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SUSTAINABLE ENERGY ECOSYSTEM BASED ON POWER TO X TECHNOLOGY

Xiaoen Li, Xue Yang, George You Zhou, Shujun Mu, John Lemmon*

National Institute of Clean-and-Low-Carbon Energy, Beijing, China

ABSTRACT

This paper discusses the concept of the sustainable energy ecosystem and introduces the main progress of our solid oxide electrolysis cell research. The latest progress of Power to X (P2X) technology realizes the sustainability of the multi-energy network by introducing the carbon-based cycling procedure. Among the P2X technologies, Solid oxide electrolysis cell (SOEC) is used to co-electrolyze CO_2-H_2O to produce synthetic gas, which is then synthesized into hydrocarbons through a fetor reactor. These two steps can effectively utilize the CO_2 in the atmosphere and realize the carbon-neutral cycle. We focus on the made of $Ce_{0.92}Ni_{0.08}O_2$/YSZ/LSM thin-film batteries at 600℃ for producing syngas. The experiment result shows that the observed current density reaches 0.1 mA/cm^2 with a Faraday efficiency of over 95% and a hydrocarbon yield around 4 ml/min/cm^2.

Keywords: sustainable energy ecosystem, Power to X, electrochemistry, SOEC

NOMENCLATURE

Abbreviations	
P2X	Power to X
SOEC	Solid Oxide Electrolysis Cell
CHY	Chinese Yuan
Symbols	
$\Delta_R H$	enthalpy of formation
$\Delta_R G$	Gibbs free energy of formation
$\Delta_R S$	entropy of formation

1. INTRODUCTION

The construction of the integrated multi-energy complementary system is a useful method for solving the imbalance in chemical production. P2X contains several electricity conversion pathways, e.g., the storage of clean energy in hydrogen, which provides a road map for energy utilization in chemical industries to realize the carbon neutrality. The fast-growing of wind power and solar power in China provides a good foundation for the development of P2X techniques, which further produce an environmentally friendly roadmap for the chemical industry.

In recent years, the chemical industry scale in China is increasing dramatically. As shown in Fig. 1, the total assets of the chemical industry increased from 5.3 trillion CHY in 2012 to 7.6 trillion CHY in 2016, while the business income growths from 6.8 trillion CHY to 8.7 trillion CHY. It should be noted that the annual operating profit in China has been around 450 billion CHY for many years. In the domestic and international chemical industry market, we should give full consideration of the tradeoff between the economy and sustainable development at the same time [1]. On the one hand, many researchers focus on the application of large-scale commercial technology [2]. On the other hand, chemical process should also stress on sustainable development based on carbon neutral concept [3], which has become the new threshold for chemical industry development in China. For example, an environmental pollution levy tax is published in 2018, containing the standard for the air pollution, water pollution, solid waste and noise pollution.

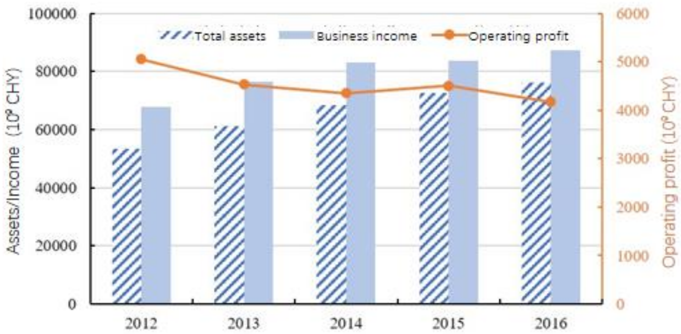


Fig. 1 The total assets, business income and operating profit of chemical industrial from 2012 to 2016 in China (from the national statistics bureau of China)

With the increase of the installed capacity of renewable energy in recent years, the volatility and intermittent problem brought by renewable energy are also becoming more serious. This situation not only promotes the development of large-scale energy storage technology but also brings development opportunities for P2X technology under for sustainable energy ecosystem [4].

This paper explains the status quo and development trends of Power to X technology on an integrated multi-energy complementary system. Based on our recent researches on SOEC modeling [5], electrochemical reforming of CH_4 [6] and carbon dioxide electrolysis [7], our latest research on SOEC technology is given in this paper.

2. STATE OF THE ART

2.1 Power to X

P2X refers to a series of energy conversion and storage technologies, primarily based on renewable energy, where the X refers to power to heat, power to hydrogen, power to chemicals, power to gas, power to liquid, power to methane, power to ammonia, power to fuel, etc. As shown in Fig. 2, P2X includes a series of energy conversion technologies based on hydrogen network, dynamic network and heat network, which realizes the coupling and complementation of energy in various forms such as electric energy, chemical energy and thermal energy, and provides a technical route for the sustainable utilization of energy. Specifically, the main advantages of the development of P2X technology system are (1) The contribution to the sustainable energy ecosystem. The feedstock of P2X process are carbon dioxide, biomass, water and other raw materials and there are almost no harmful by-products in P2X process. Thus, an ecological and environmentally friendly production process has been established from the perspective of carbon neutrality. (2) P2X provides a selection of energy storage method with a potential economy aspect. As solar and wind power are intermittent, P2X produces fuels like hydrogen, CO_2 neutral carbon-based fuels or ammonia productions, which can fully utilize these intermittent energies.

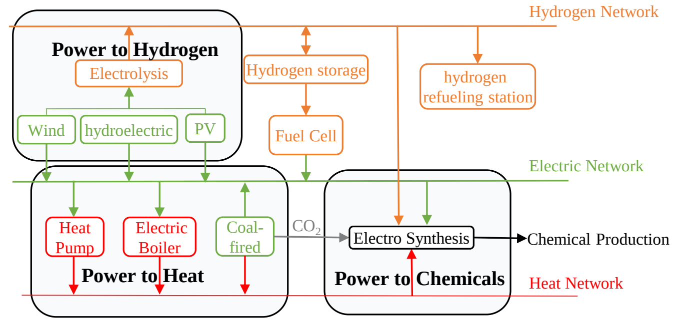


Fig. 2 The energy flow and material flow of Power to X technology on sustainable energy ecosystem

From the perspective of energy storage type, P2X technologies are classified as Power to Heat, Power to Hydrogen and Power to Chemicals in this paper.

Power to heat involves a wide range of technologies and shows an enormous potential to become the most commercial utilization among all the P2X technologies. For examples, heat pumps, electric boiler, mechanical vapor recompression and steam recompression are already available for industrial or commercial application.

Power to Hydrogen has a higher economic prospect. However, it is impossible to achieve large-scale application from the perspective of COE. Fig. 3 shows the thermodynamics of H_2O electrolysis procedure, where the terms of $\Delta_R H$、$\Delta_R G$ and $\Delta_R S$ are the enthalpy of formation, the Gibbs-free energy of formation and the entropy of formation, respectively. In many cases, it is advantageous to operate in SOEC mode at a cell voltage just above $\Delta_R H/2Far$ because no cooling or heating system for stacks is necessary, which indicate that the cheapest gas will be produced at the highest possible temperature.

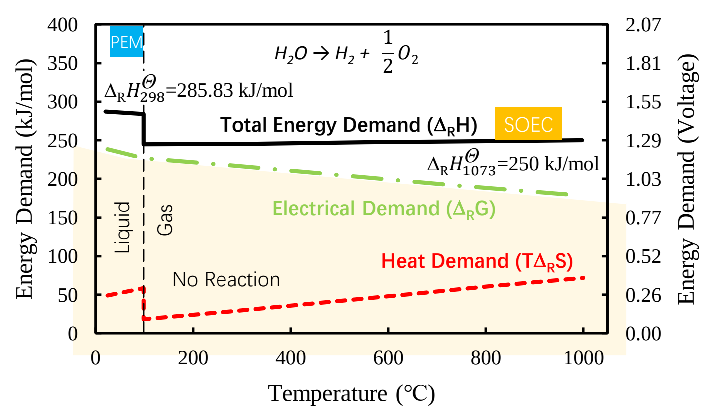
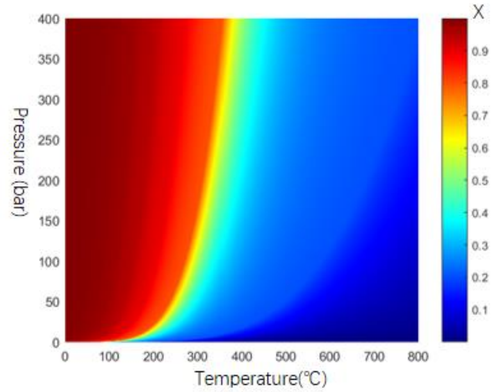


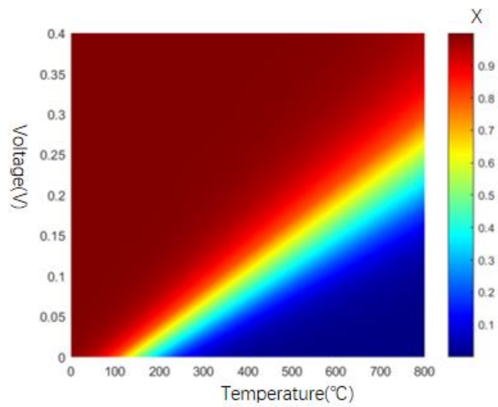
Fig. 3 Thermodynamics of H_2O electrolysis at the atmospheric pressure

Power to Chemical focuses on the use of renewable energy, e.g., wind, solar or hydropower, which are suitable for seasonal storage and utilization. Power to chemical methods enables electrical energy to chemical bonds. The electrochemical method is introduced to realize the chemical transformation process in a broader range of temperature and pressure. Fig. 4 a) and Fig. 4 b) show the energy balance of the methanation reaction by carbon dioxide and hydrogen based on thermochemistry and electrochemistry, respectively.

$$CO_2(g) + 4H_2(g) \rightleftharpoons CH_4(g) + 2H_2O(g) \quad \Delta_R H^{\Theta}_{298} = -165 kJ/mol$$



a) Thermochemistry



b) Electrochemistry

Fig. 4 The calculation of energy balance for the ammonia synthesis by nitrogen and hydrogen based on thermochemistry and electrochemistry

As shown in Fig. 3 a), Although equilibrium conversion can be much higher at lower temperature and methanation is thermodynamically favored at ambient conditions. Thus, high pressure is necessary to achieve reasonable conversions under high temperature. While as shown in Fig. 4 b), replacing pressure with voltage in an electrochemical route can promote the thermodynamics of the system without the use of elevated pressure.

3. PROGRESS ON SOEC RESEARCH

Solid Oxide Electrolysis Cell (SOEC) shows high potential for splitting $CO_2 + H_2O$ into $CO + H_2$ ($+ O_2$), which is the feedstock of various chemical productions. In our program, SOEC is used to co-electrolyze CO_2-H_2O to produce synthetic gas, which is then synthesized into hydrocarbons through a fetor reactor. In the process of methanation, the increase of CO and H_2 concentration and the decrease of steam concentration can promote the reaction kinetically. Therefore, we add pure hydrogen in the experiment to increase the concentration of H_2 to promote the methanation reaction.

After the reduction of thin film battery $Ce_{0.92}Ni_{0.08}O_2$/YSZ/LSM, the hydrogen electrode material $Ce_{0.92}Ni_{0.08}O_2$ will grow Ni particles on the CeO_2 surface (as shown in Fig. 5), thus promoting the co-electrolysis reaction and the methanation process of syngas.

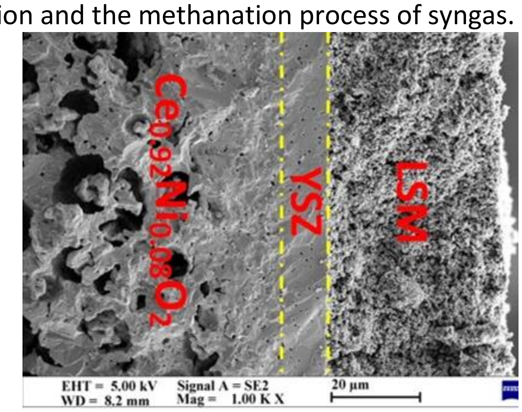


Fig. 5 the SEM photo for the cross-section of the thin-film battery

The interface remarkably improves ceria cathode performance as shown in Fig. 6. Comparing with the $CeO_{2-\delta}$, the performance of $Ce_{0.92}Ni_{0.08}O_{2-\delta}$ improves the current density from 0.5 A/cm^2 to 0.86 A/cm^2 at 2 V (Fig. 6).

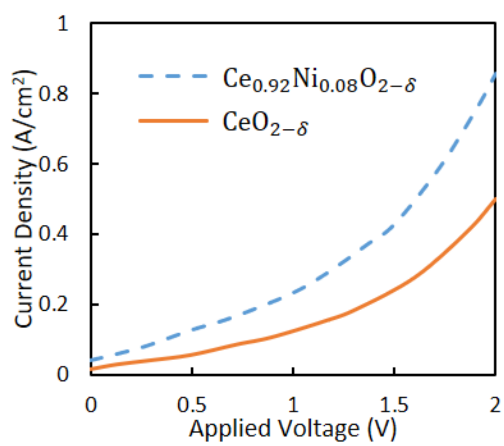
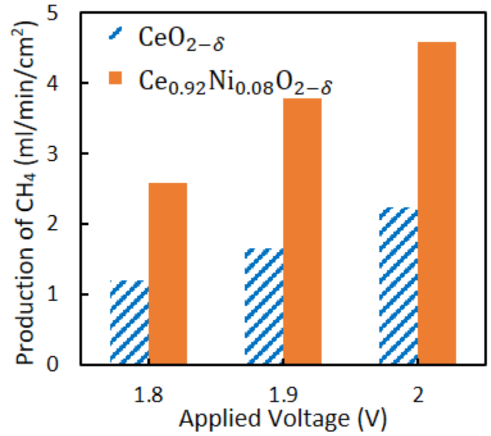
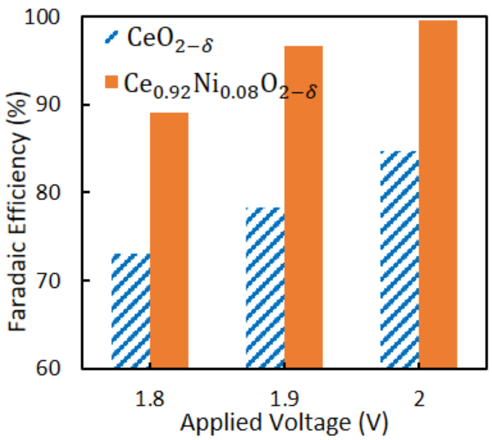


Fig. 6 Current density of CO2 electrolysis with different cathodes.

The result of CH_4 production and the corresponding Faraday efficiency is shown in Fig. 7. The experiment result shows that when the applied voltage reaches 2 V, the Faraday efficiency is over 95% and the corresponding hydrocarbon yield is around 4 ml/min/cm^2.



a) Production of CH_4



b) Faradaic efficiency

Fig. 7 The performance of CH_4 production with different cathodes.

4. CONCLUSIONS

P2X provides new technical methods to build a sustainable energy ecosystem for energy saving, emission reduction and sustainable development, based on which an intelligent energy ecosystem is proposed and discussed for carbon neutrality. Our latest research on SOEC cathode's material testing has successfully produced hydrocarbon by 4 ml/min/cm^2.

ACKNOWLEDGEMENT

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