Dean&Francis

ISSN 2959-6157

The Breakthrough Path of Chemical Industry Practitioners under the Vision of "Carbon Neutrality"

Ningning Huang

Hohhot No.2 High School

Abstract:

Carbon neutrality is an unstoppable trend. In the context of increasingly stringent policy constraints, pushing regulatory rigidity to its limits, "chemists" face severe challenges in both survival and transformation. How to respond to these changes and achieve a breakthrough is the mission and responsibility of "chemists." This article delves into the internal mechanisms of carbon neutrality, exploring the contributions and feasible paths for chemists within this vision. By enhancing management through park circularity and technological innovation through process intensification, chemists can achieve a victorious breakthrough under the carbon neutrality vision.

Keywords: Carbon Neutrality, Chemists, Pathways

1 The Dilemma faced by "chemical industry practitioners" and causes

1.1 In the eyes of outsiders, the world of chemistry is like fireworks in darkness, colorful and full of magic, but chemical industry practitioners understand that the industry situation is undoubtedly grim

PVC Index is the largest variety index in the chemical industry, so observers usually regard it as a chemical index. The PVC price remained at 13,000 yuan/ton in October 2021, but plummeted to around 6,500 yuan/ton a year after that. The halved price marks the arrival of the era of huge losses. At present, the average spot price of PVC produced by ethylene method is 6,511 yuan/ton, and the spot price of PVC produced by calcium carbide method is 6314 yuan/ton. Take the calcium carbide method as an example for further analysis. The loss of enterprises purchasing calcium carbide exceeded 700 yuan/ton and that of enterprises producing calcium carbide themselves exceeded 200 yuan/ton. The PVC industry is experiencing the flattening of the cost curve, which was rarely seen before, and loss sweeping across the chemical industry discourages the practitioners. The prophecy of chemistry, which has been nicknamed one of "Four Majors with a Gloomy Employment Outlook" by netizens, is once again confirmed.

1.2 There are multiple and intertwined causes of the dilemma faced by "chemical industry practitioners"

Generally speaking, it can be divided into two categories:

1.2.1 Policy factors

In 2005, the Fifth Plenary Session of the 16th CPC Central Committee first proposed the idea of constructing a "resource-conserving and environment-friendly" society, and clearly put forward the binding targets of saving energy by 20% and cutting emission by 10% in the subsequent "Eleventh Five-Year Plan" Four consecutive five-year plans thereafter have set up clear energy-saving and emission-reduction binding indicators, supported by corresponding work plans. With more and more policies of the same kind rolled out, the corresponding requirements are increasingly stringent. After the Chinese government put forward the goal of "carbon peaking and carbon neutrality", the hard constraint rigidity of the policies almost reaches the limit. Many enterprises were forced to shut down.

1.2.2 Non-policy factors

The pandemic, wars, cyclical recessions, superpower games, geopolitics and other factors all directly or indirectly lead to unanticipated changes in supply-demand relationship. Therefore, the dilemma may also be triggered by such factors, which are collectively referred to as market factors. For example, the Russian-Ukrainian war has led to a sharp rise in oil and gas prices, which in turn has directly increased the cost of enterprises, and epidemics and cyclical recessions can lead to a sharp drop in demand. The superposition of increased costs and reduced demand has created a dilemma that "chemical industry practitioners" cannot escape from today.

1.2.3 There are important differences between the above two types of factors

First, policies factors are persistent. In contrast, among market factors, war will end, the pandemic will disappear, and the cyclical recession will reverse, so they are short-term and unsustainable. Second, the changes in policy factors is one-way; whether it is 30 years, 60 years or even longer, they will always develop progressively, but only vary in the progressive range in the scope of technological progress and the national economy. In contrast, changes in the market factors are two-way, triggering both increases and decreases in costs and demand.

For this reason, on one hand, "chemical industry practitioners" in trouble should be eager rather than indifferent, embrace rather than reject the policy factors, and actively regard the goal of "carbon peaking and carbon neutrality" as their career vision. On the other hand, they should tackle difficulties in the technical system with diligence and wisdom, reshape the career pattern with technological innovations and get out of the dilemma by turning crisis to opportunities while changing the world.

1.2.4 Chemical change and physical change are two basic forms of material change, and the important signs to distinguish between the two are whether new substances are produced.

In this regard, greenhouse gases are mainly caused by chemical changes. Furthermore, the greenhouse dilemma faced by the earth today is caused intentionally or unintentionally by the predecessors of "chemical industry practitioners". This is the original sin of the "chemical industry practitioners". As a Chinese saying goes, "The one who tied a knot should be the one that undoes it". Today's "chemical industry practitioners" must shoulder the responsibility to atone for their predecessors and complete self-redemption in this process.

2 "Carbon cycle" and "Carbon neutrality"

2.1 "Carbon cycle"

2.1.1 "Carbon neutrality" must be viewed in the context of carbon cycle

It is generally believed that the carbon on the earth is mainly distributed in the atmosphere, the ocean sphere, the lithosphere and the terrestrial sphere, and the mutual transformation of carbon in these four spheres constitutes the carbon cycle.

2.1.2 Photosynthetic reactions are the logical starting point of the carbon cycle

The carbon in the terrestrial sphere is mainly distributed in various organisms and in the soil. First, plants absorb CO_2 from air, convert it into carbohydrates by photosynthesis and releases oxygen. This is also the basic form of carbon from the atmosphere into the terrestrial sphere. Carbohydrates in plants enter animals through the food chain, and animals emit carbon dioxide into the atmosphere during respiration. The dead bodies, litters and residues of animals and plants are decomposed by microorganisms, with the gasified part entering the atmosphere, and the rest integrated into the soil to form organic carbon in the soil. In the violent movement of the earth's crust, the enrichment plants and animals' trunks are buried in the strata and mineralized into coal, petroleum, limestone and other fuels and fossil fuels. After volcanic eruptions or weathering of exposed rocks, carbon enters the atmosphere in the form of gasification. Carbon in the atmosphere enters the terrestrial sphere and the ocean sphere through rain, rivers send carbon from the terrestrial circle to the ocean, and the ocean circle releases carbon into the atmosphere through evaporation.

The excess will settle to form rocks and enter the lithosphere.

2.1.3 In the era of agricultural civilization lasting for tens of thousands of years, carbon circulated in a multi-path interaction among the four major spheres and maintained an overall balance.

In the middle of the 18th century, with the advent of industrial civilization, the balance of the traditional carbon cycle was broken and has deteriorated in an accelerated way ever since. The Intergovernmental Panel on Climate Change (IPCC) has set the year 1750 as a watershed by multi-party calculations, which coincides with the time when Watt improved the steam engine. In 1750, the CO_2 concentration in the atmosphere was 280ppm. By 1910, when the second industrial revolution was completed, the concentration reached 300ppm, with an average annual increase of 0.125ppm. In 1960, the concentration was 320ppm, an increase of 0.4ppm from 1910. In 1987, the concentration was 350ppm, an increase of 1.1ppm from 1960. In 2007, the concentration was 380ppm, with an average annual increase of 1.5ppm. In 2014, the concentration was 410ppm, with an average annual increase of 2.1ppm.

The above data can also be expressed in another way as follows[1]:

Year	Concentration (ppm)	Increase (ppm)	Duration (year(s))
1960	320		
1987	350	30	27
2007	380	30	20
2014	410	30	7

As mentioned earlier, the carbon cycle is made up of small biological cycles and large chemical cycles. The main reason for the destruction of the traditional balance state in the carbon cycle is that the industrial revolution has opened a Pandora's Box that has been closed for hundreds of millions of years. The contradiction caused by the failure of the short-term rapid release and slow absorption of carbon dioxide after the combustion of fossil fuels in the lithosphere forces the atmosphere to become the last shelter for excess carbon dioxide. "Carbon neutrality" is nothing more than a move initiated by humans to rebalance the unbalanced carbon cycle to save themselves.

2.2 "Carbon neutrality"

"Carbon neutrality" means that all the emitted carbon is absorbed and the ideal state of "zero carbon" is reached. When expressed by an equation, it is carbon emissions - carbon accommodation = 0. Therefore, it is not hard to see that there are two basic methods to achieve "carbon neutrality". First, try to reduce carbon emissions. The greater the amount of the emitted carbon reduced, the less pressure to neutralize. The second is to strive to increase the amount of carbon accommodation. The greater the amount of carbon accommodation, the greater the success rate of neutralization. "Carbon neutrality" requires nationwide participation. For example, if you choose to travel by shared bicycle instead of driving, you will contribute positive energy to emission reduction. For another example, if you participate in an afforestation activity, you will contribute positive energy to carbon accommodation. These are basic paradigms for ordinary people to participate in "carbon neutrality". In contrast, "chemical industry practitioners" should not only participate in the grand practice of "carbon neutrality" like ordinary people, but also act as pioneers, forerunners and mainstays in this great task.

3 Carbon reduction

Carbon reduction needs to be examined from both the supply side (production) and the demand side (consumption). First of all, from the perspective of energy supply, it includes three links: production, transportation and storage. In the production link, the principal way to reduce carbon is to adjust the energy structure, that is, to reduce the proportion of primary energy and increase the proportion of secondary energy. Clean energy such as water, wind, photovoltaics and hydrogen are called "green energy" because of its "zero carbon" emissions. Among the above options, "water, wind and photovoltaics" are the fields suitable for "physical industry practitioners", and "chemical industry practitioners" only need to focus on "hydrogen". The transportation link features extra-high voltage and ultra-high voltage, which, however, are not related to chemistry. In the field of power storage, there are two major ways of physical storage and chemical storage. Physical energy storage includes mechanical energy storage, thermal energy storage and electromagnetic energy storage, and chemical energy storage includes battery energy storage and hydrogen energy storage. This reveals that on the energy supply side, the contribution of "chemical industry practitioners" to carbon reduction is mainly concentrated in two fields: hydrogen energy industry and battery energy storage. Secondly, from the perspective of energy consumption, reducing energy consumption directly contributes to the realization of carbon reduction goals, which can be divided into two categories: one is non-productive consumption, such as the consumption by residents, government agencies, institutions, the military, etc., and the second is productive consumption, with enterprises as major consumers. This is also the focus of this paper. Discussing this issue first involves a concept "energy consumption intensity". Energy consumption intensity refers to the energy consumed per unit of GDP, which reflects the efficiency of a country's use of energy, i.e., the level of energy efficiency. Over the past decade, the energy consumption has grown at a rate of 3%, which has driven the 6.5% economic growth of China. The energy consumption intensity has decreased by 26.2% cumulatively, making China one of the countries with fastest declines in the intensity. 2.94 billion tons of carbon dioxide emissions have been reduced, and 1.4 billion tons of standard coal has been saved. During the same period, Shanxi's energy consumption intensity has decreased by 33.2%, standing out among other parts of China. This shows that seen from the energy consumption (demand) side, there is huge room for carbon reduction and the prospect is promising. On the energy consumption side, major measures to reduce carbon include the implementation of energy recycling in industrial parks through management means and process refinement and strengthening in technology.

3.1 Hydrogen energy industry chain

Hydrogen is the most abundant element in the universe, accounting for 75% of the mass of the universe. Hydrogen is the gas with the smallest known density and molecular mass in the world. It is colorless, odorless, insoluble in water but highly flammable, and has high calorific value. The above characteristics determine the status of hydrogen. As the most important industrial gas, hydrogen is widely used in chemical industry, electronics, metallurgy, food, building materials and medical treatment. This paper focuses on its application in energy.

Hydrogen energy is a secondary energy source. Compared with other new energy sources, hydrogen energy plays a dominant role in the new energy revolution because of its good stability, convenient storage and transportation, wide production sources, diversified application range, and strong realizability. When comparing the emission reduction paths of developed countries, we can find that in order to achieve deep decarbonization by 2030, the United States and other western countries have generally established the dominant position of hydrogen energy in the new energy system. In Japan, hydrogen energy is designated as the main driving force of future mobile machinery. In Iceland, as early as 1999, an ambitious national goal was announced: by 2030, Iceland will take the lead in entering the era of hydrogen energy economy. In March 2022, China issued the “Medium and Long-term Plan for the Development of the Hydrogen Energy Industry”. In January 2023, the National Energy Administration issued the “Blue Book on the Development of New Power Systems”. The former planned the timetable for the development of the hydrogen energy industry from a strategic perspective. The latter clarified the technical route of coupling hydrogen energy and electric energy, and strengthened the central position of hydrogen energy in the new energy system. Most observers believe that the third energy revolution is on the horizon, and now is the eve of the hydrogen energy era.

The hydrogen energy Industry Is ma”nly ’omposed of three major links: hydrogen production, storage and use.

3.1.1 Hydrogen production

The preparation of hydrogen is the basis of hydrogen energy production. There are many kinds of hydrogen production methods. The World Energy Council divided hydrogen into three types according to the intensity of carbon emissions: gray hydrogen, blue hydrogen, and green hydrogen.

Gray hydrogen is produced by fossil fuel conversion reaction, which is currently the most common way of hydrogen production, accounting for more than 90%. As the hydrogen produced in this way has the lowest product cost but produces the greatest amount of carbon emissions, it is called “gray hydrogen”. Blue hydrogen is based on gray hydrogen, supported by carbon capture technology, which greatly reduces carbon emissions, but increases the cost as a result. Therefore, such hydrogen is called “blue hydrogen”. Green hydrogen is produced by using new energy and through the electrolysis of water, which generates a high cost but can achieve zero carbon emissions. Therefore, such hydrogen is called “green hydrogen”. It is generally believed that the development trend of hydrogen production technology is that the gray hydrogen method will be limited, blue hydrogen will be regarded as a transition scheme, and green hydrogen will become the dominant. With the iteration of the electrolytic cell technology to the direction of proton exchange membrane, coupled with the reduction of green electricity cost, the green hydrogen preparation method has great potential.

3.1.2 Hydrogen storage

Hydrogen storage is a key link in the hydrogen industry chain. It is not only related to the upstream hydrogen production link, but also serves the downstream application scenarios. The storage and transportation of hydrogen energy mainly includes physical storage and transportation and chemical storage and transportation. This paper focuses on the introduction of several chemical storage and transportation technologies.

3.1.2 .1 Solid-state hydrogen storage in metal hydrides

Hydrogen storage is realized by using the reversible hydrogen absorption/desorption reaction of hydrogen storage alloy under certain temperature and pressure conditions. Hydrogen reacts with hydrogen storage alloys to produce metal hydrides, and hydrogen is stored in the atomic state at the gap between the tetrahedron and octahedron in the metal. Hydrogen storage in metal hydrides excels in high volume density, high safety and purity, convenient transportation and low cost. It is mainly used in submarines, nuclear power plants, portable equipment and mobile equipment. This technology is adopted in the hydrogen storage equipment used in Toyota’s hydrogen-powered vehicles.

3.1.2 .2 Hydrogen storage in liquid organic compounds

The storage and release of hydrogen is achieved by using the reversibility of the hydrogenation and dehydrogenation reactions of liquid organic compounds. The density of hydrogen stored in this way is high and the storage and transportation, operation and maintenance are convenient, which can not only make full use of the existing oil storage and transportation equipment, but also allows recycling multiple times. Representative substances include toluene, ethylcarbazole, and dibenzyltoluene. Such materials have the advantages of allowing large-scale hydrogen storage and long-distance transportation, and are mostly used in hydrogen fuel cell vehicles. Japan and Germany take the lead in the development of the materials.

3.1.2 .3 Hydrogen storage in liquid ammonia

Ammonia is a hydrogen-rich molecule. Hydrogen reacts with ammonia to produce liquid ammonia which serves a carrier of hydrogen energy to achieve hydrogen storage. By using liquid ammonia as direct fuel, the power generation efficiency (69%) is equivalent to that of liquid hydrogen. Since liquid ammonia technology and storage and transportation facilities are quite mature and can greatly reduce infrastructure investment, the technology of storing hydrogen in liquid ammonia is regarded as the most pragmatic hydrogen storage technology. In December 2021, Fuzhou University signed a cooperation agreement with Zijin Mining Group Co., Ltd. And Beijing SJ Environmental Protection and New Material Co., Ltd., aiming at making more progress in the “ammonia-hydrogen” coupling technology and marching towards the trillion-level industrial chain.

3.1.2 .4 Hydrogen storage in methanol

Storing hydrogen in methanol is a technology to use the liquid methanol generated by the reaction between carbon monoxide and hydrogen under certain conditions as a carrier for hydrogen storage. Methanol can be directly used as fuel or decomposed to obtain hydrogen under certain conditions. In 2017, Peking University developed a “platinum-molybdenum carbide” dual-function catalyst to catalyze the reaction between methanol and water, which can not only release hydrogen in methanol, but also activate hydrogen in water, and finally obtain more hydrogen. This technical route has great potential. The hydrogen production project in the Winter Olympics used hydrogen production through methanol.

3.1.3 Use of hydrogen

Hydrogen energy application scenarios are diversified and expanding, which are worth exploring. To sum up, the main categories are as follows:

3.1.3 .1 Energy industry

Renewable energy is naturally intermittent and random, whether it is wind power, hydropower or photovoltaic power generation. This affects the continuity and stability of grid-connected power supply and increases the difficulty of peak shaving. In this case, hydrogen energy stands out with its excellent storage properties and complementing advantage. On one hand, the excess electrical energy is converted into chemical energy at the peak of power production. On the other hand, the chemical energy is converted into electrical energy at the peak of power demand, which realizes the electricity-hydrogen coupling in the space-time mismatch. This not only promotes the accommodation of renewable energy, but also improves the stability and flexibility of power supply, and makes hydrogen energy become the hub of the new energy system.

There are two ways to convert hydrogen energy into electrical energy: one is gas turbine power generation, and the other is fuel cell power generation.

The gas turbine is an internal combustion power machine, has the advantages of high-power generation efficiency, low emission, short construction period, less water consumption and a small footprint compared with coal-fired power stations. At present, gas turbine power plants generate about 23.1% of the world’s total electricity, but the fuel used is mainly natural gas. Using hydrogen instead of natural gas can not only reduce emissions, but also avoid corrosion of equipment and improve the service life of equipment. General Electric Company of the United States, Mitsubishi Heavy Industries, Ltd. Of Japan and Siemens Energy AG of Germany have taken the lead in this field. General Electric’s first hybrid hydrogen gas turbine has been applied in Guangdong Province, producing 1.34GW of electricity.

Fuel cells have the advantages of high energy density and high energy conversion efficiency. The existing battery technology mainly involves proton exchange membrane and solid oxide. The former is mainly suitable for small distributed power stations, while the latter applies to large stationary power stations.

3.1.3 .2 Chemical industry

Hydrogen is an important chemical dye, and the chemical industry is the major application scenario of hydrogen. At present, about 55% of the world’s hydrogen is used for ammonia synthesis, 25% for hydrogenation in refineries, and 10% for methanol production, accounting for about 90% of hydrogen demand. The most mainstream method of ammonia synthesis is the Haber-Bosch process, which has become quite mature after more than 100 years of efforts. At present, the synthetic ammonia industry is also trying to develop new preparation processes, such as nitrogenase synthesis, photocatalytic synthesis, electrocatalytic synthesis, and supercritical synthesis. Hydrogenation technology is the main means of producing clean oil products in the petrochemical industry, and also the core of the integration of refining and chemical industry. Major hydrogenation technologies include heavy oil hydrocracking to produce aromatics and ethylene, residue hydrodesulfurization, hydrogenation of C3 fraction to remove propyne and allene, and hydrogenation of benzene to produce cyclohexane. Currently, the technology of using carbon dioxide hydrogenation to produce methanol is developing from industrial demonstration to large-scale commercial application. Methanol and other hydrocarbons can effectively solve economical and safety problems encountered in "production, storage, and transportation" of the hydrogen energy industry, thus expanding the application scenarios of hydrogen energy.

3.1.3 .3 Metallurgical industry

In the traditional metallurgical process, coke is the major reactant, and its basic reaction formula is: $Fe2O3+3CO=2Fe+3CO_2$. The process will emit a lot of CO_2.

In China, hydrogen is used instead of carbon as a reducing agent, and the basic reaction formula is: $Fe2O_3+3H_2=2Fe+3H_2O$. As the effluent is water, the goal of zero carbon emissions can be achieved. Correspondingly, the former is carbon metallurgy and the latter is hydrogen metallurgy.

There are two major technical routes of hydrogen metallurgy: hydrogen-rich blast furnace reduction and gas-based shaft furnace direct reduction.

In the hydrogen-rich blast furnace reduction technology, a certain amount of hydrogen is added to the smelting process while natural gas and coal gas are injected. This can speed up the smelting process and reduce CO_2 emissions by 10% to 30%. In other parts of the world, the COURSE50 ironmaking process in Japan and the Thyssenkrupp hydrogen-based ironmaking project in Germany have adopted the technology of hydrogenation & carbon reduction to optimize the original blast furnace. In China, China BaoWu Steel Group Corporation Limited, China National Nuclear Corporation and Tsinghua University have jointly developed a low-carbon smelting technology that can reduce carbon emissions by 30%.

The gas-based shaft furnace direct reduction technology converts iron ore into direct reduced iron by using a mixture of hydrogen and carbon monoxide as a reducing agent and put it into an electric furnace for smelting. Compared with hydrogen-rich reduction technology, carbon emissions can be reduced by 50%. On December 20, 2020, the hydrogen-based direct reduction iron project of Shanxi Zhongjin Science and Technology Group was successfully commissioned, marking that the process has entered the application experimental stage.

3.1.3 .4 Transportation industry

Thanks to the further improvement of hydrogen fuel cell technology, compared with fuel power and pure electric power, hydrogen energy excels in a long battery life, fast energy supplement and low temperature resistance, which will be further demonstrated. Its application scenarios in the field of transportation will also expand rapidly.

In the automotive market, hydrogen fuel cell vehicles have obvious advantages in the field of medium and long-range, medium and heavy-duty commercial vehicles due to their higher energy density and lower dead weight. The heavy truck ownership in China reaches more than 8 million units. With the accelerated elimination of heavy trucks conforming to the third phase of emission standards and the driving ban on vehicles conforming to the fourth phase of emission standards, 6 million units of vehicle replacement demand will be released in the next 5 to 10 years. Some observers believe that taking this opportunity, heavy trucks may become the first market segment for hydrogen vehicles to win in the journey of expanding its presence. Secondly, in the field of buses and municipal vehicles, hydrogen vehicles have the opportunity to quickly rise to the top. According to the target of 50,000 hydrogen vehicles by 2025 set in the "Medium-and Long-Term Plan for Hydrogen Energy Industry Development", government subsidies will not be lower than the support for electric vehicles before. Hydrogen vehicles will make breakthroughs in the bus and municipal vehicle segments stimulated by the orders from government organs.

In the field of rail transportation, the world's first 100% hydrogen train developed by Alstom has been put into use in Germany. In China, the State Power Investment Corporation has replaced fossil energy with hydrogen fuel cell hybrid power in the Baiyinhua-Jinzhou section, putting hydrogen-powered trains into operation. On December 28, 2022, China's first hydrogen-powered city train jointly developed by CRRC Changchun Railway Vehicles Co., Ltd. And Chengdu Rail Transit Group rolled off the production line. The speed of 160 kilometers per hour makes the train the fastest one among others of its kind in the world.

In the aviation sector, Airbus has set the goal of developing the world's first zero-emission commercial aircraft by 2035. In September 2020, Airbus released three models of hydrogen concept aircrafts with a code named ZEROe. In December of the same year, it released a hydrogen-powered aircraft configuration consisting of six propulsion hanging rudders. The Aerospace Technology Institute of the United Kingdom regards dry wings, fuel cells and hydrogen fuel gas turbines as key areas of development for the British aviation industry in its report "The UK's Zero Carbon Technology Capabilities". It announced the final plan for the three models of hydrogen-powered concept aircrafts for the FlyZero project in March 2022. In July 2020, U.S. hydrogen airlines ZeroAvia announced that it had completed the first phase of test flight of the world's largest hydrogen-powered aircraft. As a sub-project of the EU's "Horizon 2020" clean aviation project, the HY4 project was undertaken by the German Aerospace Center. It first flew in September 2016 and completed the test flight of the sixth-generation hydrogen fuel cell assembly in 2021. In 2017, the first hydrogen fuel cell test plane independently developed by China successfully completed the test flight in Shenyang. Predictably, it is only a matter of time before hydrogen-powered planes appear on commercial routes.

Different from the bumpy road faced by the R&D of manned aircraft, the UAV has stayed one step ahead to realize commercial use. UAVs are divided into consumer grade, industrial grade, and military grade. Industrial-grade UAVs need to cope with different working scenarios and perform different tasks. For example, they are required to have a long battery life for pipeline inspection and mapping, high load-bearing capacity for logistics and plant protection, and wind resistance and balance ability for emergency and placement. Therefore, the requirements of industrial-grade UAVs in terms of battery life, stability, signal strength, environmental adaptability, and expansion capabilities are far higher than those of consumer-grade UAVs. However, due to the limitation of the energy density of lithium batteries, traditional batteries fail to meet the broader demands faced by industrial-grade UAVs, which provides a chance for hydrogen-energy UAVs to show their strengths. On June 2, 2020, China released the "Hydrogen Fuel Cell Power Generation System for Unmanned Aerial Vehicles", which is the world's first national standard for hydrogen fuel cells for UAVs. This is not only a sign of the relative maturity of China's hydrogen energy UAV technology, but also indicates the arrival of a fast-growing era of UAV applications.

3.2 Electrochemical energy storage

The core of electrochemical energy storage is battery technology, and the current commonly used battery technology involves lithium/sodium-ion batteries, high-temperature sodium-sulfur batteries, and flow batteries.

3.2.1 Lithium-ion batteries are repeatedly deintercalated between the positive and negative electrodes through lithium ions, thereby forming a current concentration difference in the external circuit and realizing the conversion of electrical energy to chemical energy and storage

At present, lithium-ion batteries dominate electrochemical energy storage, accounting for 92% of the total installed capacity. Lithium-ion batteries excels in high energy density, fast response speed, high energy conversion efficiency, and a long service life (allowing more than ten thousand times of use). Although sodium-ion batteries have the same working mechanism as lithium-ion batteries, the former has lower manufacturing costs and good safety. In addition, sodium resources are rich. Therefore, sodium-ion batteries may become the major option to replace lithium-ion batteries.

3.2.2 The negative active material of the high-temperature sodium-sulfur battery is molten sodium metal, and the positive active materials are liquid sulfur and sodium polysulfide molten salt, which complete the electrochemical reaction in the liquid form.

The advantages of the battery are that sodium and sulfur resources are rich, which are easy to obtain, and it has a long discharge life and high energy density. However, it has high operating temperature requirements (300-350 ℃). It is generally used in large-scale power generation side, currently accounting for 3.6% of the global chemical energy storage market.

3.2.3 All-vanadium redox flow battery

The all-vanadium redox flow battery realizes the storage and release of electric energy through the mutual conversion of vanadium ions of different valence states. Its advantages are that it is safe and environmentally friendly, has high energy conversion efficiency and favorable charge and discharge characteristics, allows deep discharge, and has large energy storage capacity and a long service life. However, its manufacturing cost is high, and it is not easy to handle. Therefore, it is mostly used for large-scale stationary energy storage. China is rich in vanadium resources, with proven reserves of 9.5 million tons, accounting for 43% of the world's total proven reserves. On October 31, 2022, the 100 MW all-vanadium redox flow station with the world's largest power and largest capacity was officially connected to the grid for power generation. Led by Li Xianfeng's team of the Dalian institute of Chemical Physics. Chinese Academy of Sciences, this project completed another benchmark attempt to "peak load shifting" on the power grid side.

3.3 Industrial park recycling

The idea of circular economy was created in the United States in the 1960s. After it was introduced into China in the mid-1990s, it became popular quickly and was highly praised by the academic and political circles. After a short period of assimilation, China introduced it to the public in the form of national laws. In the first decade of this century, the National People's Congress successively introduced the "Cleaner Production Promotion Law" (2002) and the "Circular Economy Promotion Law" (2008). At the practical level, the highlight is the recycling transformation of industrial parks. Creating 60% GDP, industrial parks are not only the main positions to drive economic development, but also the hardest-hit areas of high energy consumption and sewage discharge. The recycling transformation of industrial parks has historically and logically become a breakthrough and "critical aspect" for decision-makers to solve the resource dilemma and achieve sustainable development. The purpose of the recycling transformation of industrial parks is to realize "reduction in resource utilization, product reusing, and waste recycling", that is, the "3R Principle". Through the optimization of industrial structure, the advancement of production technology, the improvement of infrastructure, and the innovation of management mechanism, industries in industrial parks have changed from the original single one-time model to a virtuous cycle and sustainable development model. The recycling transformation of industrial parks started from pilots. From 2011 to 2022, 122 pilot industrial parks passed the acceptance and achieved significant economic and social benefits. Take Tianjin Economic & Technological Development Zone as an example. It is among the first batch of pilot industrial parks. After low-carbon transformation, although it has contributed 1/6 of Tianjin's GDP, the share of its pollutants such as chemical oxygen demand and sulfur dioxide is less than 1/10. In addition, the energy consumption per unit of output value, water consumption and major pollutant emission indicators are only equivalent to 1/7 of the national average level, realizing a multi-win result of coordinated development of economy, society and ecology. Summarizing the successful experience of the recycling transformation of the park, we can find that there are two key points of recycling transformation: one is ecological sharing, and the other is industrial coupling.

3.3.1 Ecological sharing

Ecological sharing is the scale effect of centralized construction and unified management of different industries by sharing public services and public facilities. Medical treatment and schooling services are examples of the sharing of public services, and water supply, power supply, heating are examples of public facility sharing. In the industrial park, such sharing is especially manifested in the centralized gas supply and the centralized treatment of "waste gas, waste water, and waste residues". Take Zhenjiang Economic Development Zone as an example. The chemical, photovoltaic, venous, papermaking and other industrial chains in the park can generate direct economic benefits of 1.4 billion yuan per year through waste incineration power generation, sewage treatment, hazardous waste treatment and disposal devices, and infrastructure integration and sharing. At the same time, it can also generate indirect benefits of 25 million yuan by reduction of sewage charges and comprehensive energy conservation.

3.3.2 Industrial coupling

Coupling is a concept of physics, which originally means the phenomena and process of two or more systems or two forms of motion interacting with each other to join together. If we introduce the coupling theory analysis method to industrial economics, the so-called industrial coupling refers to the state and process of the interrelation and symbiotic cycling of different industries. According to the inherent attributes of the industrial chain, the industrial integration is completed through the strategies of strengthening, complementing and extending the industrial chain. Take the "coal-electricity-aluminum" integration project of Huolin River as an example. After years of development, Huolin River has formed a circular development industrial system of "power generation in Lignite Coal Pithead Power Station-local microgrid power supply-aluminum smelting at a low electricity price-direct supply of aluminum pad for deep processing-waste resources reuse". The highlights of this system are pithead power generation, microgrid power supply and direct supply of aluminum pad, which maximize the coupling level between upstream and downstream links, realize seamless connection and reduce waste and pollution in the coupling process.

At present, refining and chemical enterprises are promoting petrochemical integration transformation. According to the "Petrochemical Industry Planning and Layout Plan", during the "14th Five-Year Plan" period, seven world-class petrochemical bases will be built in Caojing Town of Shanghai, Ningbo city of Zhejiang province, Huizhou city of Guangdong province, Gulei town of Fujian province, Changxing Island of Dalian city, Caofeidian District of Hebei Province, and Lianyungang city of Jiangsu province. By then, the refining, ethylene, aromatics production capacity of the seven bases will account for 40%, 50%, 60% of the country's total production capacity.

3.4 Process refinement and strengthening

The refinement and strengthening technology of chemical process is considered to be the main technical means to solve the "high energy consumption, heavy pollution and high material consumption" of the chemical industry and is expected to fundamentally solve the traditional chronic diseases of the chemical industry and create a new era of China's chemical industry. After years of accumulation, the chemical process in China has initially formed its own characteristics and advantages, which are mainly manifested in the following aspects:

3.4.1 Supergravity technology

Supergravity refers to the force on matter in an environment when the speed exceeds the acceleration of the earth's gravity (9.8 m^2/s). In most cases, the supergravity environment is simulated by rotating to generate centrifugal force, and such rotating equipment is called "supergravity machine". In the supergravity environment, the strong shear force can crush the liquid phase material into very small films, filaments and droplets, thus producing a huge rapidly updated phase interface. Consequently, the phase mass transfer rate is increased by 1-3 orders of magnitude compared with the traditional tower, and the molecular mixing, mass transfer process, and the linear velocity of the gas are greatly accelerated. Therefore, the supergravity technology is considered to be a breakthrough technology to strengthen the transfer and multiphase reaction process. China's supergravity technology has been in a leading position in the world. In 1994, Chen Jianfeng's team of Beijing University of Chemical Technology discovered the phenomenon of micromolecular mixing enhancement by 100 times in a supergravity environment. Subsequently, the team successfully carried out industrial development and built 8 industrial production lines to prepare nano-grade products by supergravity method. Among them, the production capacity of nano calcium carbonate production lines reached 10,000 tons/year. This achievement was evaluated by international peers as "an important milestone in the history of the development of solid synthesis". In addition, Chen Jianfeng's team also used supergravity technology for the transformation of the production process of methylene diphenyl diisocyanate (MDI). After technical transformation, the production capacity increased to 300,000 tons/year from 160,000 tons/year, the process energy was saved by 30%, and product impurities were significantly reduced[2]. Practice has proved that supergravity technology has significant advantages in increasing production, saving energy, reducing emissions, reducing consumption and improving product quality.

3.4.2 Membrane separation coupling technology

Membrane separation technology refers to a technology that achieves selective separation when a mixture of molecules with different particle sizes at the molecular level passes through a semi-permeable membrane. Membrane separation technology has multiple functions such as separation, concentration, purification and refining. Therefore, its advantages in efficiency improvement, environmental protection, and energy saving are prominent, such as carbon capture, seawater purification, sewage treatment, and low-grade raw material screening.

Membrane coupling is a process that combines membrane separation and reaction processes to from new coupling. At present, China has successfully developed a complete set of reaction-membrane separation coupling system, including membrane material design and preparation, membrane reactors, membrane process models, etc. The system has been popularized and applied in the field of petrochemical and pharmaceutical chemical industry, creating great economic, social and ecological benefits.

3.4.3 Micro-chemical technology

Micro-chemical technology is typically represented by micro-reactors, micro-mixers, micro-separators and micro-heat exchangers, focusing on the refinement, integrated and strengthened management of the chemical reaction process in micro-space-time systems. Compared with the traditional conventional system, the dispersion scale of the four types of dispersed flows of extrusion, dripping out, jet flow and laminar flow in the microstructure system is 1-2 orders of magnitude smaller, the mass transfer coefficient (ka) is 1-2 orders of magnitude higher, and the mass transfer efficiency in a single device is greater than 90%. The technology has the advantages of fast heat and mass transfer rate, balanced heating, low process energy consumption, small amplification effect, high integration, and strong controllability[3]. The above advantages of the technology are in line with the development trend of "high efficiency, low consumption, safety and controllability" in the chemical industry in the era of "zero carbon". In particular, the technology has unparalleled advantages in the production of flammable and explosive compounds and highly toxic compounds.

3.4.4 Magnetically stabilized bed technology

The magnetically stabilized bed is a special form of magnetically fluidized bed. It is a stable bed that does not change with time in the axial direction and forms only weak motion under a uniform magnetic field. When there is no fluid, it is a stationary bed. When there is fluid flowing through the bed, it expands like a piston. Such fluidized bed capable of expanding is a magnetically stabilized bed. The magnetic field effect can effectively control the interphase back mixing, and maintain uniform porosity to avoid the occurrence of channeling in the bed. Magnetically stabilized beds have advantages of both stationary and fluidized beds. On one hand, it makes up for the defects of excessive pressure drop and uneven heating In the exothermic reaction caused by the use of small particles in the stationary bed reactor. On the other hand, it overcomes the deficiencies of fluidized-bed reactors in low conversion rate and that particles are easily taken out due to their serious back mixing. A breakthrough has been made in the research of hydrofining of caprolactam in a magnetically stabilized bed by Sinopec Research Institute of Petroleum Processing in its cooperation with Sinopec Baling Petrochemical Co., Ltd. Hydrofining of 30% aqueous solution of caprolactam in a magnetically stabilized bed reactor was carried out. Compared with the commonly used kettle-type reactor, the hydrogenation effect was improved by 10-50 times, the catalyst consumption was reduced by 70%, and the economic benefits were remarkable. At present, the technology has been successfully industrialized in Sinopec Shijiazhuang Refining & Chemical Company.

3.4.5 Plasma technology

Plasma is an assembly of particles composed of electrons, ions, atoms, molecules or free radicals produced by ionization, and the total number of positive and negative electric loads is always equal, hence the name. Most of the particles in the plasma are chemically active substances, which can effectively activate some inert small molecules, such as methane, nitrogen and carbon dioxide. Therefore, plasma is prospective in controlling the "greenhouse effect". This feature shows evident advantages in the synthesis and strengthening of some special inorganic substances (such as metal nitride, metal phosphide, metal carbon, synthetic diamond, etc.). In particular, in the field of hydrogen production, because the plasma can be operated at room temperature and has good mobility, it is considered to be the preferred solution for hydrogen supply for fuel cells. The chemical strengthening property of plasma provides a new way for chemical industry practitioners to solve energy, resources and environment problems[4].

3.4.6 Ionic liquid technology

Ionic liquid refers to the liquid completely composed of ions, also known as liquid phase plasma, and is a special form of ions. Compared with traditional solvents, ionic liquids have special microstructure (such as hydrogen bond network structure and heterogeneous cluster structure) and complex interaction force (electrostatic force, hydrogen bond, van der Waals force, etc.), which show unique physical and chemical properties in practical applications, including being non-volatile and having a wide liquid temperature range, good solubility, moderate conductivity and a wide electrochemical window. In particular, depending on the arrangement and combination of anions and cations, ionic liquids can be divided into more than ten types. The diversified distribution makes the ionic liquids a lot more flexible in selection and design. As a new generation of ionic media and catalytic system, ionic liquids have shown amazing application potential in many fields such as chemical industry, metallurgy, energy, environment, biology, energy storage, etc., and are expected to replace traditional heavy-polluting media and catalysts and lead the industrial transformation of green chemical industry.

3.4.7 Supercritical fluid technology

A supercritical fluid is a form of matter whose temperature and pressure are higher than its critical state. The supercritical fluid has many unique properties. For example, its viscosity, density, diffusion coefficient, and solvation ability are highly sensitive to temperature and pressure changes, its viscosity and diffusion coefficient are close to gas, and its solvation ability is close to liquid. The supercritical fluid is between gas and fluid and has the properties and advantages of the two: favorable solubility, good diffusion, easy to control. Therefore, it has broad application scenarios. For example, by virtue of the high density and strong solubility characteristics, supercritical fluid can be used to extract a substance by changing its volume through constant temperature and variable pressure or constant pressure and variable temperature, which is called supercritical fluid extraction technology. The technology has been used to remove nicotine from tobacco and separate glycerides from soybean or corn germ. For another example, oxygen is easily soluble in supercritical water, which can accelerate the oxidation reaction, and rapidly oxidize and decompose the organic waste which is not easy to decompose, so as to make the "incinerator" environmentally friendly. This technology is called supercritical water oxidation technology. In addition, there are supercritical fluid drying technology, supercritical fluid dyeing technology and so on. Notably, supercritical fluid technology is also an important tool to "turn carbon dioxide into treasure". First of all, in the supercritical state, carbon dioxide has low viscosity and high diffusion, can easily dissolve a variety of substances, and is non-toxic and harmless, which makes it a high-quality cleaning agent. Therefore, it can be used to clean a variety of precision instruments, replace chlorofluorocarbons currently used in dry cleaning, and deal with contaminated soil. In the field of biochemistry, supercritical carbon dioxide can easily pass through the cell wall of bacteria, triggering violent chemical reactions inside it to kill bacteria. In the supercritical fluid extraction technology, carbon dioxide is usually used as the supercritical solvent. By regulating the temperature and pressure, supercritical carbon dioxide enters from the bottom of the extraction kettle and fully comes into contact with the extracted material to selectively precipitate the desired chemical components. The high-pressure carbon dioxide fluid containing the dissolved extract enters the separation kettle after being reduced in pressure by the throttle valve. Due to the sharp drop in the solubility of carbon dioxide, the solution is precipitated and automatically separates into the solute and carbon dioxide. The former is a process product, and the latter continues to be recycled. The entire separation process takes advantage of the fact that carbon dioxide has a specific increase in solubility for organic matter in the critical state and is essentially insoluble for organic matter in the normal state.

3.4.8 Microwave technology

Microwave is an electromagnetic wave with a frequency of 300MHz-300GHz and a wavelength of 1mm-100cm. In a microwave environment, the absorption of electromagnetic energy by the molecules inside the material triggers several billions of dipole vibrations that generate large amounts of heat, which is known as “internal heating”. Different from the traditional heating method, microwave heating features fast heating speed, uniformity, no temperature gradient, and small heat loss. In addition, the process of “internal heating” is accompanied by high-frequency vibration between molecules, which can directly stimulate the reaction between substances, and strengthen mass transfer and chemical reaction. At the same time, the different dielectric properties of different substances lead to differences in their capability to absorb microwaves, which makes microwave radiation obtain selectively heated space. The flexible design function of microwave technology is therefore highlighted. In addition to “internal heating”, microwave also produces non-thermal effects. In the microwave field, the electric field can polarize the molecules, and the magnetic field force will make these charged particles migrate and rotate, which intensifies the diffusion motion between molecules and greatly increases the speed of chemical reactions. Experiments show that microwave radiation can make the chromatographic outflow peak steeper or higher, and increase the speed of substances passing through the chromatographic column. When the microwave field is applied to intensify steam to extract essential oils, in the process of microwave steam diffusion, the mass transfer coefficient is 6 times of the traditional steam extraction process. These experiments were performed using diffusion effects of microwave technology. At present, microwave-assisted synthesis has been successfully used in many fields, such as alkylation, saponification, olefin addition, sulfonation and carbanion condensation[5].

The only way for “chemical Industry practitioners” to make breakthroughs lies In the revolutionary change of chemical technology. The refinement and strengthening of the above-mentioned chemical technology constitute the main breakthrough point of technological change. The development of new and efficient production processes through process refinement and strengthening technology, or the transformation and upgrading of traditional processes, can greatly reduce the energy consumption, material consumption and waste emissions of the process, fundamentally change the plight of “chemical industry practitioners” and make “chemical industry practitioners” become the backbone in realizing “Carbon neutrality”.

4 Carbonization

Carbonization is the process of absorbing and converting the emitted carbon dioxide. As mentioned earlier, due to the different participants, carbonization can be divided into natural carbonization and artificial carbonization; the former includes forest carbon sink and marine carbon sink. According to research, about 13% and 35% CO_2 produced by the burning of fossil fuels on the earth annually is absorbed by terrestrial vegetation and the ocean, respectively; The latter is initiated by human beings and is also known as “carbon negative” and “industrial forest carbon sink”. As can be seen from the foregoing, there are two ways of micro-cycling of carbon, including biological and chemical ways, such as vegetation under photosynthesis to absorb carbon dioxide in the air. Such carbon is not the focus of this paper. In other words, this paper mainly discusses chemical carbonization methods. Certainly, chemical technology-supported biological carbonization methods are also covered, such as the aggregation-induced emission technology developed by Academician Tang Benzhong, which can increase the speed of seaweed reproduction by 8 times.

Chemical carbonization specifically includes carbon capture, utilization and storage (CCUS).

The concept of CCUS was first proposed by Chinese experts at an academic conference in 2006. The International Energy Agency (IEA) believes that CCUS and renewable energy electrification, bioenergy and hydrogen energy are four pillars of global energy transition. After other means are exhausted, CCUS is considered to be the last resort for human beings to achieve carbon neutrality. The IEA predicts that, to be in line with the net zero target, the global carbon capture scale will reach 1.6 billion tons by 2030, 40 times the 40 million tons in 2021. China’s annual carbon capture reached 2 million tons in 2021 and is expected to soar to 360 million tons in 2030. The Department of Social Development, Science and Technology of the Ministry of Science and Technology of the People’s Republic of China predicts that the output value of CCUS in China will exceed 330 billion yuan in 2050, presenting broad market prospect.

4.1 Carbon capture

Carbon capture is the very core of CCUS technology, accounting for more than 70% of the cost in the entire technology chain. Carbon capture includes two major links: capture and separation. In the capture link, according to the order of the oxidation reaction, it can be further divided into three different technical routes: pre-combustion capture, oxygen-enriched combustion capture (capture during combustion) and post-combustion capture. At present, the most mature one is capture technology, and the most widely used scenario is post-combustion capture. However, due to the large number of gas impurities captured after combustion, high energy consumption and high operating costs, the first two technologies should be valued and diversified technical routes are expected to be formed in the future.

The separation process involves chemical absorption method, physical absorption method and membrane separation method. Among them, the chemical absorption method is widely used because of the advantages of large absorption capacity and good absorption effect. The chemical absorption method can be subdivided into organic amine method, ammonia absorption method, hot potassium carbonate method, and ionic liquid absorption method. The organic amine method is currently the most important chemical absorption method.

At present, the mainstream capture technology is post-combustion capture + chemical absorption method, which is known as the first-generation technology in the industry and is currently in the stage of large-scale demonstration and commercial use. The second-generation technologies are under development, such as new membrane separation technology, new absorption technology, new adhesive technology, pressurized oxygen-enriched combustion technology and chemical chain combustion technology. The new generation of capture technology will show a diversified development trend, moving from the laboratory to the specific application scenario. It is estimated that the second generation capture technology can save 30% in cost and energy consumption compared with the first generation.

4.2 Carbon utilization

The conversion and reuse of carbon dioxide, also known as “carbon dioxide utilization”, is intended to “turn waste into treasure” and manage and utilize carbon dioxide as a resource. In a word, there are two major routes to reuse carbon dioxide: chemical utilization and biological utilization. In the “Carbon neutrality” vision, CO_2 reuse technology comes into being and becomes increasingly diversified.

4.2.1 Chemical utilization of CO_2

The chemical utilization is about the use of CO_2 as a reactant to produce new target products through chain breaking, chain assembly, and other chemical processes. At present, hot technical routes are:

(1) Carbon dioxide-methanol series

The hydrogenation of CO_2 to produce methanol technology, of which the “liquid sunshine” project of Li Can’s team of the Dalian institute of Chemical Physics. Chinese Academy of Sciences is the most representative. Through solar power generation, hydrogen production by photolysis of water and hydrogenation of CO_2 to produce methanol realize the conversion from solar energy to liquid fuel methanol. As the carrier of hydrogen energy, methanol is a clean and efficient fuel and can also be used as an important chemical raw material. It can be coupled with the current mature technology and process to produce new products such as methanol to olefins, aromatics, gasoline, etc. In January 2020, the world’s first thousand-ton solar fuel synthesis demonstration project was successfully commissioned, producing 1 ton of “liquid sunlight” and consuming about 1.4 tons of carbon dioxide. In 2021, Sun Yuhan’s team of the Shanghai Branch of the Chinese Academy of Sciences realized the direct conversion of carbon dioxide hydrogenation into aviation fuel under milder conditions. In June 2022, the world’s first 10,000-ton carbon dioxide-to-aromatics industrial pilot project jointly constructed by Tsinghua University and Jiutai Group started construction. Methanol has a simple structure, is an ideal product obtained from the reduction of carbon dioxide, and is expected to become an important direction for the utilization of carbon dioxide resources.

(2) Carbon dioxide-carbonate series

The energy level study shows that less energy is required for the conversion of carbon dioxide into carbonate series, and the products produced are used for battery dissolution liquid, thus seizing the opportunities brought by new energy and being highly profitable. For these reasons, the CO_2 to carbonate track has attracted much attention from capital. The “green process of dimethyl carbonate/ethylene glycol preparation by using immobilized ionic liquid to catalyze carbon dioxide” jointly developed by Liaoning Oxiranchem Inc. and Institute of Process Engineering, Chinese Academy of Sciences is the first of its kind in the world. In addition, in a cooperation with Shenzhen Capchem Technology Co., Ltd., the team of the Institute of Process Engineering constructed a 100,000-ton industrial plant for the synthesis of carbonates from carbon dioxide catalyzed by ionic liquids in Huizhou Petrochemical Industrial Zone, Guangdong Province, which realized continuous and stable operation in March 2021. Changchun Institute of Applied Chemistry Chinese Academy of Sciences cooperated with Inner Mongolia Mengxi Construction Group Co., Ltd. and China National Offshore Oil Corporation to build two 3,000 ton/year polycarbonate industrial demonstration plants respectively.

(3) Synthesis gas from carbon dioxide

Synthesis gas is a raw gas with carbon monoxide and hydrogen as the main components and used as chemical raw materials. It is in the intermediate position in coal and petrochemical industry chains. The global synthesis gas market is forecast to grow at a compound annual growth rate of 10.74 in 2022-2028, with 60% of the market in China. The traditional technical routes for the production of synthesis gas are mainly coal gasification and natural gas steam reforming, both of which, coal gasification in particular, are highly dependent on fossil fuels and are considered to be large sources of carbon dioxide emissions, facing severe low-carbon policy constraints. To find an alternative, people has gradually shifted their focus to CO_2 synthesis gas technology. At present, depending on the heating method, major methods with CO_2 as raw material for synthesis gas are thermal catalytic method, electrocatalytic method and photocatalysis method. Among them, the thermal catalytic method has advantages of a large amount of processing, high efficiency, and easy to apply in large-scale scenarios, which makes it the major application scenario of CO_2 to synthesis gas. Although electrocatalysis and photocatalysis are still under development, they are regarded as new generation technologies with great potential because of their universality in normal temperature and pressure conditions. In CO_2 to synthesis gas process, in addition to the heating method, another key is the design and preparation of highly efficient catalysts.

4.2.2 Biological utilization of carbon dioxide

In the biological utilization of carbon dioxide, photosynthesis and microbial fermentation characteristics are utilized to complete CO_2 transformation. In general, chemical treatment of CO_2 is required before biological utilization to provide suitable environment and conditions for biological utilization. In this sense, the biological utilization of CO_2 can also be regarded as an extension of chemical utilization in biological activities. There are two major paths to conduct the biological utilization of CO_2:

The first path is to prepare new materials to accelerate the photosynthetic reaction of plants and improve the carbon sequestration level of plants, such as the aggregation-induced emission material invented by Academician Tang Benzhong. Plants, seaweed, photosynthetic bacteria and other photosynthetic organisms have different characteristics of their internal pigments, which determine that they are sensitive to only a small number of light waves; therefore, the tuning and optimization of light source wavelengths are highly likely to enhance the photosynthesis rate. The aggregation-induced emission material invented by Tang Benzhong's team shows impressive results in enhancing the rate of photosynthesis due to their excellent aggregate-state luminescence efficiency, biocompatibility, large Stokes shift, and photostability. Experiments show that the "aggregation-induced emission" material invented by Tang Benzhong's team could increase the growth rate of seaweed by 8 times, and the carbon sequestration level was also improved accordingly.

The second path is to prepare the medium with carbon dioxide as the raw material, and produce starch, alcohol, feed and other carbohydrates through microbial fermentation.

Ma Yan and his team of Tianjin Institute of Tianjin Institute of Industrial Biotechnology, Chinese Academy of Sciences used photovoltaic power generation to produce hydrogen, chemically reduced CO_2, and used the glycan pathway to build an 11-step unnatural carbon sequestration and starch synthesis pathway from scratch. They realized the total synthesis from carbon dioxide to starch molecules for the first time in the laboratory. Preliminary laboratory tests show that the production efficiency of starch synthesis was about 8.5 times that of traditional agricultural production. According to the current technical parameters, theoretically, the amount of starch produced per cubic meter by a bioreactor is equivalent to the annual output of a 5-mu corn field. This result makes it possible for starch production to change from traditional agricultural planting mode to industrial production mode, and creates a new technical route for the synthesis of complex molecules with CO_2 as the raw material, which is of great significance to solve food crisis and energy crisis[6].

4.3 Carbon storage

The original meaning of carbon storage refers to the process of injecting liquid carbon dioxide or carbon dioxide in liquid-vapor mixed state into closed and stable geological layers, including terrestrial storage and seabed storage. Currently, with the emergence of new building materials technology, the extension of carbon storage has been further expanded. In this context, it seems to be more appropriate to define carbon storage as follows. Carbon storage is a state in which carbon dioxide has been mineralized or is to be mineralized in a closed geological environment.

(1) Carbon dioxide storage by converting carbon dioxide into building materials

The idea of converting carbon dioxide into building materials while completing the mineralization storage of carbon dioxide is a promising idea. This technique dissolves CO_2 in dilute alkali, converting it to carbonate ions, and then reacts the carbonate solution with calcium or magnesium brine to produce calcium carbonate (PCC) or magnesium carbonate (PMC), which can be used in plastics, paints and adhesives. It is reported that the main business of a Canadian company CarbonCure is to inject Co_2 into the concrete mixture to form nano-scale calcium carbonate through the reaction between carbon dioxide and calcium ions in cement and by embedding carbon dioxide in concrete. This can not only realize the mineralization storage of CO_2, but also improve the strength and durability of concrete and reduce the amount of cement used. According to the report, the company has installed 550 carbon dioxide injection devices in concrete plants around the world and has so far successfully converted 50,000 tons of CO_2. The O.C. O Technology company of the United Kingdom has developed an accelerated carbonization technology (ACT). Many industrial and construction wastes react naturally with carbon dioxide in the presence of water, while ACT technology controls the reaction conditions and accelerates the reaction process through additives to produce artificial limestone finally.

(2) CO_2 flooding and storage

CO_2 is injected into low permeability oil fields after liquefaction, which can not only improve the oil field production rate, but also realize underground storage of CO_2. Flooding and storage technology was invented in the United States in the 1950s, and has been commercialized and applied in a large scale in North America. China's oil enterprises have also completed demonstration projects and entered the stage of commercial promotion, the most representative of which is the first million-ton CCUS project constructed by Sinopec Shengli Oilfield Company. It covers three links of carbon capture, utilization and storage, and is the largest CCUS whole industry chain demonstration base in China.

Compared with simple geological storage, the storage with reusability is more economically reasonable and has higher promotion value and more applicable scenarios.

To sum up, in the vision of "Carbon neutrality", chemical industry practitioners will usher in a new era which allows them to make a difference. At the carbon emission end, seen from the energy supply side, the major breakthrough is concentrated in the hydrogen industry and energy storage industry. Compared with the supply side, on the energy consumption side, the revolutionary innovation of chemical technology will lead explosive development in all aspects. At the carbon sequestration end, regardless of whether it is carbon capture, carbon utilization, or carbon storage, new theories, new technologies, and new business formats are emerging like bamboo shoots after a spring rain. They prosper like splendid fireworks. In a nutshell, in the grand practice of "Carbon neutrality", "chemical industry practitioners" are both the vanguard and the main force.

References

[1] Wang Jun. carbon management from zero to carbon neutrality [M] Beijing; China Public Information Press Group 2021 56-57

[2] Chen Jianfeng. supergravity technology and application - a new generation of reaction and separation technology [M] Beijing; Chemical Industry Press

[3] Zheng Yuting. Research progress on microchemical distillation separation technology [J] Chemical School 2022.5.75

[4] Wu Jianfei, Yuan Hongmei, and Xia Linmin. Research progress on the preparation of functional materials using low-temperature plasma modification technology [J] Material Introduction, 2022, 36:21

[5] Li Xiuping. Microwave Technology Fundamentals [M] Beijing Electronic Industry Press 2013 46-48

[6] Wu Xiaoyan and Chen Fang. Analysis of the Development Status and Trends of Carbon Dioxide Bioconversion Technology [J] China Bioengineering 2024 44 (1) 15