT. "The heat generated increases the local temperature, driving the reassembly of the surface-isolated fluorite-type grains into a dense thin layer that prevents interface reactions, thus avoiding continuous growth of the thin layer."

Using this innovative approach, the researchers found that the resulting ceria-based layers were extremely thin (about 1 μm), highly dense, and strongly adhered to the parent layers. This not only significantly reduced ionic transport resistance but also ensured the structural integrity of the multilayered membranes for various applications.

The researchers demonstrated hydrogen production from



Graphic: HE Guanghu

Schematic of multi-layered ceramic membrane fabrication with an ion-conducting dense layer via interface-reaction-induced reassembly.

water splitting, assisted by the oxidation of simulated coke oven gas containing H_2, CH_4, CO_2, CO, and H_2S, using the developed multilayered membrane. They found that the membrane with a $Ce_{0.9}Gd_{0.1}O_{2-\delta}$ (CGO) dense thin layer exhibited impressive durability (>1000 hours), highlighting the potential of high-performance membrane reactors for hydrogen production under practical conditions.

The high-performance oxygen-ion-conducting membrane developed through this approach is expected to support industrial by-product hydrogen purification, solid oxide fuel cells, electrolytic cells, and oxygen sensors. It also offers a new strategy for creating other high-performance multilayer ceramics with functional thin layers. The related patent has been authorized by the China National Intellectual Property Administration (ZL202210044306.1), and a patent has also been applied for at the European Union Intellectual Property Office (PCT/CN2022/091517).

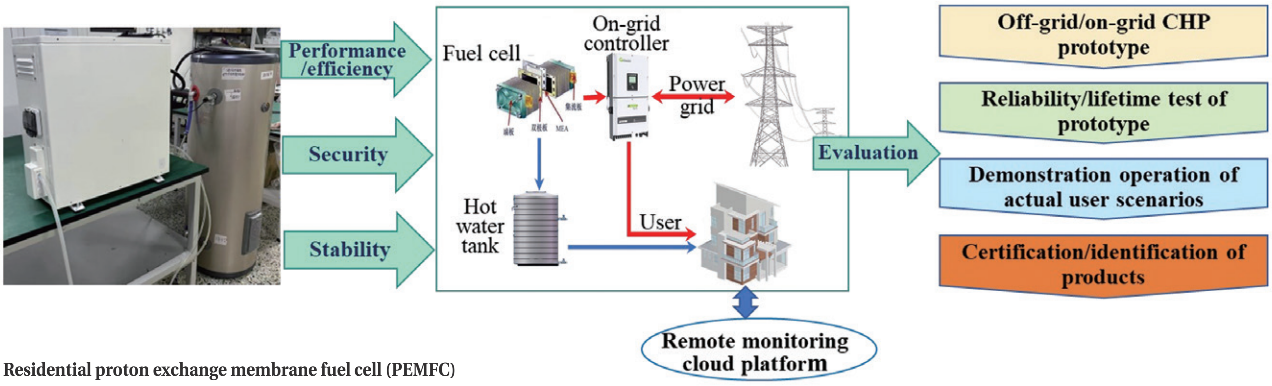
Proton Exchange Membrane Fuel Cell Cogeneration System

In a good leap towards high-efficiency hydrogen-to-electricity conversion system, scientists at QIBEBT have developed an innovative technology for residential proton exchange membrane fuel cell (PEMFC) cogeneration system. This system converts hydrogen and oxygen directly into electricity and heat, maximizing energy utilization. Meanwhile, the PEMFC cogeneration system achieves net-zero emissions, effectively addressing carbon emissions.

The annual "operational carbon emissions" from residential and public buildings in China amount to 2.1 billion tons, accounting for approximately 20% of total carbon emissions. For building power supply, heating, and cooling, promoting fuel cell cogeneration technology and multi-energy collaboration will effectively help achieve the dual carbon goal. In addition to the need for further improvements in the performance of key components, there is an urgent need to address the challenges of rapid allocation of thermal power supply and demand, the demand for high power of the system, and collaboration with renewable energy systems.

Water management is a major bottleneck in proton exchange membrane fuel cells. Self-humidified fuel cells adopt non-flowing drainage technology, which can effectively solve this bottleneck problem while offering significant technical advantages in parasitic power consumption, lifespan, and cost.

Traditional fuel cells require gas recirculation pumps and active water separators, which further increase system parasitic power consumption and stack volume,



Graphic: Dr. LI Xiaojin

Residential proton exchange membrane fuel cell (PEMFC) cogeneration system.

making the overall efficiency of PEMFC cogeneration systems unsatisfactory, especially in adapting to pipeline hydrogen supply and low-pressure fuel cell stacks, which face great challenges.

In order to overcome these difficulties, the QIBEBT Fuel Cell Engineering Research Center, led by Dr. LI Xiaojin and supported by the National Key Research and Development Plan Project, has developed, for the first time in China, a low hydrogen pressure fuel cell stack with adaptive pipeline hydrogen supply system and low-power dissipation fuel cell cogeneration system, achieving a cogeneration efficiency of 91.2% and reaching the international advanced level. Based on the Key Research and Development Plan Project of Shandong Province, the development of a 40kW graphite bipolar plate fuel cell has been completed through the molded bipolar plate stack design, assembly and optimization of operating conditions. It has passed the CANS certification check of China Automotive Research and Development Corporation, and its main technical indicators have reached the leading level in China. The team has completed the batch preparation process of molded graphite bipolar plates and developed a pilot production line with an annual output of 100,000 pieces.

The fuel cell cogeneration system can be applied in buildings such as residential areas, industrial parks, and shopping malls to enhance energy conservation and reduce carbon emissions. It can also be used for emergency power supply in banks, data centers, hospitals, and other places. The research team has reached an agreement with the Shandong Chambroad Petrochemicals Co., Ltd in Binzhou to demonstrate the application of fuel cell cogeneration system, and plans to showcase 100 residential fuel cell cogeneration units by 2025. Local governments and parks in Qingdao, Dezhou and other places have also expressed clear intentions for future cooperation.

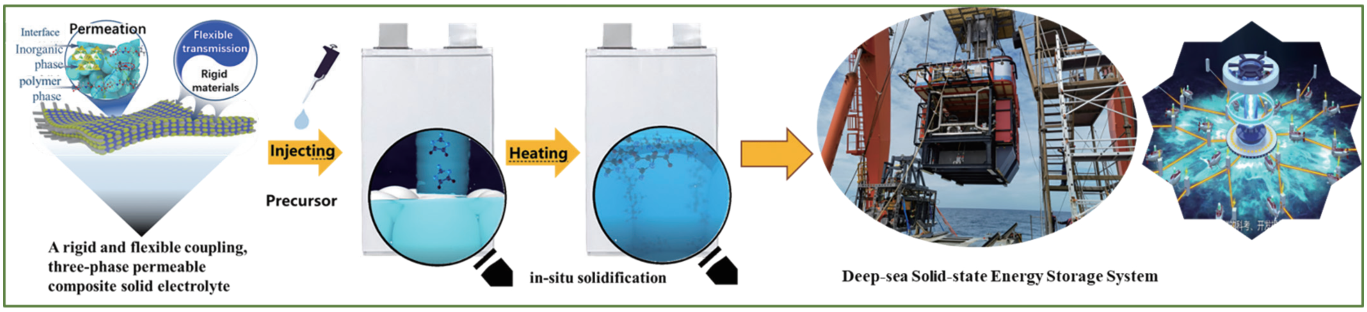
With advancement in technology and cost reductions, the performance of PEMFC cogeneration systems will continue to improve, while costs will decrease, thereby enhancing their market competitiveness.

Deep-sea Solid-state Energy Storage

Underwater equipment, an essential facility for accessing and studying deep sea, provides crucial technical support for developing and utilizing marine resources, playing a key role in advancing China's marine strategy and building a strong maritime nation. However, due to limitations in deep-sea energy supply, underwater equipment faces huge challenges, such as limited operational capability and short endurance, which hinder their ability to function long-term under complex conditions.

At QIBEBT, polymer/inorganic composite solid-state electrolytes are being used in solid-state lithium-ion batteries, replacing the commercially available liquid electrolytes that rely on flammable carbonate solvents with low flash points. These solid-state electrolytes offer key advantages, including high energy density, enhanced safety, and the ability to withstand deep-sea pressures, making them an ideal solution for deep-sea power sources.

Dr. CUI Guanglei and his team from the Solid Energy System Technology Center of QIBEBT have proposed the innovative design concept of a rigid and flexible coupling, three-phase permeable composite solid electrolyte. They have pioneered *in-situ* polymerization solid interface fusion technology, enabling solid-state lithium batteries with both high energy



Graphic: Dr. PENG Cheng

Schematic diagram of post-healing perovskite films with MA_0.

density and high safety. This has led to the creation of the world's first deep-sea energy storage system with megawatt-hour capacity, providing a sustainable and robust power source for the deep-sea *in-situ* experimental station of CAS. These breakthroughs in deep-sea technology redefine underwater energy supply for deep-sea equipment and significantly strengthen national maritime security and maritime rights protection.

Graphic: Dr. CUI Guanglei's lab

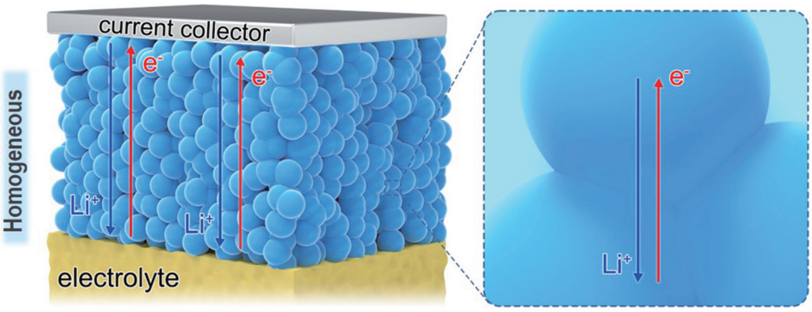
The first deep-sea energy storage system with megawatt-hour capacity are being employed for deep-sea operation.

"Since 2009, we have focused on solid-state batteries for over fifteen years. To date, we have discovered a new system of rigid and flexible coupling, three-phase permeable composite solid-state electrolytes, and innovated core technologies like *in-situ* solidification, which is suitable for conventional engineering preparation," said Dr. CUI. "We have also resolved the two major bottlenecks—the shortage of key material and the solid/solid interface contact issue—that have long plagued the development of solid-state lithium batteries. As a result, we have successfully engineered multi-generation solid-state lithium batteries with pronounced characteristics such as high energy density, high safety and deep-sea pressurization."

Since 2015, CUI's team has focused on the energy supply demands of deep-sea equipment. For nearly 10 years, they have been deeply engaged in developing deep-sea power systems and have successfully created over 110 batches of specialized deep-sea energy systems, all of which have been proven to withstand the harsh conditions of the deep sea. By 2022, they built the first deep-sea energy storage system with megawatt-hour capacity, which has been successfully operating for over 7 months under the deep sea.

Now, with the support of the National Key Research and Development Plan, the team is confident of developing a 500Wh/kg solid-state battery to provide a lighter deep-sea power source for next-generation deep-sea equipment, continuously supplying underwater energy and power for the construction of a national maritime power.

In 2024, Dr. CUI proposed a novel cathode homogenization strategy to enable long-cycle-life all-solid-state lithium batteries (*Nature Energy*, 2024. doi:10.1038/s41560-024-01596-6). This strategy effectively addresses challenges related to material energy-level mismatches and significantly improves the overall performance



Graphic: Dr. CUI Guanglei's lab

A cathode homogenization strategy for enabling long-cycle-life all-solid-state lithium batteries.

of all-solid-state lithium batteries. He also utilized a fusion bonding technique to create an ultra-thin sulfide solid electrolyte film with excellent flexibility using a new solvent-free manufacturing process (*Advanced Materials*, 2024. doi:10.1002/adma.202401909). This innovative approach has the potential to advance the commercialization of sulfide all-solid-state batteries and provide valuable guidance for developing stable, high-performance batteries.

Outlook

Looking ahead, QIBEBT will continue its mission to support the construction of a new national energy system and help achieving the dualcarbon goals. The institute will adhere to the concept of "four integrations"—integrating basic research with applied research, talent cultivation with outcome production, innovation-driven development with demand-driven traction, and national strategy with regional development.

The institute aims to develop complementary new energy technologies and large-scale energy application methods, create technologies for integrating new energy sources with fossil fuels, and establish an extended energy big data platform that combines data from energy systems with economic, social, environmental, and technological systems. QIBEBT will also seek to develop artificial intelligence-driven new energy technologies in four key areas: solar energy, biomass energy, hydrogen and fuel cells, and energy storage.

Through these efforts, QIBEBT will enhance its capacity to support high-quality development in the Yellow River basin, facilitate the transition from old to new sources of economic growth, and contribute to the creation of a pilot zone for green and low-carbon high-quality development.