浦 江 创 新 观 察

Pujiang Innovation Observation

2024-27

2024-27

（总第 27 期）

(Issue 27 overall)

上海浦江创新论坛中心 2024 年 9 月 11 日

Shanghai Pujiang Innovation Forum Center September 11, 2024

编者按：2024浦江创新论坛——未来能源论坛以"推动未来能源技术革命 加快绿色低碳转型发展"为主题，来自国内外知名专家学者围绕未来能源技术创新的最新研究成果与实践展开深入研讨。本期专报对未来能源论坛嘉宾观点进行梳理，供参考。

Editor's note: With the theme of "Promoting Technology Revolution of Future Energy Accelerating Green and Low-carbon Transition and Development", the 2024 Pujiang Innovation Forum – Future Energy Forum invited renowned experts and scholars from home and abroad to conduct in-depth discussions on the latest research results and practices of future energy technology innovation. This special report synthesizes the viewpoints of the guests at the Future Energy Forum for your information.

2024 浦江创新论坛专报之二十

Special Report 20 of the 2024 Pujiang Innovation Forum

未来能源技术革命　赋能绿色低碳转型新纪元

Revolutionize Future Energy Technology, and Enable the Transition Toward Green and Low-carbon Development in the New Era

未来能源是赢得新一轮科技革命和产业变革先机的关键，积极发展清洁能源，推动经济社会绿色低碳转型，为中国式现代化建设提供安全可靠的能源保障，为共建清洁美丽的世界作出更大贡献。**与会嘉宾一致认为，以创新驱动、经济可行、安全支撑为导向的未来能源技术发展将为创新发展注入新活力，要准确把握全球未来能源发展趋势，加强未来能源科技创新和国际合作交流，开辟未来能源新赛道。**

Future energy is the key to winning the opportunity of a new round of technological revolution and industrial transformation. We should actively develop clean energy, promote the green and low-carbon transition of the economy and society, a secure and reliable energy guarantee for the construction of Chinese modernization, and make greater contributions to jointly building a clean and beautiful world. **The guests present unanimously agreed that the development of future energy technology that is driven**

by innovation, economically feasible, and supported by security will inject new vitality into innovative development. We should have an accurate understanding of the global trend of future energy development, strengthen future energy technology innovation and international cooperation and exchanges, and open up new arenas for future energy.

一、未来能源技术发展最新趋势

1. The latest trends of future energy technology development

一是能源结构聚焦在氢能、绿色燃料、未来核心三方面的创新突破。在氢能方面，中国科学院院士包信和指出，碱性电解水制氢已实现商业化应用，如车规级氢能、波动性可再生能源中，质子交换膜电解水制氢已显现优势，国际上 PEM 电解槽已开展部分商用，固体氧化物电解水制氢技术已达样机示范运行状态，成为欧美多国的研发重点。**西门子能源发电集团中国战略项目执行总监 Michael Moeller** 认为，燃气轮机中的氢气燃烧能够实现二氧化碳零排放放电，同时弥补可再生能源波动性。**在绿色燃料方面，中国工程院院士黄震**提出，电解水制氢和空气中的氮气来制绿氨、二氧化碳加氢制甲醇，以及二氧化碳电催化制绿色燃料是未来的发展方向。**中国科学院上海高等研究院副院长魏伟**提出，生物质发酵或气化制备绿色甲醇和可持续航空燃料，已处于部分商业化生产建设阶段，但大部分仍处于研究示范阶段。可再

生绿电取代二氧化碳、氮气和水反应合成绿色燃料，将促进能源结构优化和新产业兴起。**在未来核电方面，中国能源建设有限公司首席科学家罗必雄**认为，2035 年前可实现商用快堆，未来在先进反应堆、先进材料、先进后处理等技术方面要重点突破，如熔盐净化、锕系分离与纯化等。

Firstly, the energy structure focuses on innovative breakthroughs in hydrogen energy, green fuels, and future nuclear power. In terms of hydrogen energy, **Bao Xinhe, Member of the Chinese Academy of Sciences,** pointed out that the production of hydrogen from alkaline electrolyzed water has achieved commercial application. For example, in automotive-grade hydrogen energy and fluctuating renewable energy, proton exchange membrane electrolyzed water hydrogen production has shown advantages. Internationally, PEM electrolyzers have been partially commercially used, and solid oxide electrolyzed water hydrogen production technology has reached the state of prototype demonstration operation, becoming the focus of research and development in Europe and the United States. **Michael Moeller, Executive Director of Strategic Projects in China, Siemens Energy,** believes that hydrogen combustion in gas turbines can achieve zero emission discharge of carbon dioxide while compensating for the fluctuation of renewable energy. In terms of green fuels, **Huang Zhen, Member of the Chinese Academy of**

Engineering, proposed that future development directions include producing green ammonia by mixing the nitrogen in the air and the hydrogen produced from electrolyzed water, producing methanol through carbon dioxide hydrogenation, and producing green fuels through electrocatalysis of carbon dioxide. **Wei Wei, Vice President of the Shanghai Advanced Research Institute at the Chinese Academy of Sciences,** proposed that the production of green methanol and sustainable aviation fuels from biomass fermentation or gasification has been in the stage of partial commercial production and construction, but most are still in the stage of research and demonstration. Replacing carbon dioxide with renewable green electricity, and synthesizing green fuels by reaction of nitrogen and water, will promote energy structure optimization and the rise of new industries. In terms of future nuclear power, **Luo Bixiong, Chief Scientist of China Energy Engineering Corporation Limited,** believes that commercial fast reactors can be achieved before 2035. In the future, key breakthroughs should be made in technologies including advanced reactors, advanced materials, and advanced post-treatment, such as molten salt purification, and actinide separation and purification.

二是能动技术创新呈现出多路线并行的发展趋势。中核集团首席科学家刘永提出，世界主要国家战略均聚焦于本世纪中叶实现聚变能商用，我国可控核聚变正转入工程验证（实验堆）阶段。

但目前仍面临燃烧等离子体稳态自持运行、耐高能中子轰击及高热复合材料、氚增殖与自持循环三大科技挑战，以及强场高温超导磁体、等离子体运行与控制、热量传导三大工程难题。**黄震**对未来船海绿动提出了展望指出，短距离摆渡船、小型船可利用氢能；吨位较高的内河航运、沿海短途船舶可利用电驱动；远距离万千瓦的发动机可利用绿色燃料，以及传统的柴油发动机需叠加碳捕捉系统。

Secondly, power and energy technological innovation has exhibited the trend of development through parallel multiple routes. Liu Yong, Chief Scientist of China National Nuclear Corporation, proposed that all the strategies of major countries worldwide focus on achieving commercial use of fusion energy by the middle of this century, and China's controllable nuclear fusion is entering the stage of engineering verification (experimental reactor).However, currently there are three major technological challenges: steady-state self-sustaining operation of combustion plasma, high-energy-resistant neutron bombardment and high-heat composite materials, and tritium breeding and self-sustaining circulation; as well as three major engineering challenges: strong-field high-temperature superconducting magnets, plasma operation and control, and heat conduction. **Huang Zhen** put forward a prospect for future green power for ship engineering and ocean engineering, and pointed out that short-distance ferries and small ships can use hydrogen energy; that inland waterway transportation and coastal short-distance vessels with a higher tonnage can use electric propulsion; and that long-distance engines with a capacity of 10,000 kilowatts can use green fuels, while traditional diesel engines require the addition of carbon capture systems.

三是能源储存创新多元化技术路径并举。罗必雄指出，我国主要压缩空气储能技术路线为零碳排放的非补燃式压缩空气储能系统，未来压缩空气储能技术将向单机更大（600-1000MW）、更高效（70-75%电-电转换率）、更长时间（跨日到跨月的持续放电时间）、更灵活（液化压缩空气储能、液化二氧化碳压缩储能）等方向发展。**黄震**提出，零碳电力制氢和合成燃料，既提供了绿色燃料，又是一种新型储能方式，可以实现跨季节、大规模的广域共享。

Thirdly, innovative and diversified technological paths for energy storage should be pursued simultaneously. Luo Bixiong pointed out that China's main compressed air energy storage technology route is zero carbon emission non-supplementary combustion compressed air energy storage systems. In the future, compressed air energy storage technology will develop towards larger single units (600-1000MW), higher efficiency (70-75% electricity-to-electricity conversion rate), longer duration (continuous discharge time from across days to cross months), and more flexible (liquefied compressed air energy storage, and liquefied carbon dioxide compression energy storage). **Huang Zhen** proposed that zero carbon electricity for hydrogen production and synthetic fuel not only provides green fuel, but also it is a new type of energy storage method that can achieve cross-seasonal and large-scale wide area sharing.

四是能碳捕用开展经济可行的技术路径探索。包信和认为二氧化碳转化利用（CCUS）的可能途径包括光化学过程、热催化过程和电催化过程。其中，中高温质子膜电解器实现二氧化碳和水共电解制得的 CO，与绿氢结合制合成气，实现煤化工和 CO2 转化过程零排放是现阶段可行的技术路径。

Fourthly, carbon dioxide capture, utilization, and sequestration (CCUS) should be explored through economically feasible technological paths. Bao Xinhe believes that the possible paths for carbon dioxide capture, utilization, and sequestration (CCUS) include photochemical processes, thermal catalytic processes, and electrocatalytic processes. Among them, CO produced by co-electrolysis of carbon dioxide and water using the medium- and high-temperature proton membrane electrolyzer, which is combined with green hydrogen to produce synthesis gas, and achieving zero emissions in coal chemical and CO2 conversion processes, are feasible technical paths at present.

二、研发成果转化重点关注各技术路线的经济可行，强调安全可控

2. The transformation of research and development achievements focuses on the economic feasibility of various technological routes, emphasizing safety and controllability

一是关注收益是否可观并利于推广。魏伟提出，CO2 与水电化学制合成气+费托合成制 SAF 技术，以目前 SAF 售价 2 万元/t，电价 0.2 元/度计，年营收近 1 亿元；以电价 0.5 元/度计，年营收约 2 亿元。**黄震**指出，电解甲醇和绿氨的成本分别为 0.188-0.275 和 0.191-0.269 元/MJ，与传统氨（0.172 元/MJ）持平，略高于重柴油。绿色燃料的成本很大程度取决于氢源（绿电）和碳源（生物质和碳捕集）的成本、全球碳约束，如受欧盟碳关税、碳配额及碳奖惩等，以及绿电的零边际成本特性影响。

The first is to pay close attention to whether the revenue is substantial and promotion is convenient. Wei Wei proposed that with respect to the technologies of producing synthesis gas through CO2 and hydroelectric chemistry + producing SAF through Fischer-Tropsch synthesis, calculating at the current SAF selling price of CNY20,000/t and the electricity price of CNY0.2/kWh, the annual operating revenue can reach nearly CNY100 million; calculating at the electricity price of CNY0.5/kWh, the annual operating revenue can reach nearly CNY200 million. **Huang Zhen** pointed out that the costs of electrolytic methanol and green ammonia are CNY0.188-0.275/MJ and CNY0.191-0.269/MJ, respectively, which are on par with that of traditional ammonia (CNY0.172/MJ) but slightly higher than that of heavy diesel. The cost of green fuels largely depends on the costs of hydrogen sources (green electricity) and carbon sources (biomass and carbon capture), global carbon constraints such as EU carbon tariffs, carbon quotas, and carbon rewards and punishments, as well as the zero marginal cost characteristics of green electricity.

三是关注效益是否显著且前景乐观。包信和提出，工业系统碳排放占 69.9%，其中 21%为钢铁行业，钢铁行业可通过氢气还原铁和酸性溶液电沉积铁脱碳，预计未来两种途径电耗达 4500 kWh/t Fe，经济可行，无技术挑战，总体前景可行。二氧化碳加氢制甲醇远期成本预测可达 2259 元/t，且其成本随电价降低、甲醇规模增大和碳补贴政策逐步降低。在绿氢生产方面，提高效率和降低电价是关键。

The second is to pay close attention to whether the benefits are significant and the prospects are optimistic. Bao Xinhe proposed that industrial system carbon emissions account for 69.9%, of which 21% are from the steel industry. The steel industry can decarbonize iron through reducing iron using hydrogen and electro-depositing iron using acidic solution. It is expected that the electricity consumption of the two path will reach 4,500 kWh/t Fe in the future, which is economically feasible, technically non-challenging, and has a feasible overall prospect. The long-term cost forecast for producing methanol through carbon dioxide hydrogenation can reach CNY2,259/ton, and the cost will gradually decrease with the decrease of the electricity price, the increase of methanol scale, and carbon subsidy policies. In terms of green hydrogen production, improving the efficiency and reducing the electricity price are key.

三是都是技术创新、风险预控、安全保障及资源可持续性。英国皇家工程院院士 Joan Cordiner 提出，工业脱碳需提高新兴技术的风险预备度，如引入新的政策和监管体系，以及预测式制订新的标准。**黄震**认为，除发动机可用性、大规模制备经济性、燃料可供性、法律标准完备性外，安全性也是绿色燃料规模化应用的关键因素。**罗必雄**指出，压水堆/快堆与热堆构成“二元体系”，成为叠加发展的主力核电堆型，确保铀资源安全高效利用，实现我国能源安全。

The third is to pay close attention to technological innovation, risk pre-control, safety and security, and resource sustainability. Joan Cordiner, Fellow of the Royal Academy of Engineering in the UK, proposed that industrial decarbonization requires an increase in risk preparedness for emerging technologies, such as introducing new policies and regulatory systems, as well as formulating new standards on a predictive basis. **Huang Zhen** believes that in addition to engine availability, large-scale production economy, fuel availability, and completeness of legal standards, safety is also a key factor for the large-scale application of green fuels. **Luo Bixiong** pointed out that pressurized water reactors/fast reactors and thermal reactors form a "binary system" and have become the main nuclear power reactor types for superimposed development, ensuring the safe and efficient utilization of uranium resources, thereby achieving energy security in China.

三、上海推进未来能源发展的相关建议

3. Recommendations for Shanghai to Promote Future Energy Development

一是制定绿色燃料的上海本地化方案。魏伟提出，上海的生物质资源有限，生物质生产绿色燃料的能力也因此受到制约。在这种情况下，上海应谨慎部署生物质合成燃料路径，明确上海绿色燃料的技术路线与产业布局具有重要的战略意义。

The first is to develop a localization plan for green fuels in Shanghai. Wei Wei pointed out that Shanghai's biomass resources are limited, which restricts its ability to produce green fuels from biomass. Under such circumstances, Shanghai should prudently deploy the biomass synthetic fuel path, and define that the technical route and industrial layout of Shanghai's green fuels have important strategic significance.

二是提升上海可再生能源利用率和利用途径。可再生能源不仅可以为制氢提供电力，还能作为转化二氧化碳的重要途径。当前，上海在深远海风电领域具有较大的发展潜力，若上海能够将20%的绿电用于绿色燃料生产，将为上海绿色燃料产业发展提供有力支持。**罗必雄**还提出，绿色燃料的来源可以充分利用东北地区的风电和生物质资源。东北的风电资源丰富，生物质储量充足，通过整合生物质、风能和光能进行制氢，再输送至上海是可行的路径。同时，长江中下游的湖南、湖北和江西也是生物质的重要来源。

The second is to improve the utilization rate and utilization methods of renewable energy in Shanghai. Renewable energy can not only provide electricity for hydrogen production, but also serve as an important path for converting carbon dioxide. Currently, Shanghai has great potential for development in the field of deep-sea offshore wind power. If Shanghai can use 20% of its green electricity for green fuel production, it will provide strong support for the development of Shanghai's green fuel industry. **Luo Bixiong** also suggested that the source of green fuel can make full use of wind power and biomass resources in the Northeast China. Northeast China has abundant wind power resources and sufficient biomass reserves. Producing hydrogen by integrating biomass, wind energy and solar energy and then transporting hydrogen to Shanghai is a feasible path. Meanwhile, Hunan Province, Hubei Province, and Jiangxi Province in the middle and lower reaches of the Yangtze River are also important places for sources of biomass.

整　理：李丹妮、王　越

Compiled by: Li Danni, and Wang Yue

编辑：殷梦宇　　责任编辑：王　冰

Editor: Yin Mengyu　　Editor in Charge: Wang Bing

电话：021-53300806　　传真：021-64381056　　E-mail: wangbing@siss.sh.cn

Tel: 021-53300806　　Fax: 021-64381056　　E-mail: wangbing@siss.sh.cn

地址：上海市淮海中路 1634 号 3 号楼 102 室　　邮编：200031

Address: Room 102, Building 3, No.1634 Huaihai Middle Road, Shanghai　Postcode: 200031