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Carbon Neutrality by 2060
White Paper on the Low-carbon Development of the Petrochemical Industry

April 2022

Contents

Preface

Li Mingfeng
The president of SINOPEC Research Institute of Petroleum Processing

Carbon peaking and carbon neutrality are major strategies of the CPC Central Committee. These thoughtful strategies are relevant to the sustainable development of the Chinese nation and a global community for a shared future. China has fully acted upon its great power and responsibilities in addressing climate change.

Important to transportation energy and chemical raw materials, the petrochemical industry is irreplaceable in national economic development but produces a large amount of CO_2. The annual carbon emissions from petroleum refining and chemical production account for almost 6% of the national total, nearly 600 million tons. Therefore, reducing carbon emissions is an urgent mission for the petrochemical industry.

The complex industrial process hinders the industry with insufficient data, severe constraints, and high carbon reduction requirements. The SINOPEC RIPP delved into the synergy of public and regional carbon reduction resources, coordinating the national with the local, and established a Low-Carbon Petrochemical Economy Research Center, which supports sustainable and low-carbon development to balance emission reductions. Furthermore, the RIPP developed a series of low carbon technologies to meet the industry's emission reduction needs for the short, medium, and long term, and created a circular economy and a renewable energy system to scientifically reduce carbon to establish the new and abolish the old.

Paul Siu
Corporate Development Lead Partner, Deloitte Asia Pacific
Oil, Gas and Chemicals Sector Leader, Deloitte China

The Paris Agreement in 2015 set a direction for the world and established global climate change goals. In 2020, China announced its carbon peak and neutrality targets and emphasized low carbon development as a fundamental solution. In 2021, the Action Plan for Carbon Dioxide Peaking Before 2030 issued by the State Council of China specified carbon peaking initiatives for the petrochemical industry and made higher requirements for its low carbon development. Low-carbon transition is at the critical stage. Only by acting now can we reshape the future.

In this context, SINOPEC Research Institute of Petroleum Processing (hereinafter referred to as "RIPP") and Deloitte China jointly prepared the Report. Based on RIPP's deep understanding of the petrochemical industry and related technology, the Report expounded approaches to achieve carbon reduction by 2025, the technical support for carbon peaking by 2030, the route strategy for carbon neutrality by 2060, and the low carbon roadmap to 2060. According to years of advisory experience and insights into the petrochemical industry, the Oil, Gas & Chemicals Sector of Deloitte China, together with Deloitte Research, Deloitte Climate and Sustainability Institute, and Deloitte Global Benchmarking Center pointed out global and China's low carbon development needs, and discussed driving factors, key points and challenges of low carbon transition in the petrochemical industry. I believe this Report will facilitate relevant industries to think positively and achieve the ultimate goal of low carbon development through technological exploration and breakthroughs.

Enjoy reading!

Executive Summary

As the impacts of climate change increase, China announced the goal of "striving to peak CO_2 emissions by 2030 and achieve carbon neutrality by 2060". Due to its resource and energy-intensive nature, the petrochemical industry has the highest carbon emissions in the industrial sector. The Plan for the Green Development of Industrial Sectors during the 14th Five-Year Plan period (2021-2025) states that by 2025, the specific energy consumption of key products, like ethylene, should reach an advanced world level and the petrochemical industry's resource utilization significantly improves to help perfect the green manufacturing system.

To better analyze the current situation and critical steps for low carbon petrochemical development, RIPP and Deloitte China jointly prepared this Report. It starts with China's low carbon development needs, extends to driving factors, development trends, key points, and challenges to the low carbon transition, and explains key tasks and technical development by 2025, 2030, and 2060 (targeted emission reduction timeline) in detail.

Carbon Reduction by 2025 – Approaches: During the 14th Five-Year Plan period, integrating management improvements, efficient energy utilization, process optimization, and intelligence will lay a solid foundation for low carbon transition in the petrochemical industry. RIPP provides an enterprise carbon emission statistics and accounting service through a "carbon peaking and neutrality" platform, uses carbon asset management software to assist in managing carbon reduction, develops carbon reduction technologies for efficient energy/resource utilization, refining/chemical process and intelligent optimization to reduce carbon emissions comprehensively, precisely and efficiently. As a global leading professional service provider, Deloitte developed specialized management software for low carbon investment and operations.

Carbon Peaking by 2030 – Technical Support: To achieve carbon peak goals by 2030, the petrochemical upstream and downstream industries need to work together on scientific, industrial planning, and reasonable productivity construction to ensure economic development and green transition go hand-in-hand. Based on the carbon reduction efforts by 2025, bio-based fuels and lubricants, innovative technology for a circular economy, and low-carbon basic chemicals production technology can firmly support and accelerate the carbon peaking in the petrochemical industry, while laying the groundwork for building a low-carbon value chain.

Carbon neutrality by 2060 – Route Strategy: To achieve the strategic goal of carbon neutrality in the petrochemical industry by 2060 and to create a green, low-carbon, circular economy and a clean, low-carbon, safe, and efficient energy system, the industrial and energy structures will undergo disruptive adjustments, and new and renewable energy will snowball and lead to the development of the industry. Upgrades and breakthroughs of green hydrogen, CCUS, or electrification are important routes for the petrochemical industry to achieve carbon neutrality.

As the petrochemical industry gradually shifts to green and low-carbon development, the carbon neutrality goal is an inevitable challenge and an opportunity to adjust industrial structure, improve competitiveness and realize ecological conservation and sustainable development. Enterprises should turn the challenge into an opportunity by embracing the industrial transformation and low carbon trend. By modeling carbon reduction contributions of technologies available in petrochemical production processes over time, typical refining enterprises are projected to achieve Net-Zero by 2060.

Chapter 1 Global and China's Low Carbon Development Needs

Section 1 Global low carbon development needs

Climate change is an absolute and urgent challenge for the world, which affects the survival and development of human beings in the environment, society, and economy. The Report released by Intergovernmental Panel on Climate Change (IPCC) listed eight catastrophic risks posed by climate change, including:

- Death and destruction from coastal flooding
- Injury and economic loss from inland flooding
- Breakdown of power, emergency, and other systems due to extreme weather events
- Impact of extreme heat on poor areas
- Food insecurity linked to warming, drought and flooding
- Agricultural and economic losses from water shortage
- Loss of marine ecosystems
- Loss of terrestrial and inland water ecosystems

The Green Book of Climate Change, jointly compiled by the Chinese Academy of Social Sciences and the China Meteorological Administration, further explained that over 90% of global economic loss from natural disasters is related to climate. From 1980 to 2018, the number of severe weather events and climate disasters increased from 135, 59 and 28 in 1980 to 359, 382 and 57 in 2018, respectively. The impacts of global climate change on natural ecosystems, economies, and societies are deepening and global climate risks continue to rise. Climate change is not a challenge to the future, but a threat to the present. If there is no response, all of humanity will suffer the consequences.

In response to climate change, nearly 200 countries worldwide signed the Paris Agreement in 2015, setting a milestone in the direction and goals of global climate change cooperation. Under the Agreement, each party will work together to enhance initiatives to address the threat of climate change and reduce greenhouse gas emissions, limiting the global average temperature to well below 2°C above pre-industrial levels by the end of the century and pursuing efforts to limit it to 1.5°C. In November 2021, the Climate Change Conference in Glasgow (COP26) to United Nations Framework Convention on Climate Change COP26 concluded with the Glasgow Climate Pact. During COP26, the parties reached several agreements that provide definitive and predictable methods for climate mitigation, including:

- Urge and encourage developed countries to meet their commitments to invest USD 100 billion a year in Green Climate Fund for developing countries until 2025;
- Achieve global Net-Zero emissions (Net-Zero) with the support of 500 financial service companies that control over USD 130 trillion in private assets;
- Set up a global carbon trading market mechanism;
- Make the Global Methane Pledge to limit methane emissions;
- Reduce the use of coal electricity without carbon capture and storage gradually, and transit to low emission energy systems.

The parties have submitted or are now making their medium and long-term low-carbon development strategies. We believe that climate change will be a key issue for governments and enterprises over the next decade. It is essential to take shared responsibilities and positive actions on climate change. Meanwhile, the urgent need for global low carbon development brings many opportunities. Task Force on Climate-related Financial Disclosures (TCFD) summarizes these opportunities in five aspects: resource efficiency, energy sources, products and services, markets, and resilience.

The impacts of climate change are rippling across the globe and may cause irreversible losses. Avoiding these impacts depends on our choices now and in the next decade. Therefore, China and other economies worldwide have accelerated emission reduction plans as a viable way to a low-emission future that delivers long-term development and prosperity while avoiding the worst effects of climate change. We can reshape the future by working together with global forces and acting now.

Section 2 China's low carbon development needs

In 2020, China announced the goal of "peaking CO_2 emissions before 2030, and achieving carbon neutrality before 2060". In October 2021, the State Council issued an Action Plan for Carbon Dioxide Peaking before 2030, aiming to cut energy consumption per unit of gross domestic product (GDP) by 13.5% and CO_2 emissions per unit of GDP by 18% before 2025 compared with 2020 levels. In January 2022, a Comprehensive Work Plan for Energy Conservation and Emission Reduction during the 14th Five-year Plan Period released by the State Council specified the goal of energy consumption per unit of GDP in 2025. It requires energy efficiency and significant pollutant emissions in key industries at advanced international levels by 2025, with great signs in the green transition of economic and social development. Addressing climate change is imperative for China's sustainable development. Looking ahead, if China is to achieve socialist modernization by 2035 and develop into a great modern socialist country by the middle of the 21st century, green and low carbon development is a fundamental solution, in which there are also opportunities: immediate action to mitigate climate change as a new engine for China's economic prosperity, and lead global economic growth.

Decarbonization becomes a new engine of China's economy

Through scenario simulation and analysis, Deloitte found that climate actions could create significant economic profits of about RMB 116 trillion[1] (in present value) from 2021 to 2070 in China. According to our predictions, economic profits will come out in the first year with bold climate policies and rapid investments and technology R&D in relevant fields, which contribute to the goal of limiting the global average temperature increase to below 1.5 °C by 2050. What seems like a high cost is a long-term investment in climate-driven transition for a more secure future. We need to change our mindset to take global warming mitigation initiatives as a necessity and new opportunities to expand businesses rather than a non-essential cost.

China can share decarbonization experience with the world

In a leading place in raising renewable energy consumption, China has become the world's largest producer of solar panels, wind turbines, batteries, and electric vehicles, with the highest hydrogen production, top production and sales in electric vehicles, and leading investments in clean energy worldwide. China is rapidly advancing its decarbonization process, promising to widely share key technologies, methodologies and expertise. This contributes to accelerating the global transition to a low carbon future and creates more development opportunities for Chinese enterprises.

China will lead the world towards a low-emission future

China is more likely to diversify its economy and scale green products and services, with low carbon knowledge, skills, investment and finance, as well as supply chain networks, forming an advanced "green economy complex". In addition, China has a favorable economic base, enabling an increased share of green exports, and an increased range and quantity of low-emission products with a competitive export advantage. This helps leverage our leadership in the consumption economy, technology and advanced manufacturing fields, restructure the economy in the transition to a low-emission model, and drive the spread of low-carbon technologies around the world through clean energy export markets. Accelerated carbonization will benefit China and the world significantly, and China is able to lead the world toward a comprehensive low-carbon development and systematic transition with its unique advantages.

In the years ahead, policies and investment decisions will significantly affect the economy and climate in China and the world. During the critical period of action from the moment to the next decade, we must seize opportunities for transformation, make correct decisions, promote economic prosperity, and inject new impetus into sustainable development to move forward together to a better future.

1. Deloitte Research: China's Turning Point: How Climate Action Can Drive Our Economic Future

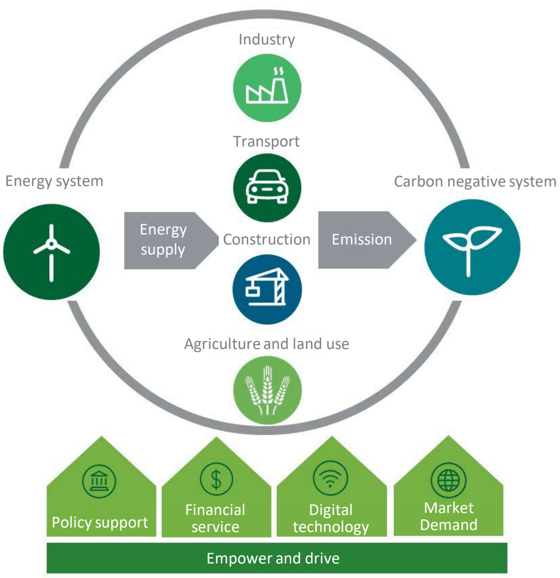
Section 3 Systematic low carbon development across industries

Many countries and companies in the world have put low carbon development on the agenda, suggesting carbon emission goals and climate initiatives. Still, the progress remains slow in reducing global carbon emissions. The United Nations Environment Programme issued the 2021 Emissions Gap Report, stated: "Announced promises to reduce emissions have limited impact on global greenhouse gas emissions which are expected to fall by only 7.5% by 2030, with a 30% reduction required to meet the Paris Agreement's temperature control goal of 2°C and a 55% reduction required for 1.5°C.[2]"

Accelerating the emission reduction process needs the combined efforts of multiple systems, mainly energy, industry, transport, construction, agriculture and land use, and carbon negative. These correlative core systems are roughly the primary sources of today's greenhouse gas emissions and the key process for removing CO_2 from the air. In addition, government policies, financial services and digital technology will act as catalysts to support and promote the low carbon development across industries. Various market factors, including consumer preferences and investor demands, will also drive the low-carbon transition. For example, the transport system will intersect with the energy and manufacturing industry in decarbonization, and it can sufficiently reduce emissions only by using clean and renewable energy, and sustainable raw materials (e.g., recycled plastics from the chemical recycling of waste plastics).

Figure 1 shows the six core systems' status quo, low carbon future, and critical transitional initiatives. The listed initiatives are not fixed and will be continuously improved with the profound changes in processes, technologies, supply chains and business models. These systems are deeply interconnected and interdependent, in carbon reduction practices, and need to work together for low carbon development.

Figure 1: Low carbon development of the six core systems



Status quo	Low carbon future	Some transitional initiatives
The emissions mainly come from burning fossil fuels but renewable energy expands rapidly; oil mainly supports transport and industrial processes.	Renewable energy is the mainstay of power generation with load adjustments by energy storage & smart grid, and transport and industries are decarbonized to reduce oil demands.	• Transition to a low-carbon energy structure • Establish flexible and intelligent power systems • Build large-scale energy storage facilities • Utilize carbon negative technology
The emissions mainly come from burning fossil fuels and chemical reactions in production process.	Manufacturing industries continue to improve efficiency with the popularization of smart factories and digital supply networks, and heavy industries increase green hydrogen use and implement electrification.	• Optimize fuel structure • Implement electrification and use green hydrogen or other technologies in high carbon process • Improve equipment efficiency and increase energy conservation • Develop circular and addictive manufacturing
Greenhouse gases mainly come from fossil fuels used in transport; the share of electric vehicles is only 1% with a rapid growth.	Low carbon motors dominate vehicles, such as electrical vehicles and hydrogen fuel cell vehicles; applications of biomass and green hydrogen expand and seamlessly integrate with urban transport.	• Electrify transport means • Explore hydrogen and biomass energy • Drive intelligent logistics
Emissions are mainly from the fuel burned in construction and the use of construction equipment (e.g. air conditioner).	Low and zero carbon buildings are widely deployed and renewable energy drives power and heating supply systems.	• Increase building energy conservation • Decarbonize building heating supply • Electrify cookware and use energy-saving appliances
Greenhouse gases mainly come from manufacturing and use of agricultural fertilizers, livestock breeding, and production of meat and dairy.	Regenerative agriculture scale up with diet structure shifting to less meat.	• Promote regenerative agriculture technology and meat substitutes • Make supply chain transparent • Enhance waste disposal • Proceed afforestation projects
Natural carbon sinks such as forests, grasslands and oceans are degrading; carbon negative technologies are costly and scattered with limited applications.	The carbon market works well and transparently with the powerful role of carbon capture and storage technologies and the deployment of various natural solutions.	• Formulate robust policies, regulations, and financial/tax incentives for carbon market • Restore and protect ecosystems • Invest heavily in carbon negative technology

Source: Deloitte Insights, Deloitte Research

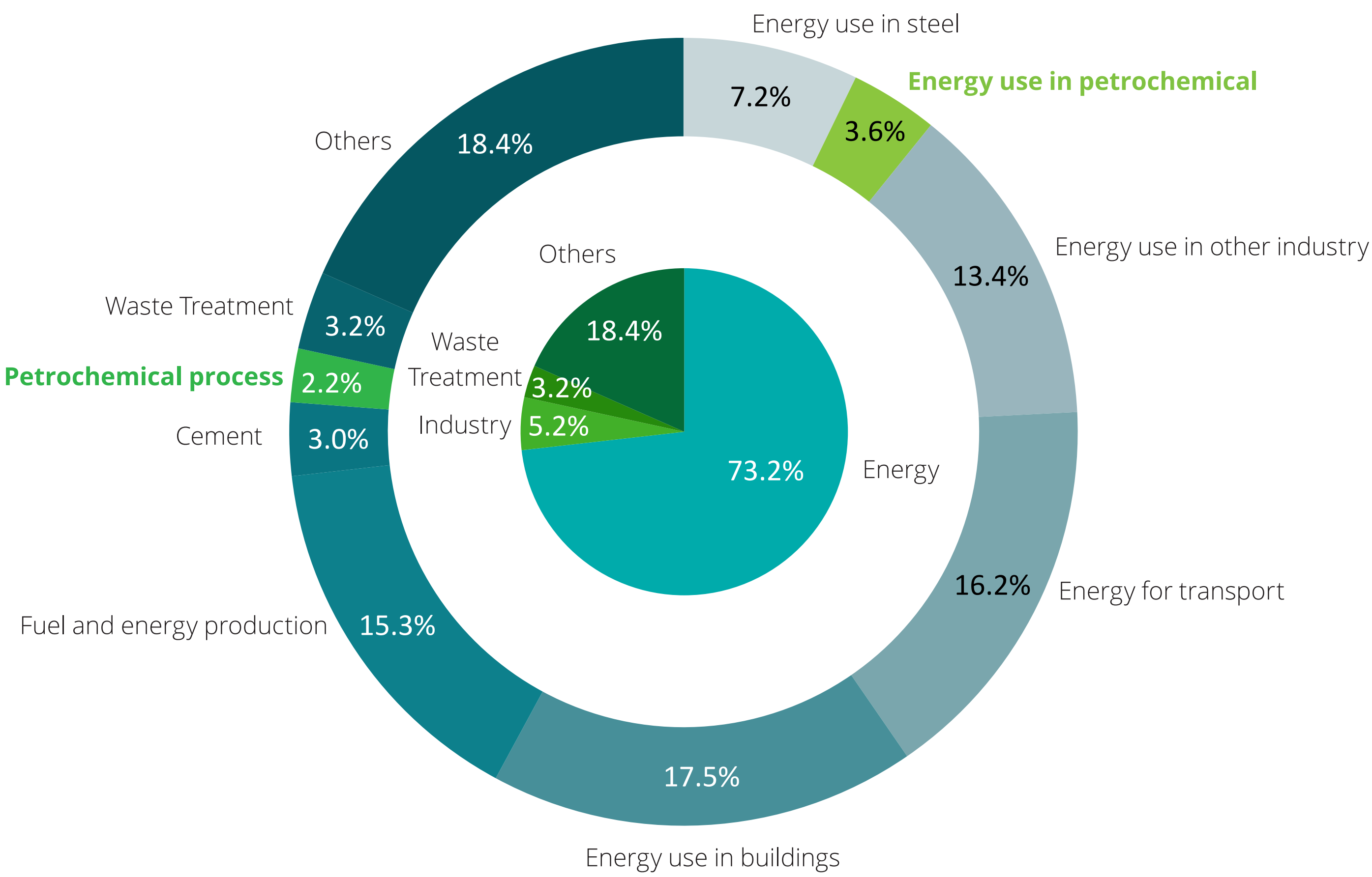
2. Emissions Gap Report 2021, United Nations Environment Programme, October 26, 2021, https://www.unep.org/zh-hans/resources/emissions-gap-report-2021

Siu Paul, the Oil, Gas, and Chemicals Sector Leader, said:" Duo to a resource and energy-intensive nature, the petrochemical industry has one of the highest carbon emissions. The primary CO_2 emissions of the petrochemical industry come from fossil fuel used in the product life cycle and from the production process." According to data[3], the greenhouse gas emissions from the global chemical and petrochemical industry account for 5.8% of total emissions, particularly 3.6% from energy use and 2.2% from industrial processes.

Low carbon development will profoundly impact the petrochemical industry, and policy support, consumer preference changes and new technology applications will drive petrochemical enterprises to develop new sustainable products and business models. For example, more countries will limit the use of plastics with high carbon intensity, and manufacturers will increase the proportion of recycled plastics in their products. In this way, the circular economy concept will permeate the production process, thus creating new business models.

In response to "carbon peaking and carbon neutrality" goals, many petrochemical enterprises have set carbon reduction targets and put them into practice. Sinopec, for example, has declared Net-Zero as its ultimate goal, aiming to achieve carbon neutrality by 2050, and launched the construction of China's first CCUS project with a million-ton capacity in July 2021, which makes a positive contribution to dealing with global climate change.

Figure 2: Global greenhouse gas emissions by sector (%)



Source: Our World in Data

3. Sector by sector: where do global greenhouse gas emission come from, Our World in Data, 2020-09, https://ourworldindata.org/ghg-emissions-by-sector

Chapter 2 Imperative Low-carbon Transition for the Petrochemical Industry

Section 1 Driving factors of low-carbon transition

As a fundamental industry, the petrochemical industry supports national economic development with a wide range and high relevance of products. As one of the largest emitters of carbon dioxide, the petrochemical industry is impacted by carbon peak and neutrality in many aspects and embraces new development opportunities.

From a policy perspective, the Action Plan for Carbon Dioxide Peaking before 2030 issued by the State Council in October 2021 proposed:

- Optimizing the scale and layout of production capacity and accelerating the elimination of backward production capacity to effectively resolve structural overcapacity conflicts;
- Tightening project admission, arranging reasonable construction timelines, and strictly controlling new refining capacity;
- Guiding enterprises to change their energy use and replace coal with electricity and natural gas;
- Adjusting the structure of raw materials and expanding import of hydrogen-rich raw materials to promote the use of light petrochemical raw materials;
- Optimizing product structure, promoting the coordinated development of industries such as petrochemicals, chemicals and coal mining, metallurgy, building materials, and chemical fibers, and making full use of refinery by-product gases like dry gas and liquefied gas;
- Encouraging enterprises to upgrade their energy efficiency and promoting energy cascaded utilization and material recycling;
- By 2025, the domestic crude oil primary processing capacity will be under 1 billion tons and the capacity utilization rate of major products will increase to over 80%.

In February 2022, the Implementation Guidelines for Energy-saving and Carbon-reducing Transformation and Upgrading in Key Areas of High Energy-Consuming Industries (2022 Edition) issued by four ministries, including the National Development and Reform Commission, clearly provided to transform and upgrade the refining industry in energy conservation and carbon reduction, with the following initiatives.

Apply advanced technologies: promote the development and application of deep refining technologies, such as inferior heavy oil processing (e.g., residue slurry bed hydrogenation), advanced separation, component and molecular refining, low-cost olefin and aromatic production increase, and crude oil cracking.

Adopt **green upgrading technologies**, such as intelligent optimization technology for higher energy efficiency and advanced control technology for boundary operation (high yield, low energy consumption, and acceptable quality).

Promote **major energy-saving equipment**, for example, high-efficiency heat exchangers. For actual production needs, the right type of high-efficiency heat exchanger is selected to increase boiling heat transfer efficiency by analyzing the energy-saving and carbon-reducing effects and economic benefits of different heat exchangers, and then reasonably assessing the effectiveness and need to replace/apply heat exchangers.

Optimize energy system: promote the synergistic optimization of steam power system, heat exchange network, and low-temperature heat utilization to diminish temperature and pressure reduction and transfer losses; promote distillation system optimization and transformation for a higher energy efficiency by optimizing the tower feedstock temperature and inter-tower heat integration with intelligent optimization control system, advanced partition distillation tower, heat pump distillation, self-heat recuperation distillation and other technologies.

Optimize hydrogen system: promote the integrated optimization of refinery hydrogen network system. Hydrogen pinch analysis technology and mathematical programming are adopted for rigorous simulation, diagnosis and optimization of the refinery hydrogen network system to promote collaborative optimization of the hydrogen network and hydrogen-using devices; coupled with optimizing hydrogen supply units, hydrogen using the management of hydrogenation devices, and comprehensive recovery of hydrogen and light hydrocarbon, fine management and comprehensive utilization of hydrogen resources are implemented to improve hydrogen efficiency, and reduce hydrogen consumption, system energy consumption and carbon dioxide emissions.

From a market and business perspective, the Global Sustainable Investment Review 2020 issued by the Global Sustainable Investment Alliance (GSIA) suggested that sustainable investment across regions covered in this report has reached USD 35.3 trillion by 2020, an increase of 15% over that of 2018. Moreover, the 2022 Global Chemical Industry M&As Outlook of Deloitte showed that the Action Plan for Carbon Dioxide Peaking before 2030 has contributed to the investment in the environment, society and governance, as well as greater global cooperation. To reach the goal of carbon peak and neutrality, enterprises in the resource- and capital-intensive petrochemical industry accelerated the transition, started a new round of supply-side structural reform, and comprehensively promoted the low-carbon transition and development by vigorously developing the hydrogen energy, continuously cultivating the renewable energy, and focusing on the new materials industry.

Under the background of carbon peak and neutrality, leading international petrochemical enterprises first announced their carbon neutrality or Net-Zero target year publicly. They rose to challenges on the Net-Zero path by making rapid strategic adjustments, building carbon management capabilities, and actively investing in carbon reduction technology innovations. The new technological revolution will drive low carbon development in the petrochemical industry, such as carbon reduction, zero-carbon, and carbon negative technology applications.

Among the current technologies that enable low carbon production and operation optimization, higher energy efficiency is the primary method to slow the growth of carbon emissions. According to International Energy Agency (IEA), the increased energy efficiency is expected to reduce energy-related greenhouse gas emissions by over 40% in the next 20 years. In addition, energy-intensive industries usually have a high product carbon footprint, so recycling products is important to reduce carbon emissions.

Alternative energy technologies and re-electrification are the main paths to Net-Zero. Replacing fossil energy with clean energy and decarbonizing the energy structure will reduce total carbon emissions. In addition to clean energy such as hydro, solar, wind, and nuclear, leading petrochemical enterprises are accelerating R&D and application of new technologies like low-carbon hydrogen and biomass to gain win-win economic and social benefits.

Carbon negative technology can balance out and even reuse the unavoidable carbon emissions, essential for carbon neutrality. With technical progress and the formation of industrial clusters, it will be more economical and commercially viable, and CO_2 will be recycled as a resource to enable various industries.

Section 2 Analysis of low carbon development in the petrochemical industry

In October 2021, the Central Committee of the Communist Party of China and the State Council issued the Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy. It made systematic planning and overall deployment for carbon neutrality in the next forty years, specified 2025, 2030 and 2060 as important transition milestones, and set low carbon development targets such as promoting the construction of a low carbon circular economic system, reducing carbon intensity and increasing the consumption of non-fossil energy.

Figure 3: Overall carbon neutrality path in China

2025

- An economic system featuring green, low-carbon, and circular development takes shape with much higher energy efficiency in key industries.
- The energy consumption and CO2 emissions per unit of GDP fall by 13.5% and 18% from 2020 respectively.
- The proportion of non-fossil energy consumption nears 20%, forest coverage rate reaches 24.1% and forest volume rises to 18 billion cubic meters.

2030

- The overall green transition of economic and social development achieves remarkable results with international advanced energy efficiency in key energy-consuming industries.
- The energy consumption per unit of GDP falls sharply and CO2 emissions per unit of GDP drop by over 65% compared with 2005.
- The proportion of non-fossil energy consumption reaches about 25%, total installed capacity of wind and solar power exceeds 1.2 billion kilowatts, forest coverage nears 25%, and forest volume rises to 19 billion cubic meters.
- CO2 emissions peak, and fall steadily.

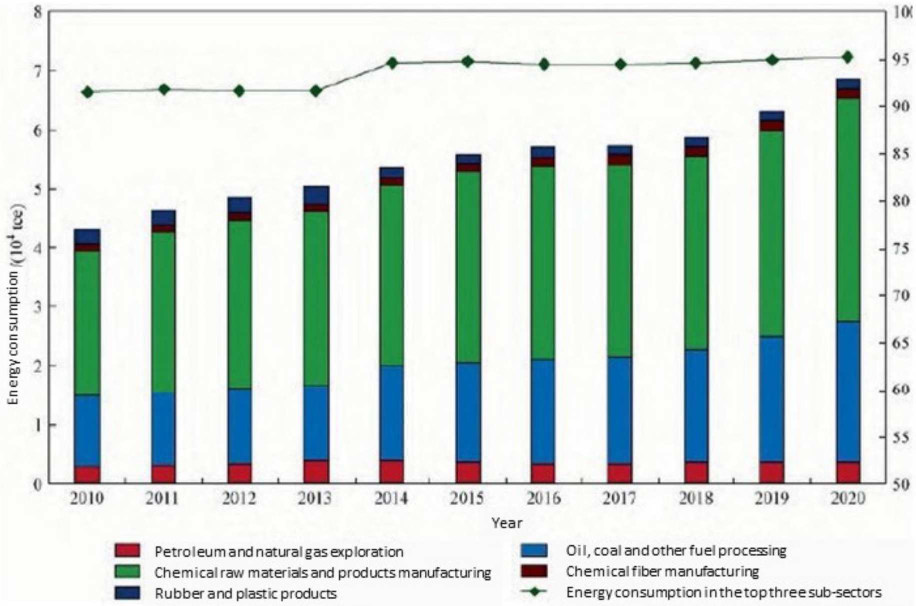
2060

- An economic system of green, low-carbon and circular development as well as a clean, low-carbon, safe and efficient energy system are well established with international advanced energy efficiency.
- The proportion of non-fossil energy consumption exceeds 80%.
- Carbon neutrality comes true.

Source: Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy

The energy-concentrated petrochemical industry has high energy consumption and emissions in the overall industrial system, accounting for 4%-5% of China's total annual emissions[4]. In 2020, energy consumption in the petrochemical and chemical industry totaled 685 million tons of coal equivalent, up 59.7% compared to 2010[5]. According to IEA projections, nearly half of the world's new crude oil demand will come from the petrochemical industry by 2050, overtaking freight, aviation and shipping as the biggest driver of crude oil consumption growth[5]. China's petrochemical industry started to upgrade during the 13th Five-Year Plan period focusing on scale and refining integration. Still, the scale up of refining and growth in ethylene capacity has raised total energy consumption in the petrochemical industry (Figure 4). A Plan for Industrial Green Development during the 14th Five-Year Plan period stated that by 2025, the specific energy consumption of key products like ethylene should reach an advanced world level and the petrochemical industry's resource utilization significantly improves to help perfect the green manufacturing system.

Figure 4: Energy consumption of China's petrochemical industry in 2010-2020



Source: National Bureau of Statistics (NBS)

Carbon emissions of the petrochemical industry mainly originate from direct combustion of fossil fuels, industrial processes, purchased electricity and heat indirectly, and the supply chain, with fossil fuel and industrial process-related emissions dominating nearly 80% of the total. Although the petrochemical industry's total carbon emissions are lower than industrial sectors such as steel and cement, its carbon intensity is high, with energy efficiency lagging behind the world's advanced level. Therefore, low carbon transition in the petrochemical industry, whose products are both fuel and raw materials, is critical for energy security, energy transformation, and overall carbon peaking and carbon neutrality.

4. CEADs, China CO_2 Inventory 1997-2019 (IPCC Sectoral Emissions)
5. Pathway of Carbon Emission Peak for China's Petrochemical and Chemical Industries, 2022, Pang Lingyun, etc.

While continuously optimizing its industrial and product structure, the petrochemical industry can reduce direct emissions with higher energy efficiency, improved processes, or alternative raw materials. Petrochemical companies can reduce indirect emissions through the use of green electricity, and reduce product value chain emissions by embracing a circular economy, developing and producing green and low-carbon products, and optimizing transportation and storage. Furthermore, carbon capture, utilization, and storage technologies (CCUS) and carbon-offsetting schemes can help the petrochemical industry reduce life-cycle carbon emissions and accelerate the progress toward carbon neutrality.

Energy conservation and emission reduction with higher energy efficiency:
- Enhance overall energy conservation management and eliminate outdated production capacity.
- Greatly reduce resource and energy consumption and improve comprehensive energy efficiency to effectively control total fossil energy consumption.
- Develop clean, efficient and recyclable processes to reduce emissions in production.
- Identify opportunities for energy conservation in operations, and upgrade processes and equipment.

Renewable energy alternatives and energy structure optimization:
- Consider investing in distributed renewable energy generation for self-use to replace purchased electricity.
- Actively notice and participate in intra-provincial and interprovincial renewable energy trading to purchase green power.

Carbon capture, utilization, and storage (CCUS) technologies:
- Promote projects on CO_2 capture, utilization and storage, and CO_2 as a raw material for chemical products.

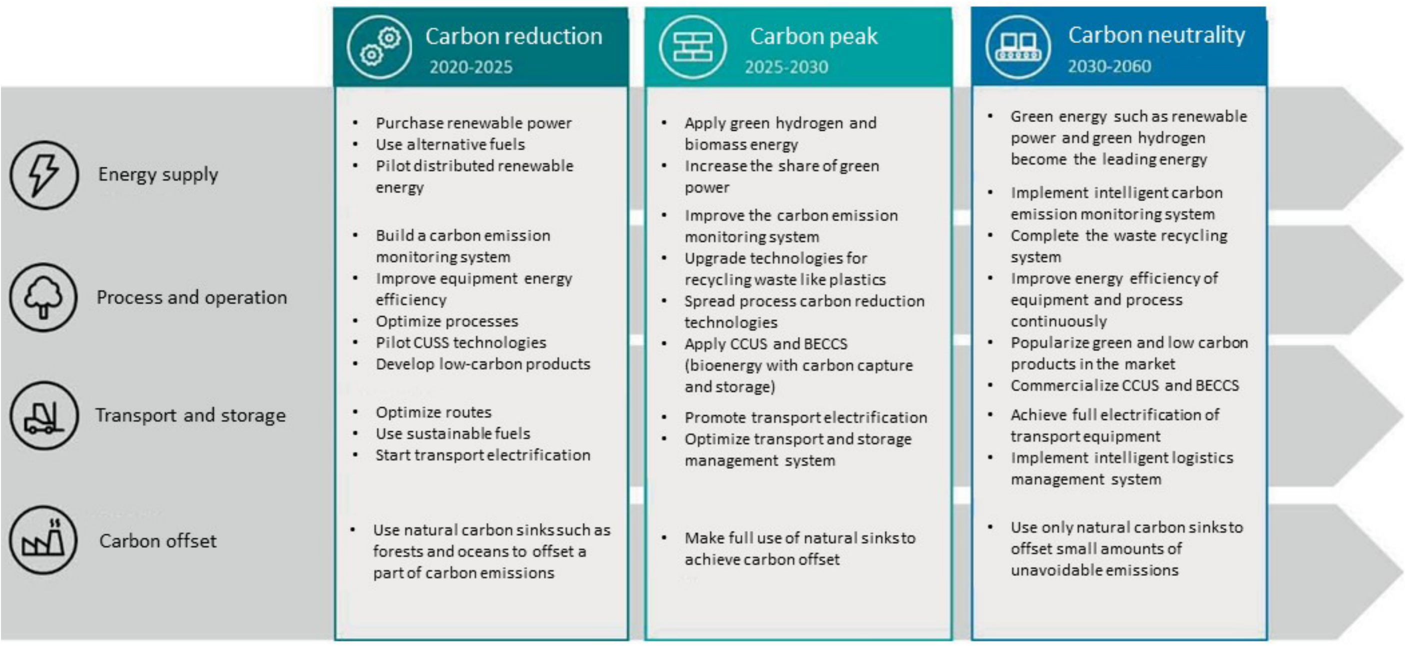
Circular economy:
- Develop new technologies, materials and models to promote the recycling of solid waste like plastics and reduce petrochemical wastewater pollution.

Develop green and low carbon products:
- Develop green products with a lower life-cycle carbon footprint to reduce emissions from use.

Emission reduction in transport and storage:
- Reduce emissions in transport and storage through sustainable fuel alternatives, electrification, intelligent management, etc.

Carbon offsetting schemes:
- Purchase carbon-offsetting products such as China Certified Emission Reduction (CCER) or International Renewable Energy Certificate (I-REC) to balance out the remaining emissions after energy conservation and emission reduction as well as renewable energy use.

Figure 5: Low carbon transition route for the petrochemical industry



Carbon neutrality in the petrochemical industry should follow a technology-driven, value-led approach, adhere to the principle of establishing the new before abolishing the old in well-ordered steps, and go through three stages of carbon reduction (2020-2025), carbon peaking (2025-2030) and carbon neutrality (2030-2060) with continuous decarbonization in all segments.

Source: Deloitte Research

Section 3 Challenges for the petrochemical industry

Challenges for low carbon transition in the petrochemical industry:

Make strategic planning for low carbon transition

- As of January 2022, over 2200 enterprises globally have joined the Science Based Targets Initiative (SBTi) to make positive corporate emission reduction targets in line with the Paris Agreement goals. From 2022, listed companies are required by law to disclose environmental information, including their greenhouse gas emissions. Regulators, investors, and consumers expect high-carbon companies to take scientific, effective, and transparent actions to reduce emissions, in which low-carbon transition strategic planning is powerful for companies to communicate with their stakeholders. However, most petrochemical enterprises have not yet set targets and action plans consistent with the goals of the Paris Agreement or nationally determined contributions.

Enhance carbon assets management ability

- In July 2021, China Carbon Emission Trade Exchange was officially launched. With the expansion of its industry coverage and the continuous improvement of its pricing mechanism, the petrochemical industry is under increasing pressure to reduce emissions. Moreover, carbon assets related markets and financial instruments such as carbon trade exchange and carbon finance can raise funds and improve efficiency for enterprises to reduce emissions. Due to complex production processes, various kinds of products, and frequent production adjustments, petrochemical enterprises generally lack systematic and mature carbon asset accounting management methods and tools, and are challenged to improve their management abilities in carbon assets.

Promote technology innovations and applications

- Petrochemical enterprises face the challenges of technology breakthroughs and applications for low carbon development. Firstly, there is a lack of effective decarbonizing technologies in high carbon emission processes. Despite various CCUS and BECCS technology demonstration projects, their economy needs to be further improved with a gap in scale application; and green hydrogen and electricity technologies have yet to mature for large-scale application. Secondly, subject to the complex process system, low carbon element technologies can only maximize their value based on the overall optimized process, and it is more difficult to couple new technologies with existing processes; the petrochemical industry started later than other industries in digitalization, and the multi-energy coupled intelligent low carbon energy system has not yet been applied in the industry.

Improve energy efficiency

- IEA indicates that the stated carbon neutrality requires energy efficiency improvements to contribute 37% to global CO_2 reductions. Various calculations show that energy conservation and energy efficiency improvements need contribute more than 70% to China's carbon peaking before 2030. The energy efficiency of China's petrochemical enterprises is still lower than the world advanced level, so it is urgent to improve energy efficiency through the optimization of energy conservation, utilization and recovery.

Upgrade industry landscape and profit model

- The industry-wide and life-cycle low carbon transition is gradually deepening with increasing demands for low-carbon raw materials and products from petrochemical downstream industries. Changes in downstream industries, e.g., promoting new energy vehicles, have reduced the demand for traditional high carbon products in the petrochemical industry. The regulation on the new capacity of high energy-consuming projects, new material technology iterations and alternative products have aggravated competition and elimination and increased concentration in the petrochemical industry. Enterprises need to reshape management and operating models and profitability when adjusting business and products.

Improve the low carbon standard system

- The current low carbon standard system fails to fully support carbon peak and neutrality due to an imperfect standard system and deficient low carbon management rules. It is necessary to comb the progress of existing standards, policies and technologies to solve carbon inventory and carbon footprint accounting problems in key areas, products and enterprises in the petrochemical industry. For the lack of standards in low-carbon products, carbon capture and utilization, a standard system need be well established to support the high-quality low carbon transition and development in the petrochemical industry.

Section 4 Key to low carbon development and transformation – rebalancing the technology mix

There are many routes to carbon reduction in the petrochemical industry with possibilities of coupling and interaction. These routes depend on each other and constrain each other. Energy efficiency and process improvements can reduce production carbon emissions and material recycling can reduce life-cycle carbon emissions. Still these reductions are insufficient to achieving Net-Zero. Although CCUS is the key to achieve Net-Zero, its application scenarios are to be expanded and its economy significantly improved. Therefore, the petrochemical industry needs to rebalance and explore a technology mix to reduce emissions.

For low carbon transition, the petrochemical industry needs to rebalance three categories of technologies, including carbon reduction, zero-carbon and carbon negative technologies.

The following trends will affect reductions and economy of technologies at different stages:

- The cost of renewable energy technology falls sharply with the wind power cost expected to fall by 58% and the solar power cost by 71% by 2050 compared to 2018[6]
- The cost of green hydrogen tumbles and is expected to be below USD2 per kg in most markets by 2030, falling to USD1 per kg by 2050[7]
- Electrification continues and electricity becomes the main form of energy, with its share in final energy consumption expected to grow from 20% at present to 50% by 2050[8]
- The overall cost of CCUS technology is expected to decline from RMB 310-770/ton of CO_2 by 2030 to RMB 140-410 /ton of CO_2 by 2060, based on 250 km transport[9]
- Infrastructure is further improved, including renewable energy, hydrogen, carbon dioxide and thermal energy pipelines, and the synergy is increased in waste logistics and recycling
- Carbon pricing mechanisms and carbon trading markets are maturing with surging carbon price, and China's carbon price is expected to rise from about RMB 50/ton in 2021 to RMB 100/ton in 2030[10]

Figure 6: Decarbonizing technology categories in the petrochemical industry

Carbon reduction technology	• Energy efficiency improvement • Intelligent process efficiency improvement • Short process chemical production • Component refining • Process carbon reduction	• Electrification of process heating and renewable energy heating • Production of low-carbon basic chemicals • Chemical recycling of waste plastics • Process emission reductions by proprietary equipment
Intelligent process efficiency improvement	• Bio-based fuels and lubricants • Production and utilization of green hydrogen	• Power supply with Zero-carbon energy, such as wind, solar and nuclear
Short process chemical production	• Carbon dioxide capture • Carbon dioxide synthesis (e.g., preparation of syngas, methanol)	• Biological uses of carbon dioxide (e.g., seaweed farming) • Geological use and storage of carbon dioxide (e.g., enhanced oil and gas exploitation)

Source: RIPP research/Deloitte Research

6. BNEF, June 2018, https://www.china5e.com/news/news-1032591-1.html
7. "2021 Hydrogen Levelized Cost Update", BloombergNEF, April 2021
8. "Global Energy Transformation: A road map to 2050", IRENA, 2019, https://www.irena.org/publications/2019/Apr/Global-energy-transformation-A-roadmap-to-2050- 2019Edition
9. http://www.caep.org.cn/sy/dqhj/gh/202107/W020210726513427451694.pdf
10. https://pdf.dfcfw.com/pdf/H3_AP202107011501123385_1.pdf?1625151003000.pdf

Chapter 3 Carbon Reduction by 2025 – Approaches

During the 14th Five-Year Plan period, integrating management improvements, efficient energy utilization, process optimization and intelligence will lay a solid foundation for low carbon transition in the petrochemical industry. RIPP responded rapidly to national and industry needs by founding the Low-Carbon Economy Research Center of Petrochemical Industry. RIPP actively builds a "carbon peaking and carbon neutrality" platform, provides carbon emission statistics and accounting services for enterprises, uses carbon asset management software to help enterprises manage carbon reduction, develops and promotes carbon reduction technologies on efficient energy/resource utilization, refining/chemical process and intelligent optimization to reduce carbon emissions comprehensively, precisely and efficiently. As a global leading professional service provider, Deloitte has developed specialized management software for low carbon investment and operations, providing high-level guidance for strategic and transitional changes in enterprises.

Figure 7: Carbon reduction in the petrochemical industry by 2025 – Approaches

Management improvements	• "Carbon peaking and neutrality" platform of the petrochemical industry • Carbon emission statistics and accounting • Carbon asset management tools
Efficient resource/ energy utilization	• Integrated optimization of heat exchange networks • Steam power system optimization • Efficient utilization of low-temperature waste heat • Efficient hydrogen utilization • Component refining
Typical low carbon refining processes	• Catalytic cracking of crude oil for chemical raw materials • Low coke-formation catalytic cracking • Diesel liquid phase hydrogenation refining with low energy consumption • Hydrocracking with low carbon intensity for chemical raw materials • Efficient stripper to reduce emissions from catalytic cracking process
Typical low carbon chemical processes	• Vapor phase rearrangement of cyclohexanone oxime to caprolactam • Slurry bed for hydrogen peroxide
Intelligence	• Intelligent optimization of separation systems • Reactor simulation optimization

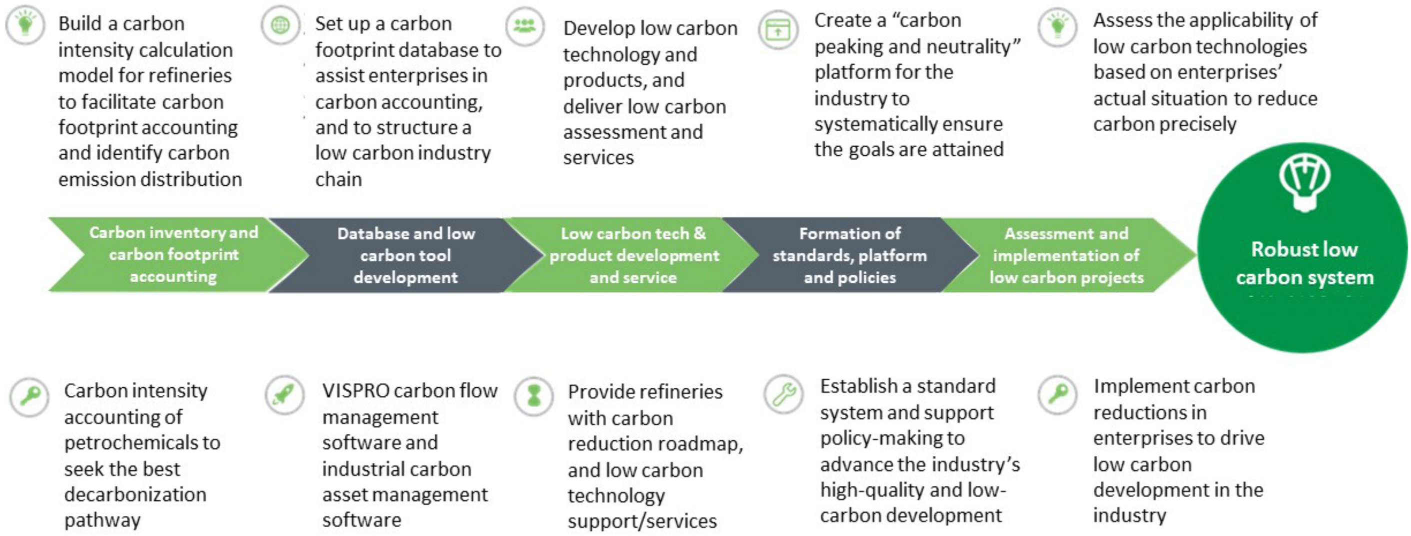
Section 1 Carbon peaking and neutrality platform in the petrochemical industry

Carbon peaking and neutrality set a direction for high-quality development in the petrochemical industry. They put up systematic requirements for carbon emission data, low-carbon technology, low-carbon products, and low carbon standards.

Accurate carbon emission statistics and accounting can quickly locate the emission sources as well as support rapid decisions on carbon reduction pathways. Low carbon technology is critical to reduce carbon emissions and is the core of producing low carbon products. Low carbon standards systematically place guardrails for the industry's low-carbon development.

Therefore, RIPP built a comprehensive low carbon system. It is also actively constructing both a low carbon technology evaluation and verification and product inspection and testing platforms, as well as a petrochemical carbon footprint database and a low carbon standard system to facilitate low carbon industry development.

Figure 8: RIPP's low carbon system



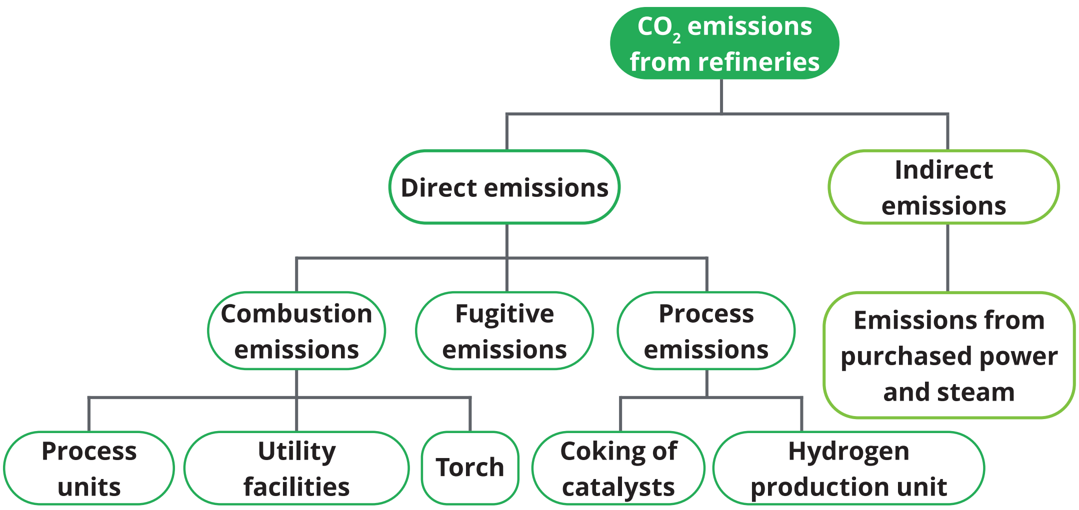
Section 2 Low carbon development basis – carbon inventory

The petrochemical industry must take practical and effective measures to achieve the green and low carbon transition under carbon reduction pressure and challenge. Accurate carbon emission data is the basis for low carbon development of the industry and enterprises and should be backed by a standardized and scientific accounting system.

Accurate carbon emission statistics and accounting can draw a clear picture of carbon footprints, help quickly identify key emission sources, make strategic decisions on carbon reduction, and carry out targeted carbon reductions to ultimately achieve carbon peaking and neutrality.

RIPP has been providing powerful technology support for developing the petrochemical industry. In response to China' s significant strategic decision of carbon peaking and neutrality, RIPP accelerated the green and low carbon development, and attached importance to carbon emission statistics and accounting. According to the characteristics of the petrochemical industry, it has put great efforts into enterprise carbon emission accounting and petrochemical product carbon footprint accounting, and has further improved the carbon emission statistics and accounting methods as well as the standard system.

Figure 9: Refinery carbon emission accounting



Section 3 Carbon asset management tools

Carbon emission rights can trade on the market as a commodity, with the value varying with supply and demand, making them an asset. Enterprises' carbon emissions change dynamically with operation modes, and energy conversation and carbon reduction technologies at different times. As the overall carbon emission management constantly upgrades in the industry, the carbon emission intensity will decline gradually. However, at the same time, quota allocation policies and consumers' low carbon standards are also changing. Enterprises must balance the needs of all parties to maximize the value of carbon assets. Efficient carbon assets management tools will be conducive to analyzing carbon reduction potentials and formulating carbon reduction plans at different times to make full use of carbon assets.

RIPP's VISPRO software system can build a carbon emission assessment model based on the refinery's overall process model, optimizing carbon inventory, product carbon footprint calculation and carbon flow for the whole plant. With the carbon emission model, refinery materials and carbon flow can be optimized, providing reliable support for carbon compliance and carbon asset management.

Figure 10: VISPRO model

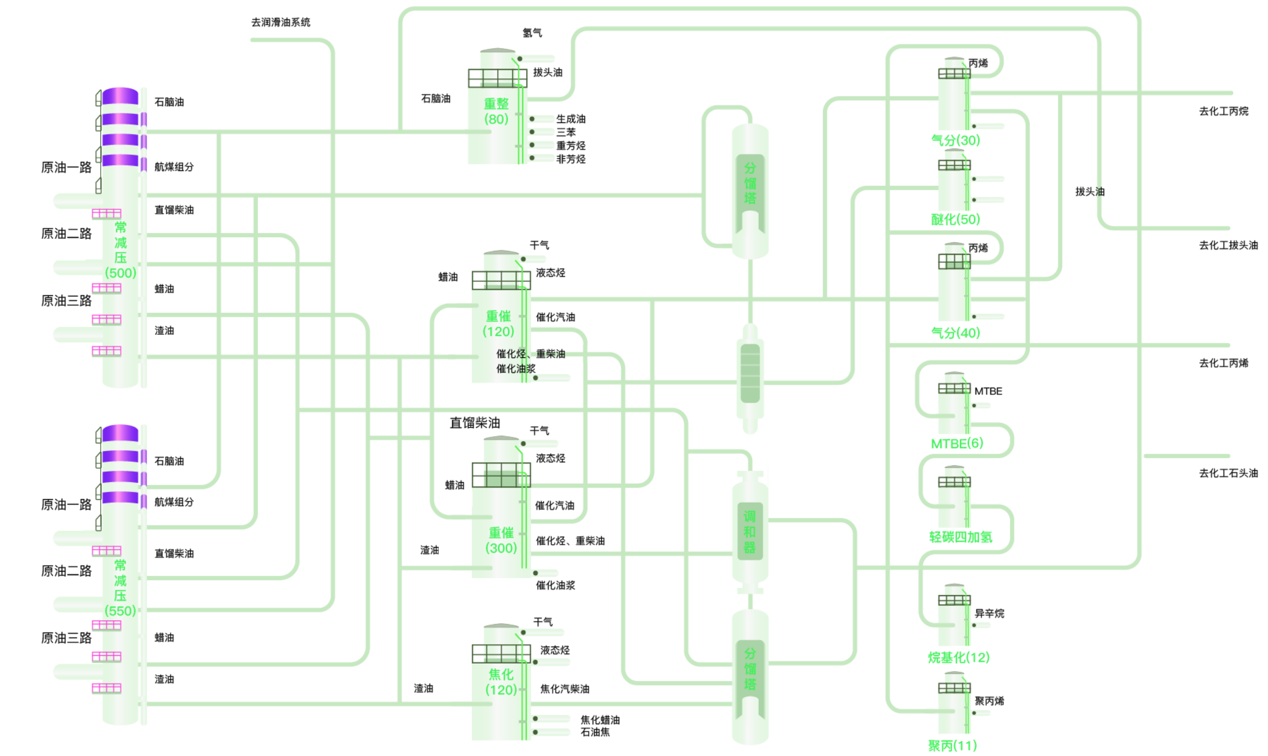
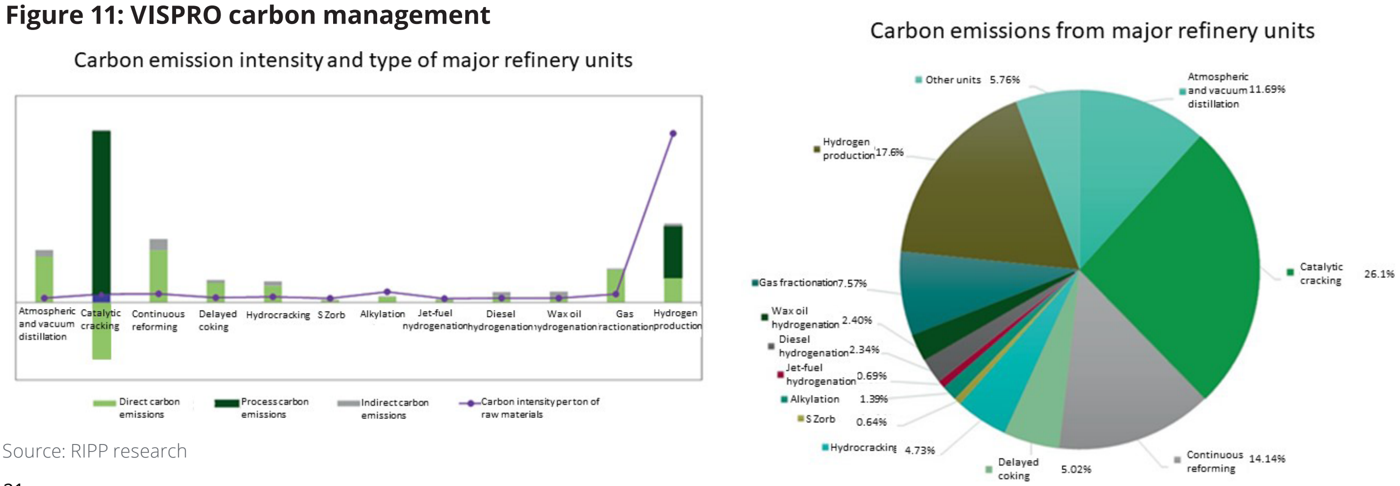


Figure 11: VISPRO carbon management



Source: RIPP research

Decarbonization life cycle extends across business operations and the value chain. Deloitte Decarbonization Solutions™ roadmap provides high-level guidance for strategic and transitional change of enterprises. The roadmap includes seven steps and clarifies their importance, inherent risks and main efforts for building a robust process. Enterprises can use this frame to assess their progress of comprehensive decarbonization strategy and plan follow-up initiatives as well as future actions.

Figure 12: Deloitte Decarbonization Solutions™ roadmap

Emission data and prediction
- Current and predicted emission data by region, fuel type, business operations, etc.

Climate risks
- Physical and transition risk assessment for all businesses in different IPCC scenarios (regulation, market and stakeholders)

Emission reduction pathway
- IPCC scenarios combined with financial impact assessments to formulate emission reduction pathway and possible SBTi compliance approaches

Operating emission governance
- Emission reduction project optimization
- Policy analysis and assessment
- Product portfolio optimization

Value chain cooperation
- Insight into current and future value chains and emissions
- Value chain partnerships for common needs

Internal and external communication
- Consistency in external statements and activities
- Employee engagement
- Consistent positioning of industry associations

Project development and deployment
- Financing
- Digital transformation
- Strategic influence
- Digital and risk analysis
- Operating structure

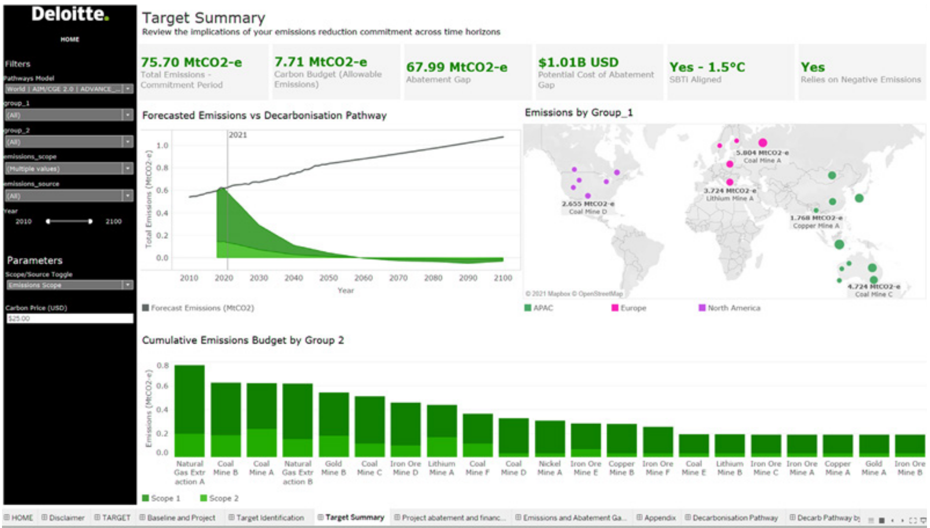
Emission data and projections

- Enterprises can use baseline emission data to forecast, measure, and monitor the target progress and assess the field most likely to be decarbonized.
- Enterprises must ensure the accuracy of emission data. Otherwise, it may lead to regulatory penalties and incorrect investor valuation.

Climate risk assessment

- The framework of TCFD provides climate-related risks and opportunities, where risks include transition risks and physical risks.
- Transition risks are arising from changes made to achieve low carbon development. The key is to judge the possible responses of different stakeholders over the next decade. Enterprises should consider the potential impact of varying emission reductions on value chain participants and themselves, especially on revenues and valuations.
- Physical risks include direct damage to assets and indirect damages from supply chain changes. In addition to fires, floods and hurricanes, changes in raw material availability, transportation modes, and product demands will also pose such risks.

Figure 13: Emission data graphing



Emission reduction pathway selection

- Before setting an emission reduction target, enterprises should judge the impact of emission changes in business costs and determine whether the target is in line with social expectations.
- To find the right emission reduction pathway, it is necessary to know the past and present emissions and consider the future emission target to identify adjustments and ultimately select a proper emission reduction pathway.

Project management

- Financial viability is critical to the success of projects, including carbon reduction projects. In anticipation of carbon reduction project benefits, enterprises should also develop a comprehensive reduction plan that addresses the timing, technology selection and geographic area of project implementation.
- Enterprises need to evaluate investment costs, benefits and implementation risks for proposed emission reduction projects; analyze the value chain of each emission reduction project and prioritize them to maximize benefits at the lowest cost.

Value chain cooperation

- Subject to carbon emissions of the product value chain, enterprises need to take increasing responsibility for emissions in the value chain (both upstream and downstream). The carbon emissions from the upstream and downstream are beyond their control, so will bring some risks.
- Compared with operating emissions, value chain emissions are more difficult for enterprises to control due to constraining upstream and downstream industries. Therefore, the governance of value chain emissions needs cooperation with partners. By working together to construct a low carbon value chain, enterprises can solve complex technical problems in synergy, and exert greater pressure on laggards, thus promoting low carbon development of the whole value chain.

Internal and external communication

- Internal and external stakeholders expect enterprises to actively explore an economically efficient low carbon transition. Being socially responsible, enterprises should communicate with or be open to stakeholders about their emission reduction actions and results. Effective communication mechanisms are essential to get solid support from stakeholders and maintain business operations.

Project deployment

- For sustainable carbon reductions, decarbonization should be carried out in three dimensions: short-term projects that can be delivered immediately; medium-term strategic projects; and long-term projects with difficult emission reductions.
- Emission reduction projects should be closely integrated with businesses and benchmarked to advanced projects to attract investments and reduce capital costs.

Figure 14: Reduction target identification

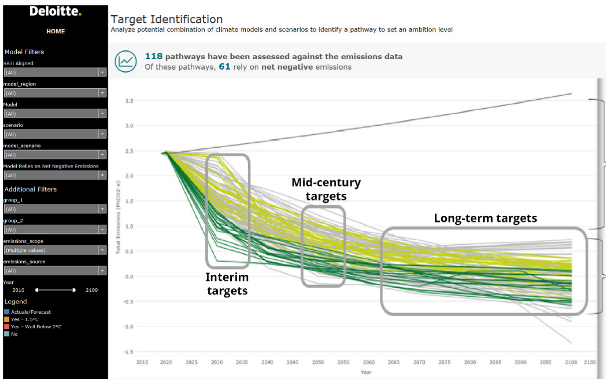
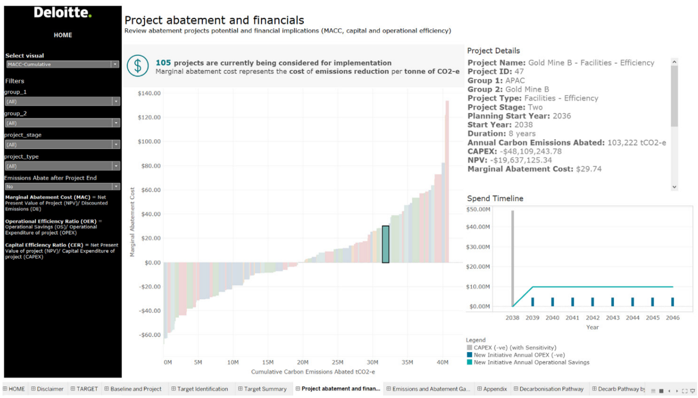


Figure 15: Prioritizing the lowest cost reduction



Section 4 Efficient utilization of energy and resources

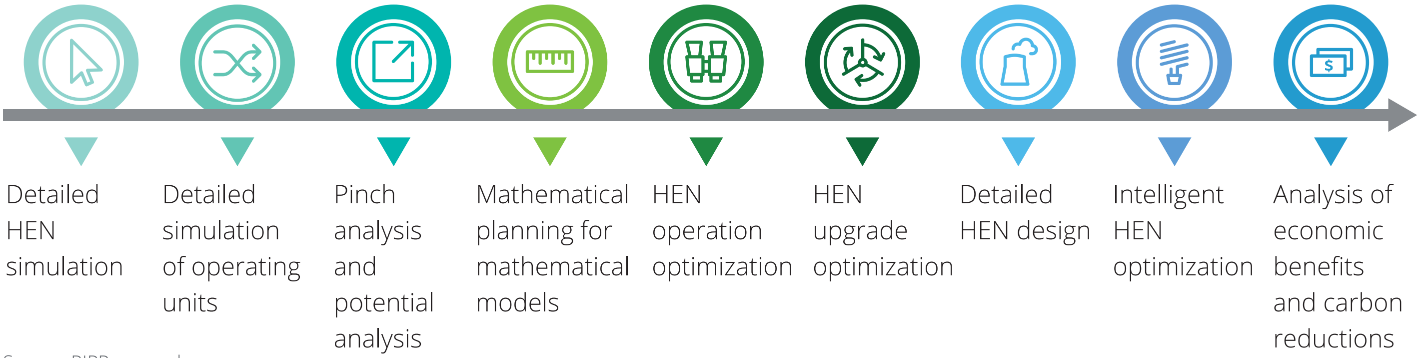
Integrated optimization of heat exchange networks

Heat exchange networks (HEN) play a vital role in the energy recovery of the petrochemical industry. Higher HEN thermal efficiency is significant for refineries in energy reservation and carbon reduction, economic efficiency improvement, long-term stable operation, and environmental protection.

Combining pinch analysis with mathematical planning, the integrated HEN optimization can achieve a rigorous HEN simulation of the whole plant and individual unit for detailed diagnosis and elasticity analysis. Operation and upgrade optimization suggestions are then proposed given characteristics and constraints of energy utilization for units to achieve optimal distribution and comprehensive use of energy medium. An intelligent HEN optimization platform can automatically generate solutions for different refineries' processes and optimization targets, and energy conservation and efficiency solutions with better economic benefits are provided, helping the petrochemical industry to save energy and reduce carbon emissions.

The HEN integrated optimization technology can be widely applied to thermal combinations of refinery intra- and inter-units to achieve energy saving and carbon reduction by improving energy efficiency and reducing the heater's fuel gas and steam consumption. For example, the integrated HEN optimization of an atmospheric and vacuum distillation unit (AVDU) with a capacity of 10 million tons can reduce carbon emissions by 20,000 to 50,000 tons/year, improve energy efficiency by 1 to 3 kgoe/ton and increase economic benefits by RMB 15 to 30 million per year.

Figure 16: Integrated optimization of heat exchange networks



Source: RIPP research

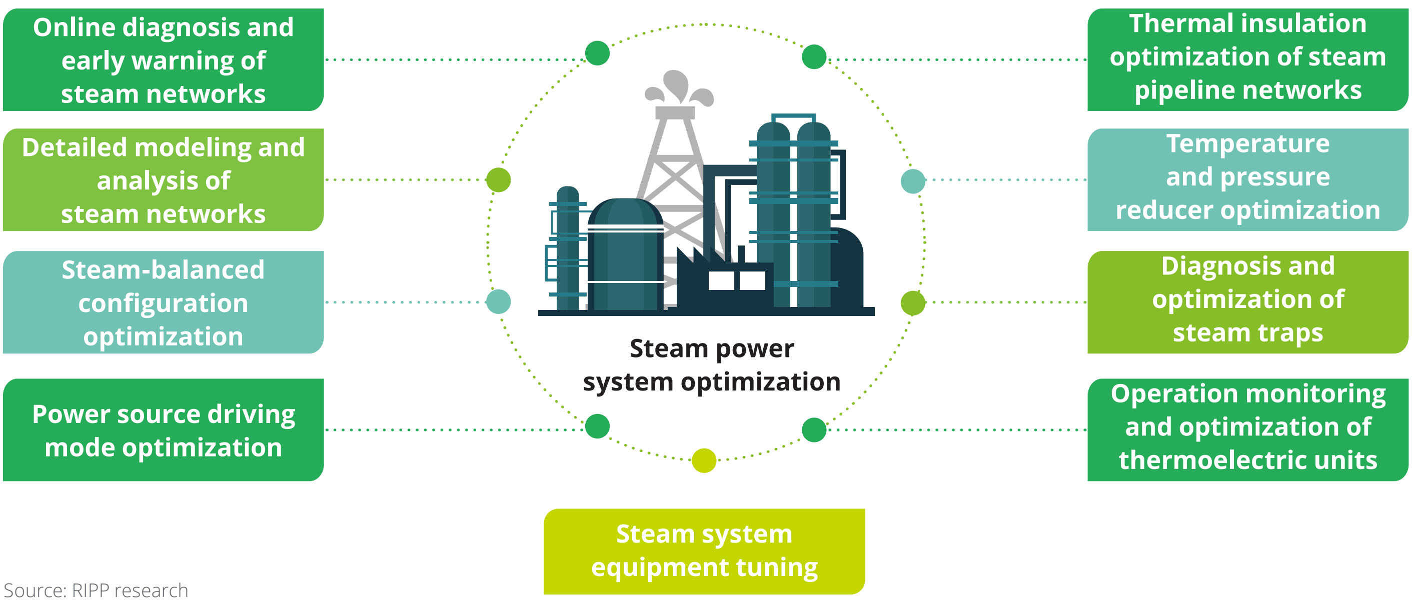
Steam power system optimization

The steam power system in the petrochemical industry has characteristics such as multi-level parameters, multiple fuel sources, the need for more steam production and supply, and multi-period conditions. It locates at the front end of energy conversion, where primary energy must first be converted into heat, steam, and power before used by process units. Process units, other utilities, auxiliary, and subsidiary production systems can easily influence its optimization. In petrochemical enterprises, the energy conservation effect of its optimization is mostly the reduction in electricity, steam and fuel gas consumption. Its optimization is an integral part of refinery energy conservation and carbon reduction. The reasonable configuration and operation of the steam power system is a necessary basis for building an energy saving process system as well as a key step for changing the energy savings of the process system into economic benefits.

The optimization of the steam power system can satisfy the energy conservation and carbon reduction needs of the petrochemical industry. Process simulation is used to assist in building a complete mathematical model of the steam power system, which helps identify and solve mixed integer nonlinear programming problems, including steam system equipment tuning, power source driving mode optimization, steam network optimization and steam-balanced configuration optimization. The optimization of steam power system can also enable safe and stable operation in the petrochemical industry. Specifically, the operation plan is evaluated and analyzed based on coupled hydraulic and thermodynamics calculations for steam pipeline networks. The online monitoring module is implemented to assist enterprises with real-time monitoring and overload alarm of steam pipeline networks. Besides, according to enterprises' different operation stages, the operation status of the steam power system is statistically analyzed, or the upgrade plan is evaluated and optimized.

By optimizing the steam power system, CO_2 emissions can be reduced by 0.17-0.29 tons for every ton of steam saved; 10 million ton scale refineries can save energy by 13-19 kgoe per ton of steam, reducing CO_2 emissions by 25,000-60,000 tons/year.

Figure 17: Steam power system optimization



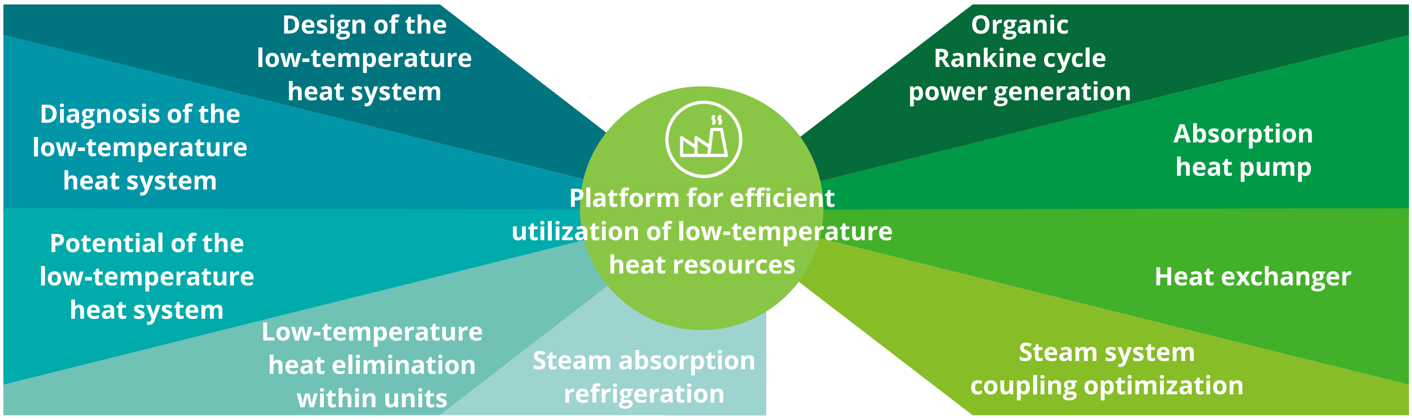
Source: RIPP research

Efficient utilization of low-temperature waste heat

The key to the low energy efficiency of the petrochemical industry in China compared with developed countries is that the low-temperature waste heat resources are not fully utilized. The current rate of waste heat utilization in the US is 60% and 50% in Europe, while the rate in the petrochemical process in China is only 30%. Low-temperature waste heat is the heat that cannot be utilized after the internal heat recovery of the production system, which is also essentially derived from the thermal energy converted by the fuel. Therefore, reasonable utilization and recovery of low-temperature waste heat are significantly important for energy conservation and carbon reduction.

To meet the needs of energy conservation and carbon reduction as well as quality and efficiency improvements in petrochemical enterprises, it is necessary to carry out detailed modeling, diagnosis, analysis and optimization of the low-temperature heat resource system for the whole plant, combining process simulation with computational fluid dynamics to assist diagnosis and analysis. In addition, on the principle of "temperature alignment and step-by-step utilization", the utilization of low-temperature heat resources throughout the plant needs to be comprehensively optimized in balance with the steam power system.
For 10-million-ton refineries, efficient utilization of low-temperature waste heat can reduce CO_2 emissions by 40,000 tons/year for the whole plant in the case of a 10% increase in low-temperature heat recovery rate.

Figure 18: Efficient utilization of low-temperature waste heat



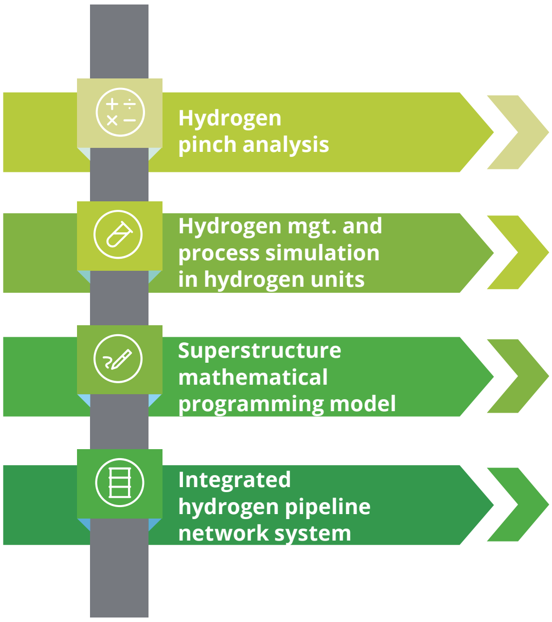
Source: RIPP research

Efficient hydrogen utilization

In China, as available crude oil is more heavy and inferior and with increasingly stringent oil cleanliness, the hydrogenation process is widely used in Chinese petrochemical enterprises. Their hydrogen demand increased yearly, while the carbon-based grey hydrogen production process can cause huge energy consumption and carbon emissions. As a result, petrochemical companies need to reduce carbon and increase efficiency through integrated optimization of the hydrogen system for a higher hydrogen utilization rate.

For "carbon peaking and neutrality", refineries' concept of hydrogen utilization should gradually move from hydrogen balance to hydrogen management. Refineries should proceed from hydrogen resource recovery and utilization, hydrogen saving management in hydrogen units as well as integrated optimization of the hydrogen network system to achieve the cascaded hydrogen utilization, the hydrogen efficiency improvement, and the reduction in hydrogen consumption, system energy consumption as well as CO_2 emissions. At present, the main industrial hydrogen is carbon-based grey hydrogen. In particular, the carbon emission of coal-based hydrogen is about 24kg of CO_2/kg of H_2 and natural gas-based hydrogen about 10kg of CO_2/kg of H_2. The efficient and optimal utilization of hydrogen resources in 10-million-ton refineries can reduce carbon emissions by 20,000 to 30,000 tons/year and increase the economic benefit by RMB 30-60 million per year.

Figure 19: Efficient hydrogen utilization



Diagnose refineries' hydrogen network operation, identify bottlenecks of hydrogen use, analyze hydrogen saving potentials and optimization directions, and provide matching rules of hydrogen streams.

Achieve the collaborative optimization of hydrogen networks and units, as well as integrated optimization of hydrogen distribution networks and optimum operating parameters for hydrogenation unit.

Optimize the topology of hydrogen networks under practical constraints.

Optimize and upgrade the hydrogen pipeline network based on the existing one, considering the refinery's layout, the pipeline network pressure, and the hydrogen consumption characteristics of regional hydrogenation units, as well as engineering investment costs and operating costs.

Section 5 Typical low carbon refining processes

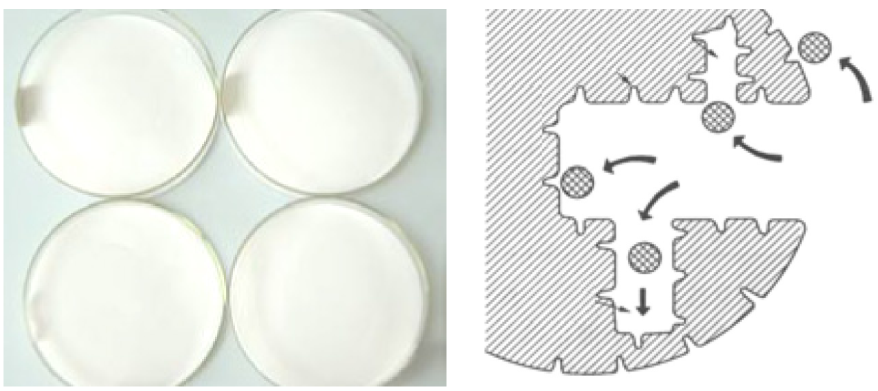
Catalytic cracking of crude oil for chemical raw materials

Refining-petrochemical integration can convert crude oil into chemicals, but has a long process flow, high investment intensity, and high carbon emissions. The crude oil catalytic cracking is an innovative breakthrough in producing chemical raw materials in short processes, and a new technology converting crude oil direct to chemicals to cope with carbon peaking and oil conversion.

Based on the cracking property of hydrocarbon molecules and the process characteristics of the catalytic cracking reaction-regeneration system, the technology uses reaction zoning coupling conversion to achieve the efficient conversion of molecules with significantly different cracking properties in the same system, which can greatly improve chemical selectivity and reduce process carbon emissions.

Compared with the integrated light oil steam cracking and heavy oil catalytic cracking, the technology reduces carbon emissions by more than 30%.

Figure 20: Low coke formation catalytic cracking



Source: RIPP research

Low coke formation catalytic cracking

Catalytic cracking is a major source of carbon emissions in the petrochemical industry. Over 50 million tons/year of carbon emissions are from catalytic coking in China's petrochemical industry. Low coke formation catalytic cracking effectively supports carbon reduction in the petrochemical industry for "carbon peaking and neutrality".

The core of the technology is the use of a weakly acidic matrix platform with medium to large pore, ultrastable small grain molecular sieve, a micro-meso-macro pore structure by anti-metallic components, and catalytic cracking catalyst with an adjustable active site. It enables efficient conversion of heavy oil with lower coke in the reaction process to reduce carbon emissions during catalyst regeneration.

Taking a catalytic cracking unit (CCU) with a capacity of 2 million tons/year as an example, the technology can reduce carbon emissions by more than 50,000 tons/year.

Diesel liquid phase hydrogenation refining with low energy consumption

The relatively high hydrogen to oil volume ratio and low hydrogen single-pass conversion rate in traditional diesel hydro refining units lead to a large hydrogen cycle, and the energy consumed to maintain the hydrogen cycle accounts for about 50% of the total for diesel hydro refining units, resulting in unnecessary energy consumption.

The diesel liquid phase hydrogenation refining technology eliminates the hydrogen recycle compressor and largely reduces the energy consumption of diesel hydrogenation units without compromising reaction performance. Compared with the traditional trickle bed diesel hydro refining technology, this technology can reduce the units' energy consumption and carbon emissions by more than 50%.

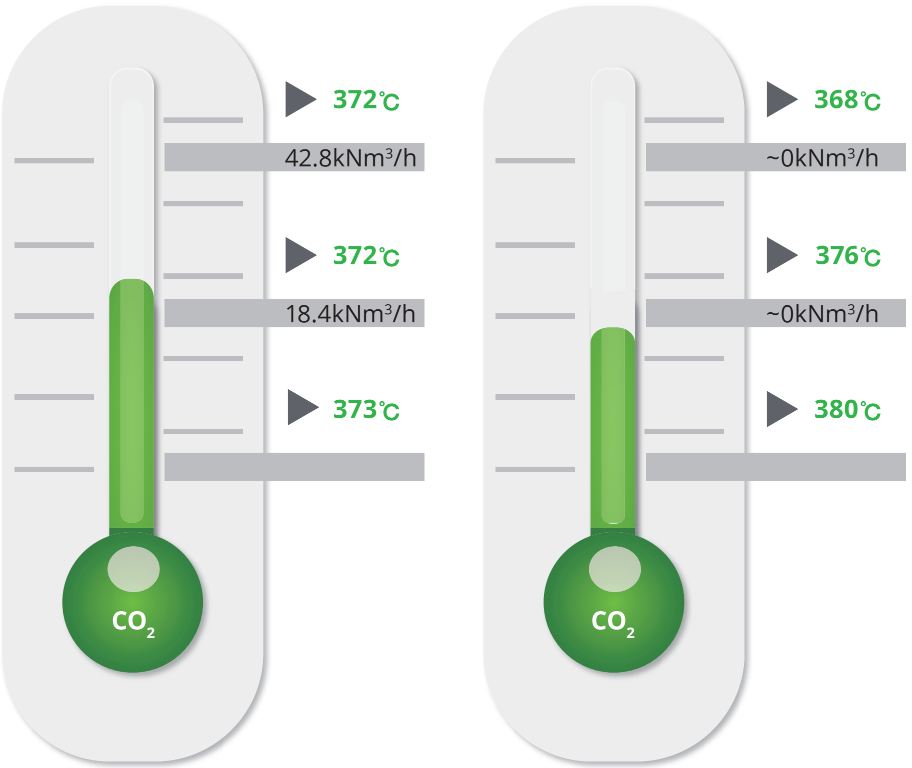
Hydrocracking with low carbon intensity for chemical raw materials

Hydrocrackers account for 6%-10% of the overall refining energy consumption and about 50% of hydrogen consumption in the refinery. This proportion will rise as refining transfers to chemical engineering. Lower energy consumption and carbon emissions in the hydrocracking process are important for hydrogenation technology.

Through high performance and selectivity hydro-refining, / hydrocracking catalysts and grading technologies, the precise matching of target chemical reactions within hydrocracking reaction zones, and the zoning for reaction enhancement, the low carbon hydrocracking technology for chemical raw materials improves the selectivity of the hydrocracking process, reduces chemical hydrogen consumption, and makes full use of the hydrocracking reaction heat for the matching between catalyst's optimal reaction temperature and the hydrocracking reaction temperature rise in each zone. The technology can reduce carbon emissions in terms of electricity, hydrogen and fuel gas consumption.

Taking a 2 million tons/year hydrocracker as an example, the technology can reduce overall energy consumption by 10%-20%, chemical hydrogen consumption by 5%-10%, and direct and indirect carbon emissions totally by about 50,000 tons/year.

Figure 21: Hydrocracking with low carbon intensity for chemical raw materials



Source: RIPP research

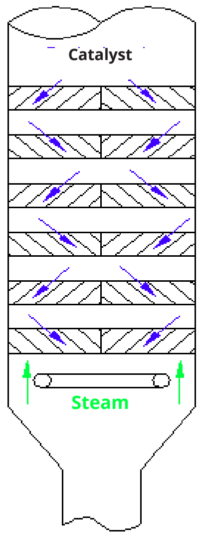
Efficient stripper to reduce emissions from catalytic cracking process

Stripper is an important part of a CCU, and its performance directly affects the economic efficiency, stability and carbon emissions of the CCU.

RIPP developed a packing stripper with guide plates to improve stripping efficiency and reduce carbon emissions. The stripper is divided into separate zones by spaced packing components in the axial direction, and each internal component is subdivided into multiple zones by guide plates in the radial direction. As a result, the components divide the stripper bed into several small flow units, in which gas and solid phases are exchanged, facilitating sufficient contact between the gas and the gas-solid "emulsion phase" in the bed. The design gives the stripper significant advantages in terms of stripping efficiency, processing capacity, operating stability, and flexibility, effectively reducing carbon emissions by increasing stripping efficiency by about 20% and reducing steam consumption by 20%.

The packing stripper reduces the regenerator's carbon dioxide emissions by stripping the spent catalyst. For a CCU with a capacity of 2 million tons/ year, it can reduce carbon emissions by nearly 110,000 tons per year.

Figure 22: Efficient CCU stripper



Source: RIPP research

Section 6 Typical low carbon chemical processes

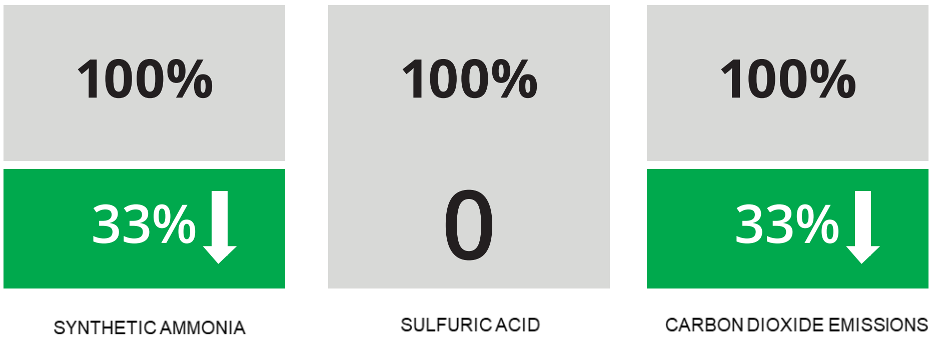
Vapor phase rearrangement of cyclohexanone oxime to caprolactam

Caprolactam is a primary organic chemical raw material. Currently, caprolactam is mainly produced through the Beckmann rearrangement of cyclohexanone oxime (liquid phase rearrangement). The technology needs transformation and upgrading as it uses sulfuric acid and liquid ammonia, has low-value ammonium sulfate as a by-product, requires a long process time, and generates a large quantity of three wastes (solid waste, wastewater, and waste gas).

The vapor phase rearrangement technology eliminates sulfuric acid and ammonia and features a high atom economy, short production process, and low "three wastes" emissions. It was included on the Petrochemical Green Process List in 2018. As a disruptive technology for the caprolactam production process, the technology is rapidly adopted in the industry, which significantly increases the competitiveness of the production process and is expected to lead to the high-quality and green development throughout the industry.

With the vapor rearrangement technology, a caprolactam production plant with a capacity of 600,000 tons/ year can reduce carbon emissions by 1.1 million tons per year, and 1.2 tons per RMB 10,000 of output value, with an over 65% drop in carbon intensity.

Figure 23: Characteristics of vapor phase rearrangement of cyclohexanone oxime to caprolactam

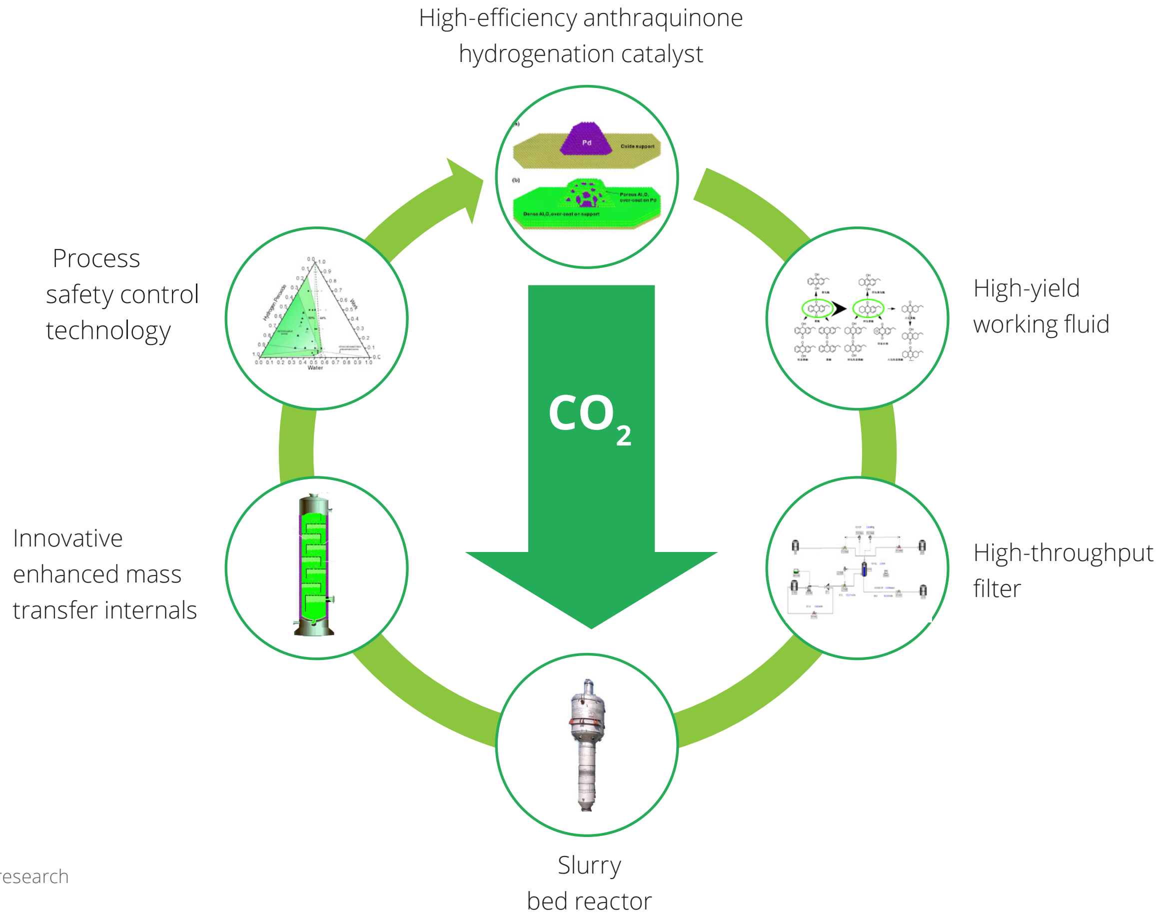


Source: RIPP research

Slurry bed for hydrogen peroxide
The anthraquinone process is the mainstream for hydrogen peroxide preparation both at home and abroad. Subject to the production of microsphere anthraquinone hydrogenation catalyst and slurry-bed reaction process, anthraquinone hydrogenation is mainly based on a fixed-bed process, which leads to limited production efficiency and scale, and restricts the expansion of downstream green chemical technologies for caprolactam and propylene oxide. Therefore, it is an urgent task to improve the technology bottleneck.

The slurry bed process applies a series of core technologies, such as enhanced oxidation process and high-yield working fluid formulation, making it the most competitive green hydrogen peroxide preparation process. China's first industrial slurry bed device for hydrogen peroxide production was built and put into operation in 2019, which set a significant model for the industry. Compared with the traditional fixed-bed technology, the process reduces carbon emission intensity by 27%.

Figure 24: Green production process of hydrogen peroxide with slurry bed



Source: RIPP research

Section 7 Intelligent improvement of process efficiency

Intelligent optimization of separation systems

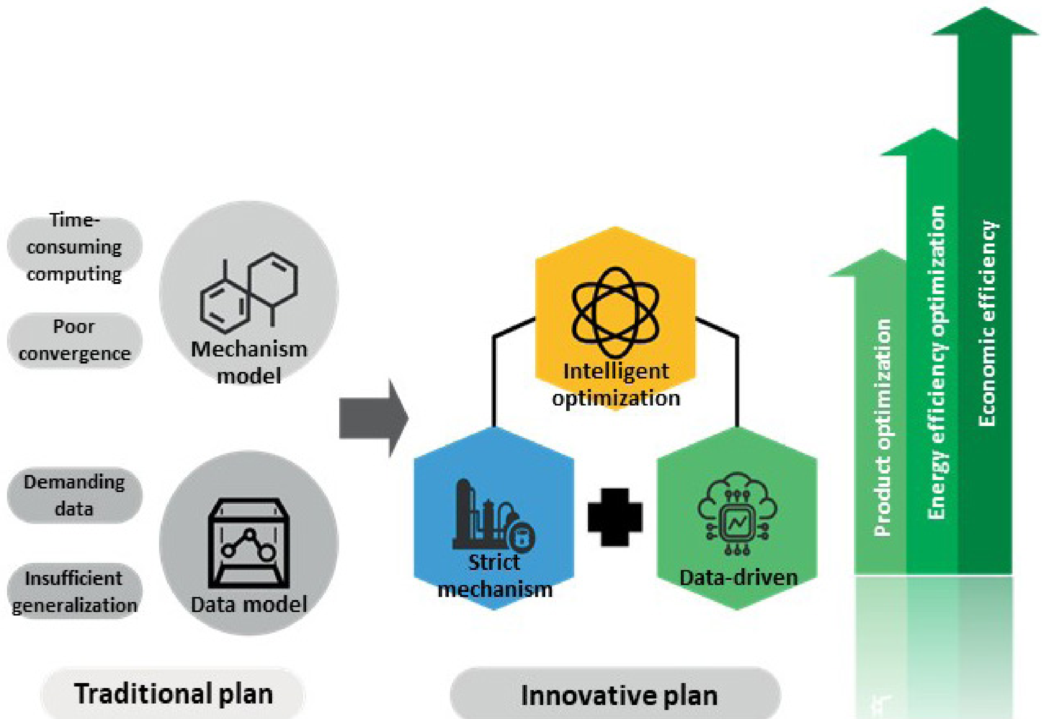
The petrochemical industry involves many complex separation systems. In addition to the leading AVDU, catalytic cracking, delayed coking, hydrocracking, and other units also contain complicated separation systems with high processing capacity, complex structure, and frequent changes in working conditions, whose energy consumption accounts for 30% to 50% of the total in a plant. Thus, the separation system is important for petrochemical enterprises to optimize energy saving and carbon reduction.

As automation advances in the petrochemical industry, it is applied in most processing units. However, its parameters and process settings are still experience-based, which poses a significant risk to the unit's stable operation and product distribution. With the development and application of artificial intelligence (AI) and big data technology, intelligent solutions are increasingly valued in the petrochemical industry. Using AI and big data mining to simulate and optimize complex separation systems in the petrochemical industry contributes to the quality and efficiency improvement, energy-saving, emission reduction, and technology innovation of petrochemical enterprises.

Intelligent separation system optimization technology adopts an AI-driven process optimization algorithm that organically combines the process mechanism model, AI model, and efficient, optimized algorithm. Without compromising model accuracy and convergence, it improves model computing speed and timely response to adjusting production conditions and optimization targets. It provides operation optimization solutions that maximize economic efficiency (considering the energy consumption index).

With the intelligent separation system optimization platform, an AVDU with a capacity of 10 million tons can raise the final heat transfer temperature by 4-6▯, reduce energy consumption by 0.5-2.1 kgoe/t, cut carbon emission by 10,000-42,000 tons per year, increase the light oil yield / total distillate yield by 0.5%-1.5%, and improve profitability by RMB 20-50 million per year.

Figure 25: Intelligent optimization platform for separation systems



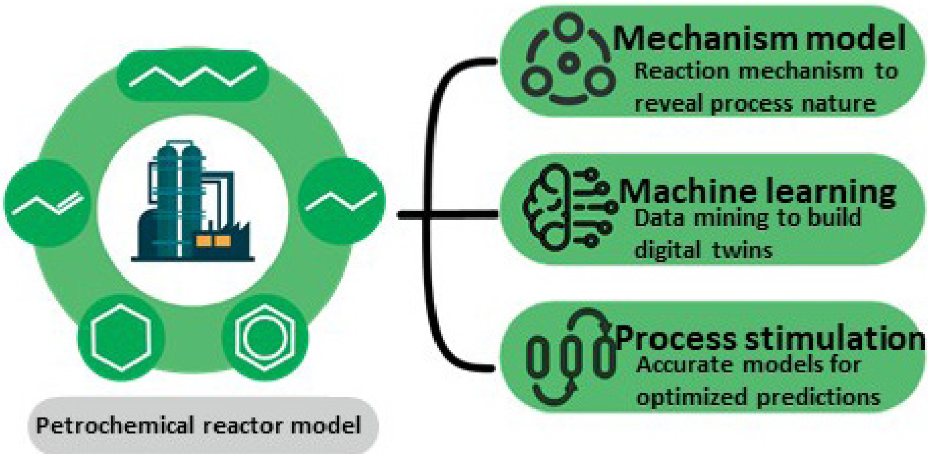
Source: RIPP research

Reactor simulation optimization

With the comprehensive implementation of the "carbon peaking and carbon neutrality" strategy and strict control of two energy consumption indicators (total amount and intensity of energy consumption), energy-saving and carbon reduction have become a major trend in the petrochemical industry. As a result, the green and low-carbon oriented optimization for reactor simulation is the focus and inevitable trend of refining process innovation and upgrading in the industry. Based on process mechanism, process simulation, and data-driven technology, simulation models in single mode, multi-mode and collaborative mode are built for reactors of refineries, which fully utilize the advantages of diversified and customized modeling. The dynamic correlation model allows energy flow to drive material flow, and material flow generates or affects energy flow. Thus, production operation is optimized by improving production efficiency and product quality while reducing energy consumption and carbon emissions.

According to practical applications, reactor simulation optimization can effectively improve energy efficiency and reduce carbon emissions, with a 2% to 15% reduction in energy consumption and carbon emissions.

Figure 26: Reactor simulation optimization platform



Source: RIPP research

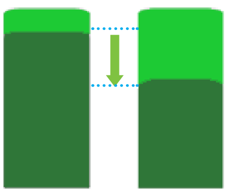
Section 8 Component refining

The traditional refining process separates crude oil into various fractions by boiling range and further processes them into petroleum products. In this process, some components of fractions are not sufficiently and reasonably utilized, leaving room for improvement in reaction selectivity and efficiency during refining.

Component refining is a better method to improve efficiency and reduce energy consumption. It adopts advanced separation technology to separate hydrocarbon components from crude oil or its fractions and then refines the separated components. Concentrated processing of similar hydrocarbon components can significantly improve reaction selectivity, enhance products' added value, and reduce carbon emissions.

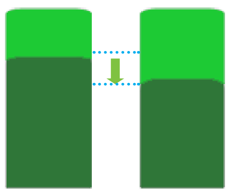
For a refinery with a capacity of ten million tons, the re-engineered component refining process can reduce carbon emissions by nearly 450,000 tons per year, and 0.26 tons per RMB 10,000 of output value, an over 10% decrease in carbon intensity.

Figure 27: Carbon reduction diagram of component refining



Total carbon emissions reduced by 445,700 tons per year

The component separation process significantly reduces the amount of coke burned in the catalytic cracking unit resulting in a total carbon emissions reduction of 445,700



Carbon emissions reduced by 0.26 tons per 10,000 yuan of output value

The component separation process reduces the total carbon emissions and increases product output value, resulting in a reduction of CO_2 per million yuan of output value by 0.25 tons

Source: RIPP research

Chapter 4 Carbon Peaking by 2030 - Technology Support

To achieve carbon peak goals by 2030, the petrochemical upstream and downstream industries need to work together on scientific industrial planning and reasonable production capacity construction to ensure economic development and green transformation go hand-in-hand. Although the industry enters a new stage and faces new challenges in new conditions, innovative core technologies provide a solid support for clean production, process upgrading, and value enhancement. Based on carbon reduction efforts by 2025, bio-based fuels and lubricants, innovative technology for a circular economy, and low carbon intensity basic chemical production technology can greatly support and accelerate the carbon peaking in the petrochemical industry, while laying the groundwork for building a low-carbon value chain.

Figure 28: Carbon peaking by 2030 in the petrochemical industry– technology support

Bio-based fuels and lubricants	· Bio-jet fuel · Biodiesel · Bio-based lubricant
Innovative technology for a circular economy	· Chemical recycling technology for waste plastics
Low carbon intensity basic chemical production technology	· Low carbon intensity propylene production technology · Low carbon intensity aromatic production technology

Section 1 Bio-based fuels and lubricants

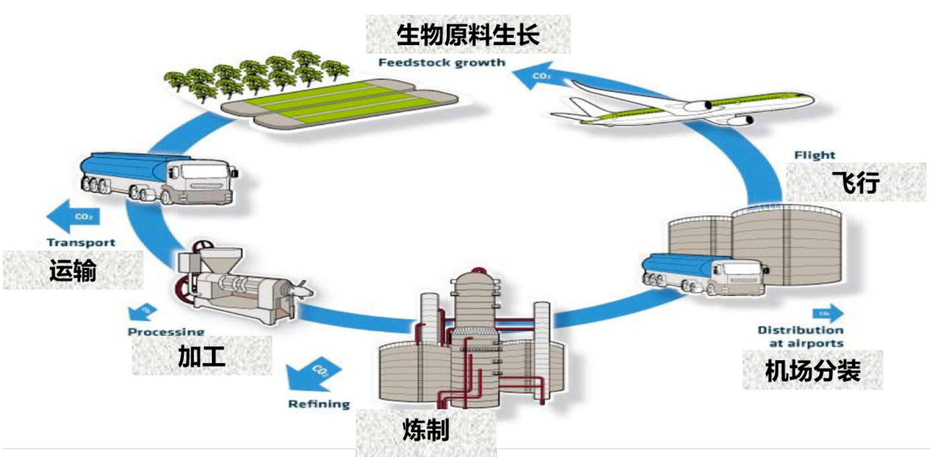
Bio-jet fuel

Full life cycle studies show that sustainable jet fuels are the primary option for the aviation industry to reduce carbon emissions. As an important sustainable material, biomass-derived fats, oils and greases (FOGs) are still the main source of bio-jet fuels.

Hydrogenation technology is commonly used in the production of jet fuels with FOGs. FOGs are pretreated to remove part of the impurities and then hydrogenated while O, S, N and other heteroatoms are removed, to prepare jet fuel components. According to the current standards, bio-jet fuels can contribute up to 50% of the total aviation kerosene in an aircraft.

The carbon emissions of jet fuels vary by raw material and manufacturing process. Jet fuels produced with waste FOGs can reduce carbon emissions by more than 80% throughout the life cycle compared with petroleum-based jet fuels.

Figure 29: Full life cycle of bio-jet fuel



Produces with RIPP technology

Source: RIPP research

Biodiesel

Hydrocarbon-based biodiesel with hydrogenation technology features high heat value, high cetane number and excellent low-temperature fluidity. Such biodiesel has unique advantages over fossil energy in sustainable development. For example, combined with the modern transportation system, it can significantly lower the dependence on fossil energy and reduce carbon emissions.

To produce biodiesel, FOGs are first pretreated to remove impurities and hydrogenated while O, S, N, and other heteroatoms are removed and then go through an isomerization reaction to adjust the freezing point. With similar hydrocarbon compositions, petroleum-based diesel and hydrogenated biodiesel can be blended in any ratio. Compared with petroleum-based diesel, biodiesel derived from waste FOGs can reduce carbon emissions by more than 80% throughout its life cycle.

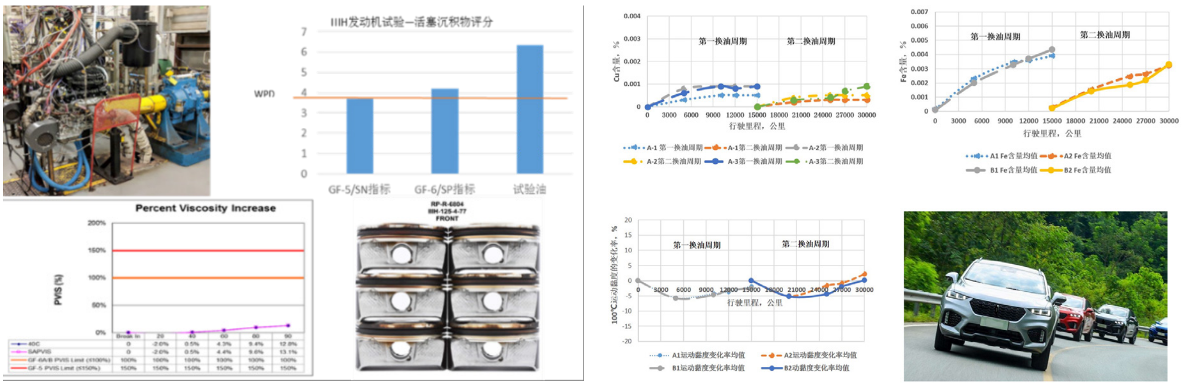
Bio-based lubricant

China produces and consumes many lubricants, more than 98% of which are prepared in traditional petroleum processing. If lubricants leak, spill, evaporate, or are improperly disposed of, they can seriously pollute the natural environment. As environmental protection is increasingly important, bio-based lubricants have become a new growth point for the lubricant industry as they are renewable, biodegradable and applied to environmentally sensitive areas. The bio-based GF-5 gasoline engine oil developed by RIPP effectively compounds bio-based lubricants and functional additives and has passed the physical and chemical performance test, simulation evaluation test and all of the seven standard engine evaluation tests. It is the only bio-based GF-5 engine oil technology with core intellectual property rights in China. Moreover, the comprehensive performance of the bio-based hydraulic oil meets all ISO15380

standards for the HEES category, with some indicators significantly exceeding the requirements. The bio-based gasoline engine oil and hydraulic oil have passed the biological toxicity test, with a biodegradation rate of over 60%.

Bio-based lubricant technology can lower dependence on petroleum, and greatly reduce a product's lifecycle carbon footprint.

Figure 30: Engine test and running test of bio-based GF-5 gasoline engine oil



Source: RIPP research

Section 2 Innovative technology for a circular economy

High-value recycling of waste plastics has become a major issue worldwide. China has about 1 billion tons of waste plastics in its dumping sites and produces more than 60 million tons of plastics each year. Currently, most plastic waste is burned to generate electricity, discharging large amounts of CO_2.

RIPP's plastic waste recycling technology enables a pyrolysis oil yield of more than 80% by choosing appropriate pretreatment routes for different plastics. The technology helps petrochemical enterprises to realize a closed-loop plastic recycling process by efficiently converting pyrolysis oil into plastic monomer or polymer, forming advantages in reducing carbon emissions and generating circular economy benefits.

The carbon footprint producing plastic monomer by chemical recycling is 40% lower than that of crude oil. The carbon emissions per RMB 10,000 of output value by chemical recycling is 80% lower than incineration for power generation at the crude oil price of USD80/barrel. If two-thirds of China's waste plastics are chemically recycled, carbon emissions will decrease by 47 million tons per year.

Section 3 Low carbon intensity basic chemicals production technology

Low carbon intensity propylene production technology

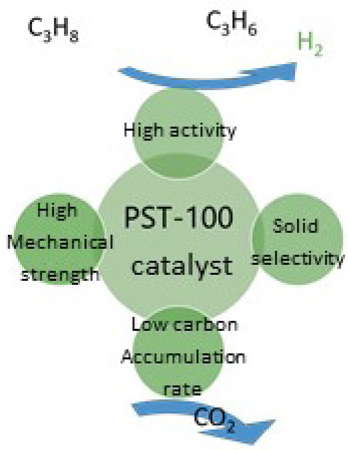
Under the "carbon peaking and carbon neutrality" strategy, propane dehydrogenation technology is increasingly important for low carbon propylene production. Propane single-pass conversion and propylene selectivity are key factors determining the carbon emissions in the propane dehydrogenation process. Higher single-pass conversion and selectivity can improve reaction efficiency and reduce energy consumption for the separation of propane and propylene.

RIPP fully understands the catalytic reaction process, and independently developed PST-100, a high-efficiency moving bed propane dehydrogenation catalyst, which has high activity, high selectivity and low carbon deposition rate, and can effectively improve conversion rate, increase target product yield and reduce carbon emissions.

Based on the PS T-100 catalyst, RIPP developed a set of (moving bed) propane dehydrogenation (SPDH) technology with low energy consumption and carbon emissions. The technology improves single-pass conversion and selectivity by adjusting the reaction pressure and hydrogen to hydrocarbon ratio and further reduces energy consumption by optimizing the heating furnace and reaction-regeneration process. With advantages of high mechanical strength and less dust generation, the PST-100 catalyst enables long-term stable operation with optimized process design, significantly reducing the ineffective carbon emissions in startup and shutdown processes, and maintaining a low propylene carbon footprint.

A propane dehydrogenation unit applying the SPDH technology can reduce carbon emissions by over 10% with advanced catalyst and process.

Figure 31: Characteristics of low carbon intensity propane dehydrogenation technology



Low carbon intensity aromatic production technology

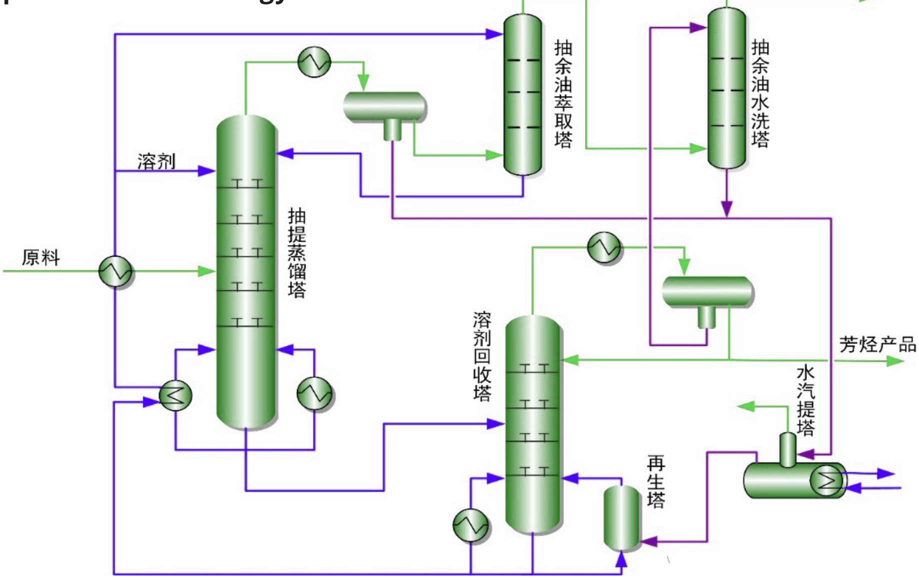
Aromatic is an important chemical raw material, mainly produced with liquid-liquid extraction and extractive distillation processes. The liquid-liquid extraction process is energy consuming since it requires blending with a large amount of raffinate oil to process raw materials with high aromatic content. Large volumes of backwashing liquid circulate between the extractor and stripper. The extractive distillation process requires lower investment and consumes less energy, but when producing benzene, toluene and Xylene (BTX), the benzene yield, and toluene purity are not ideal.

RIPP developed next-generation low energy consuming aromatic extraction technology (SED-BTX) by integrating the liquid-liquid extraction process into extractive distillation technology.

The SED-BTX technology increases the yield of high purity BTX products while greatly reducing the energy and material consumption of the plant, thus serving the goal of energy-saving and carbon reduction.

Compared with the traditional liquid-liquid extraction process the SED-BTX process reduces comprehensive energy consumption by 18% per ton of feedstock and carbon emissions per RMB 10,000 of output value by 58 kg.

Figure 32: Process of low carbon intensity aromatic production technology



Source: RIPP research

Chapter 5 Carbon Neutrality by 2060 - Route Strategy

To achieve the strategic goal of carbon neutrality in the petrochemical industry by 2060 and to create a green, low-carbon, circular economy and a clean, low-carbon, safe and efficient energy system, the industrial and energy structures are expected to experience disruptive adjustments, and new and renewable energy will grow rapidly and lead the development of the industry. To build a "zero-carbon" industry, enterprises need to leverage industrial strengths and strengthen scientific and technological support by focusing on key products and developing key technologies. The upgrading and breakthrough of green hydrogen, CCUS, or electrification implementation are important routes for the petrochemical industry to achieve carbon neutrality.

Figure 33: Carbon neutrality in the petrochemical industry by 2060 – route strategy

Green hydrogen technology	· Water electrolysis for hydrogen · Biomass gasification for hydrogen
CCUS technology	· CO_2 hydrogenation for jet-fuel · CO_2 hydrogenation for methanol · CO_2 and methane dry reforming for syngas · CO_2-assisted chemical viscosity reduction for enhanced thick oil recovery · Microalgae technology to fix carbon
Electrification technology	· Electrification implementation technology
Low carbon path for typical refining technologies	· Catalytic cracking

Section 1 Green hydrogen technology

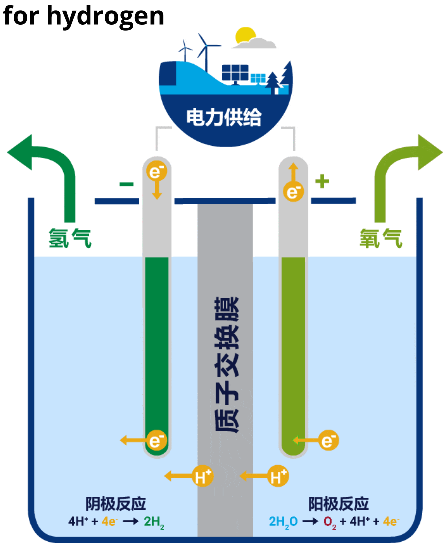
Water electrolysis for hydrogen

Currently, China consumes around 30 million tons of hydrogen per year, mainly produced with fossil energy, generating a large amount of carbon emissions. The PEM water electrolysis process converts water into hydrogen and oxygen with renewable energy, producing minimal carbon emissions.

Water electrolysis hydrogen production uses a proton exchange membrane (PEM) with excellent chemical stability, proton conductivity, and gas barrier property as a solid electrolyte. It electrochemically splits water into hydrogen and oxygen at the cathode and anode. The technology features high hydrogen production efficiency (>85%), high hydrogen purity (99.999%), high hydrogen pressure (>3 MPa), fast response (in seconds), compact structure and small size. Therefore, it is the perfect complement to volatile renewable energy such as wind and solar power.

Compared with hydrogen production from coal and natural gas, PEM water electrolysis based on renewable energy can reduce CO_2 emissions by 20 tons and 10 tons, respectively, for each ton of H_2 produced. In China's 30 million tons of annual hydrogen output, 65% is produced from coal, and 15% is from natural gas. Carbon emissions will decrease by 35 million tons per year if 10% of the hydrogen output is produced with PEM.

Figure 34: Water electrolysis for hydrogen



Source: RIPP research

Biomass gasification for hydrogen

Biomass is the only natural renewable carbon source and an effective alternative to most fossil fuels. Compared with nuclear, hydro, wind, and geothermal energy, biomass is widely distributed, abundant, renewable and low-polluting, so it is considered an ideal renewable energy source. Using biomass to produce green hydrogen can reduce the energy industry's dependence on fossil fuels, and contribute to a circular economy by reducing CO_2 emissions. Therefore it is a key trend for the energy industry.

The technology fully considers the gasification characteristics of different biomasses. After drying, grinding, crushing, and granulating, the biomass is treated by gasification, gas purification, water-gas shift, and hydrogen purification to produce hydrogen with nearly net-zero carbon emission. It can effectively address high carbon emissions from the existing hydrogen production process using fossil energy.

The biomass gasification for hydrogen production technology can reduce about 9 tons of CO_2 emissions per ton of H_2, compared with natural gas's existing hydrogen production process.

Figure 35: Water electrolysis for hydrogen

Source: RIPP research

Section 2 CCUS technology

CCUS technology is a key to addressing global climate change. It is an effective and necessary step to achieve carbon neutrality as it can capture and convert large amounts of CO_2.

CO_2 hydrogenation for jet-fuel

Many countries are developing comprehensive CO_2 utilization technologies based on CO_2 capture. CO_2 hydrogenation produces multi-carbon organic compounds with higher economic value. Specifically, CO_2 hydrogenation for jet-fuel production is a disruptive strategic technology.

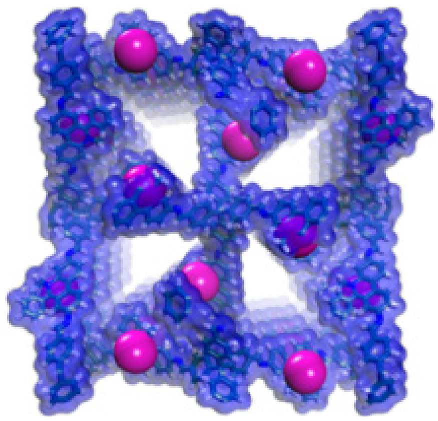
New materials, catalyst design, and catalytic system construction based on the latest research strategy is the key to CO_2 hydrogenation conversion.

RIPP's comprehensive high-efficiency CO_2 to jet-fuel technology can achieve a single-pass CO_2 conversion rate of 41.6% and jet-fuel fraction selectivity of 51.1%.

Compared with petroleum-based jet fuel, the CO_2 hydrogenation process can reduce nearly 3.0 tons of life-cycle carbon emissions per ton of jet-fuel.

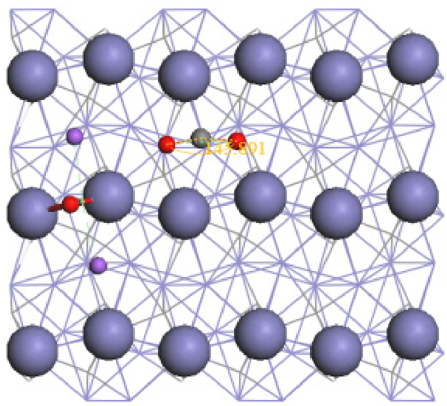
According to the EIA's forecast in 2019, the global jet fuel demand will reach 649 million tons by 2050. If 20% of the demand is met by CO_2 hydrogenation, the global CO_2 emissions will drop by nearly 400 million tons per year.

Figure 36: New porous reaction material



Source: RIPP research

Figure 37: Computer simulation of CO_2 adsorption



Source: RIPP research

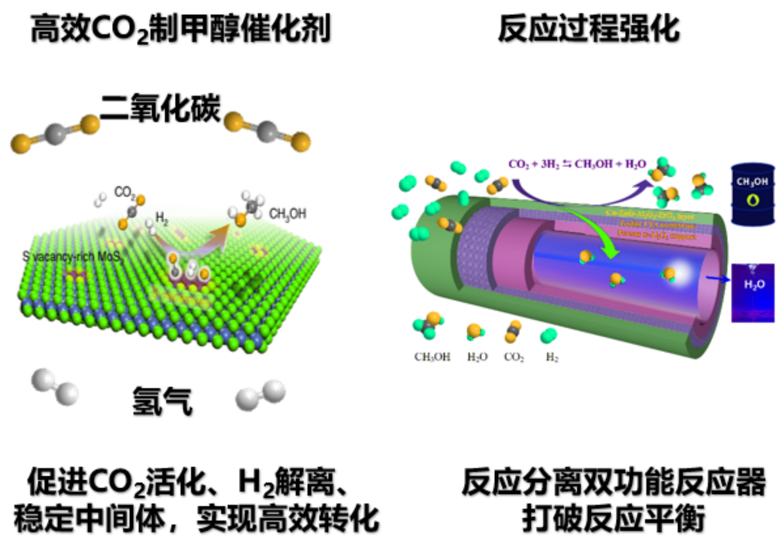
CO_2 hydrogenation for methanol

The CO_2 hydrogenation for methanol production technology can utilize CO_2 and convert green electricity generated by wind and solar energy into chemical energy that can be stored and transported. As a green and low-carbon energy storage technology, it strongly supports the carbon neutrality goal.

The project team of RIPP researched on an indium-based catalyst system. It developed a catalyst with a single-pass CO_2 conversion rate of at least 15%, methanol selectivity of at least 85%, and organic phase methanol concentration of at least 99.5%. Using a membrane reactor, the technology breaks thermodynamic limits to enhance the reaction process, and provides process package for units with a capacity of 100,000 tons per year.

Methanol production from CO_2 and green hydrogen reaction reduces two tons of CO_2 per ton of methanol as compared with coal production. According to the IMF forecast, to hold the global average temperature rise to below 2°C by 2030, CO_2 should be priced at around USD 75 per ton. At this price, 100,000 tons of methanol produced from CO_2 hydrogenation can create a carbon reduction value of USD 15 million per year.

Figure 38: CO_2 hydrogenation for methanol



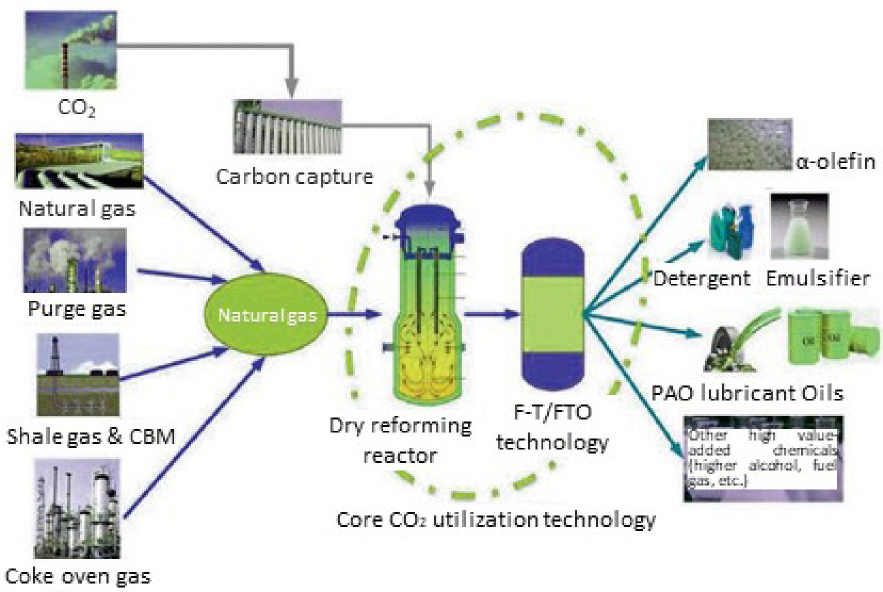
Source: RIPP research

CO_2 and methane (CH_4) dry reforming for syngas

Dry reforming of methane (DRM) is the process converting CH_4 and CO_2 into syngas. The reaction makes use of two greenhouse gases, and produces important basic raw materials for the chemical industry which can be used in the synthesis of methanol, F-T and carbonyl. Therefore, DRM is supposed to be an effective process for large-scale CO_2 utilization.

With this technology, a syngas unit with a capacity of 360,000 tons per year can consume a remarkable 62,000 tons of CO_2 per year, equivalent to the CO_2 absorption of 3.4 million trees.

Figure 39: CO_2 and methane dry reforming for syngas



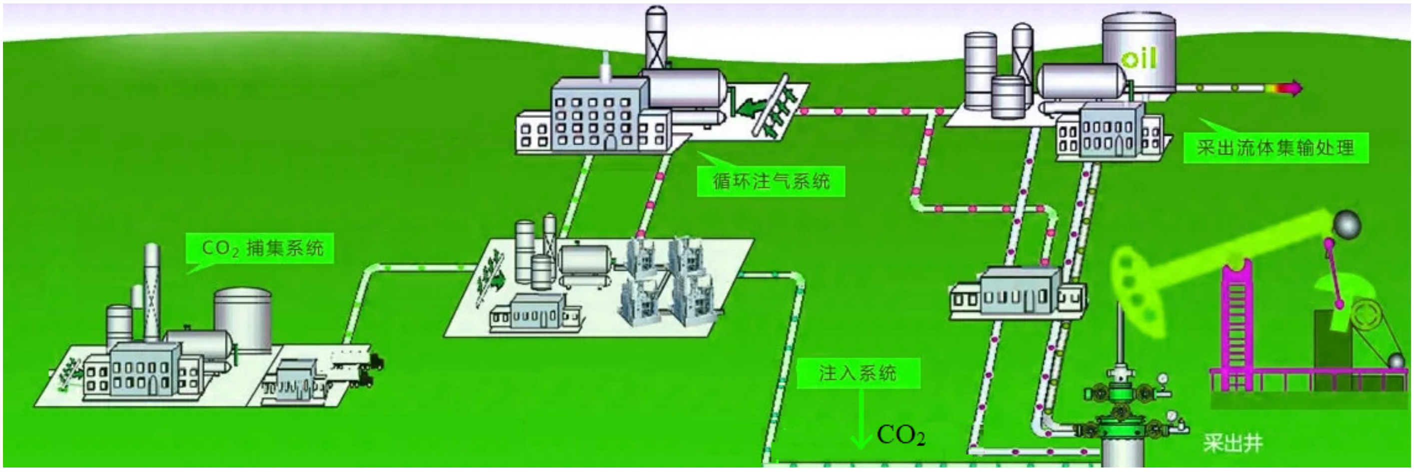
Source: RIPP research

CO_2-assisted chemical viscosity reduction for enhanced thick oil recovery

As the underground reserves of light crude oil decrease and the proportion of thick oil gradually rises, the efficient recovery of thick oil is increasingly important. However, thick oil is tough to exploit, gather and transport due to its high density, high viscosity and poor fluidity, so an efficient viscosity reduction technology is in urgently needed to improve the efficiency of thick oil recovery.

CO_2's excellent solubility in crude oil can significantly reduce crude oil's viscosity, expand crude oil's volume, and enhance strata's elasticity. CO_2 dissolves in water to carbonate it and then reacts with carbonates in oil reservoirs. This improves stratum permeability and unblocks oil flow channels. Injecting CO_2 from captured industrial exhaust gas into thick oil reservoirs assists in reducing viscosity chemically, improves fluidity, and enhances recovery, during which most of the injected CO_2 is consumed or retained underground.

Figure 40: Oil recovery process with CO_2-assisted chemical viscosity reduction technology



Source: RIPP research

Microalgae technology to fix carbon

Microalgae are single-celled organisms that efficiently convert inorganic carbon and nitrogen into organic carbon (mainly carbohydrates and lipids) and nitrogen (mainly proteins) through photosynthesis, showing outstanding application value.

Microalgae produce large amounts of biomass rich in fat and protein and also contribute to carbon peaking, carbon neutrality and air pollution control by absorbing and fixing CO_2 and NOx released from fossil energy.

For every ton of microalgae biomass produced, 1.83 tons of CO_2 and 0.2 tons of NOx are absorbed. A farm with 3,400 mu of microalgae can absorb 10,000 tons of CO_2 and produce about 5,400 tons of high protein microalgae biomass per year, with a market value of RMB 70 million.

Source: RIPP research

Section 3 Electrification implementation

In addition to the carbon emissions from the burning of fossil fuels, the petrochemical industry also causes indirect carbon emissions with purchased electricity, which produces about 10% of the total emissions in the industry. There are two main measures to reduce carbon emissions caused by electricity, applying new energy-saving technologies and equipment, optimizing power facilities, and, more importantly, adopting a new power system. As China aims to build a new power system dominated by new energy, the power grid is shifting focus to cleanliness, and carbon emissions from electricity consumption in the petrochemical industry are expected to decrease.

According to the NBS, in 2021, about 71.13% of China's total electricity was thermal power, mainly produced by coal. It is predicted that after 2050, the proportion of wind and solar power will rise substantially to more than 30%, while hydropower and nuclear power will remain at about 10%, respectively, and thermal power will be less than 9%. By 2060, the carbon emission factor of China's national grid will plummet by about 97%, and the indirect carbon emissions from electricity consumption in the petrochemical industry will drop sharply by about 97%.

Section 4 Low carbon path for typical refining technologies – Catalytic Cracking

Catalytic cracking is a key technology in refining and an irreplaceable part of heavy oil processing. However, it is necessary to accelerate the transition to a low-carbon development path because of its high carbon emissions. The path covers the following aspects.

1. Catalytic materials

Active component materials of catalysts will remain the widely used zeolite molecular sieves before 2025, and shift to shape-selective zeolites before 2030 as gasoline demand peaks with propylene as a by-product; shape-selective zeolites and solid alkalis by 2040; and zeolite-confined metals, solid alkalis and oxides by 2050.

2. Reaction mode

Currently, catalytic cracking is mainly realized through the riser reaction process. In the future, for maximizing the production of light olefins such as propylene, the reaction mode is expected to consist of a riser tube plus a bed or multiple reaction zones. Meanwhile, a restructured fluidization reaction system will be developed and gradually become the main reaction mode for emerging low-carbon catalytic cracking technology.

3. Coking method

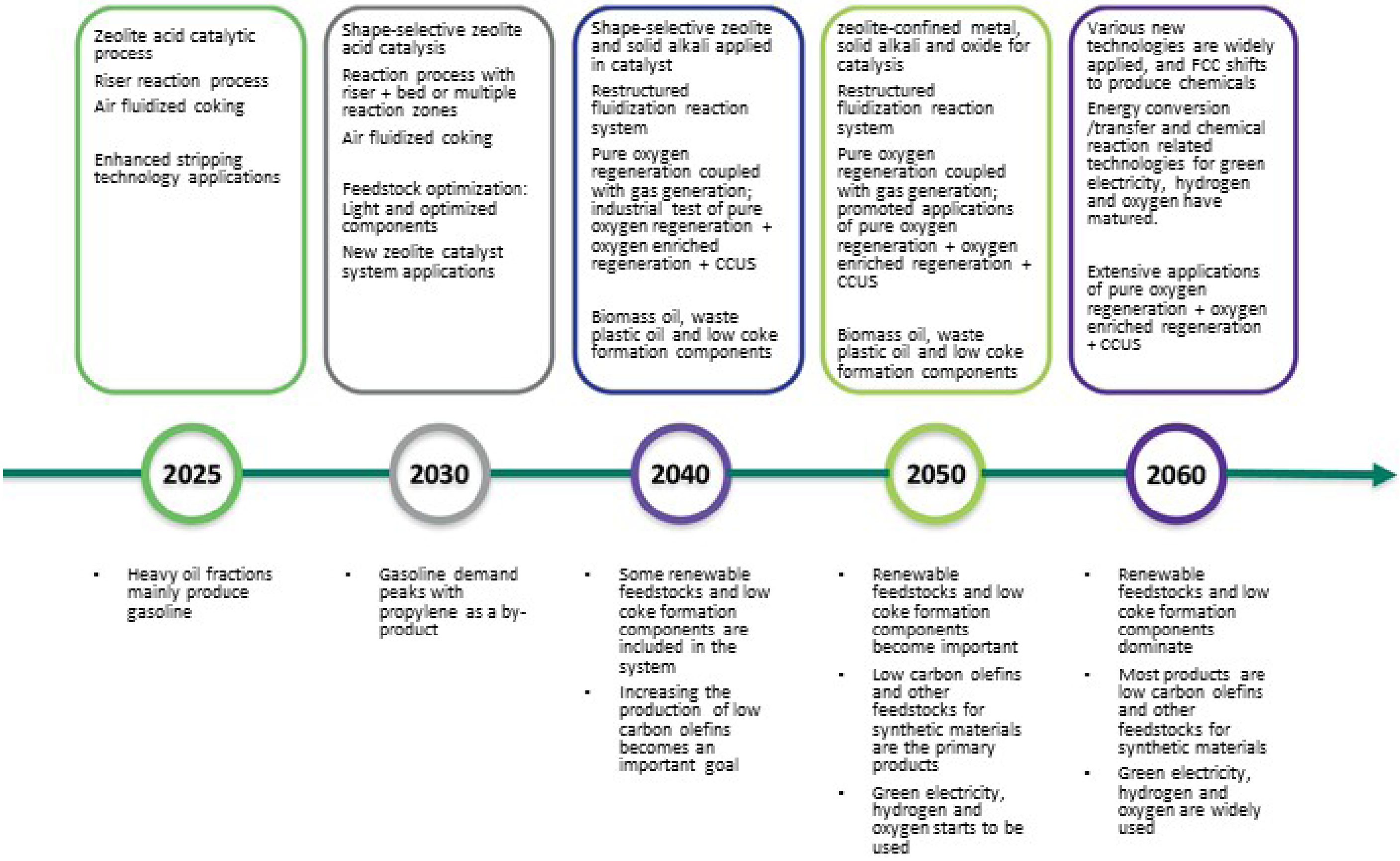
The current air-fluidized coking method will prevail until 2025, while coupling pure oxygen regeneration with gas generation and developing the oxygen enriched regeneration + CCUS regeneration coking method. As refineries advance towards carbon neutrality targets, low-carbon emission coking methods will be widely adopted.

4. Feedstock type

At present, increasing the use of light catalytic cracking feedstock is the most feasible carbon reduction method, including renewable feedstock such as biomass oil and waste plastic oil, and low coke formation components. As the circular economy develops, renewable feedstock will become the main component for catalytic cracking.

The future of low-carbon catalytic cracking technology will convert renewable feedstock and low coke formation components into low carbon olefins and other feedstock for synthetic materials and will extensively utilize mature green electricity, hydrogen, and oxygen in energy conversion/transfer and chemical reactions.

Figure 41: Low carbon path for catalytic cracking technology

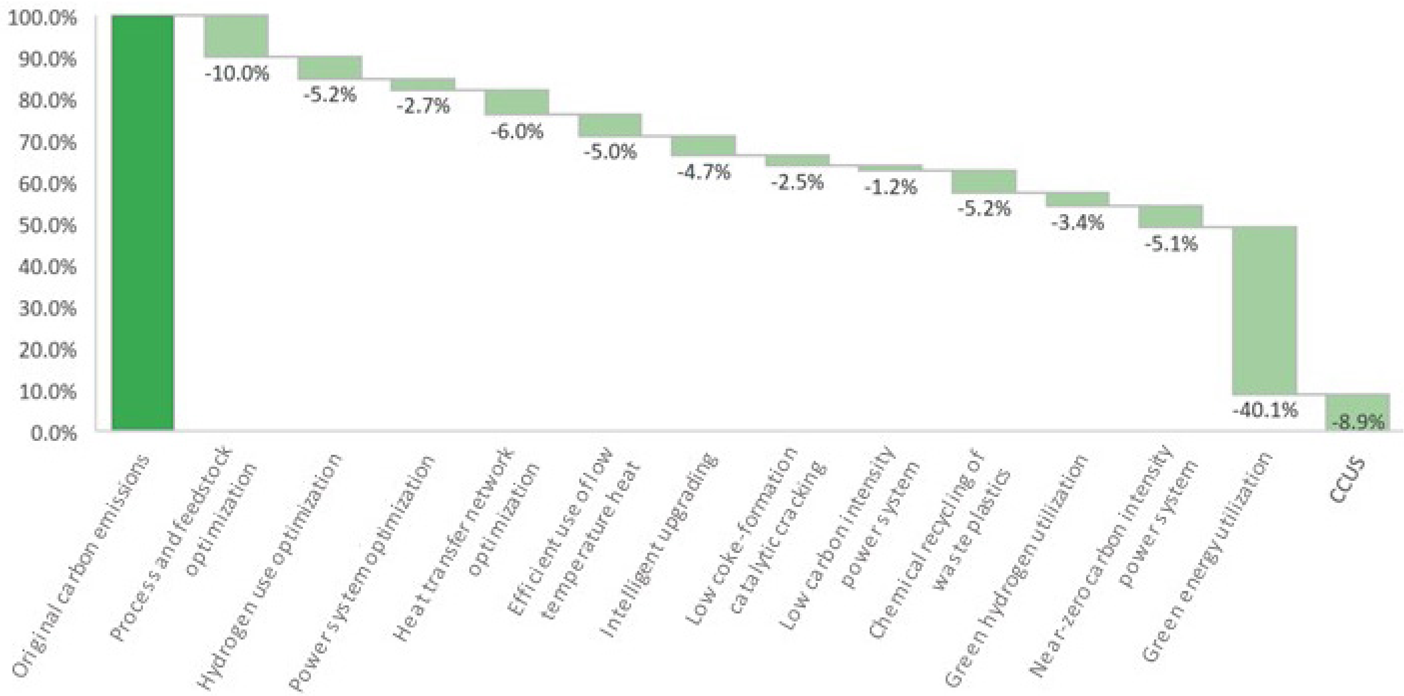


Source: RIPP research

Chapter 6 Low Carbon Roadmap to 2060

Looking into the future, as the petrochemical industry gradually shifts to green and low-carbon development, the carbon neutrality goal is an inevitable challenge as well as an opportunity to adjust industrial structure, improve competitiveness and achieve ecological conservation and sustainable development. Enterprises should turn the challenge into an opportunity by embracing industrial transformation and low-carbon trends. Specifically, they shall increase the energy efficiency of existing units through efficient energy utilization, process optimization, and alternative clean energy and get ready for the low-carbon transformation by promoting development and commercialization of advanced carbon reduction technologies and carrying out pilot projects. By modeling carbon reduction contributions of technologies available in petrochemical production processes over time, typical refining enterprises are projected to achieve Net-Zero by 2060.

Figure 42: Carbon reduction roadmap for refining companies



Source: RIPP research

Carbon neutrality is a challenging transition goal and cannot be achieved overnight. The Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy proposes three phased goals by 2025, 2030 and 2060. Accordingly, the petrochemical industry shall decompose the carbon reduction target and process.

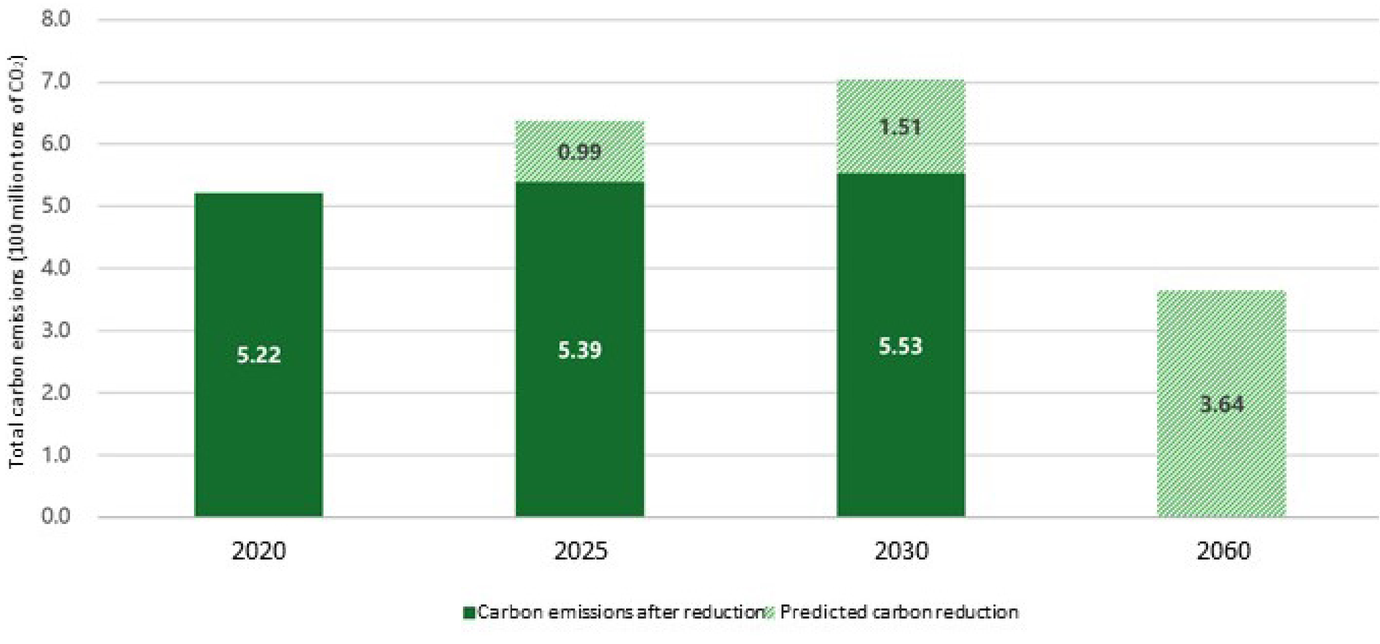
We studied the oil processing and petroleum products production process. We forecasted the total carbon emissions and emission reduction potential of different stages, considering the emission reduction technology matured at each stage. At the current stage, refined oil products still dominate terminal petroleum consumption. In the forecast model, the petrochemical industry emits 522 million tons of CO_2 per year.

It is predicted that China's crude oil processing volume will be 790 million tons in 2025. Meanwhile, the consumption of refined oil products is expected to be near the peak, and the production of chemical raw materials will rise significantly. If no emission reduction measures are taken, the carbon emissions of the petrochemical industry will reach 638 million tons. However, suppose enterprises take feasible carbon reduction measures such as improving energy efficiency and hydrogen use efficiency, even though only 70% of such measures can be implemented considering that there are only three years from now to 2025. In that case, the carbon emissions of the petrochemical industry will decrease by 99 million tons to 539 million tons.

With the promotion of the "carbon peaking and neutrality" policy, petroleum's fuel function is weakening, while the improved living conditions of people are creating massive demands for petrochemical raw materials, and enterprises with integrated refining and chemical operations are expanding their advantages. As a result, China's oil demand will peak in 2030 at 820 million tons. Without emission reduction measures, the petrochemical industry's carbon emissions will amount to 704 million tons by 2030. However, with the implementation of energy-saving and carbon-reducing measures, as well as the maturity and promotion of process carbon reduction technologies, the petrochemical industry can reduce carbon emissions by 151 million tons and keep CO_2 emissions at 553 million tons per year.

By 2060, with the accelerated spread of fossil fuel alternatives and electric vehicles, oil consumption will gradually decline to below 250 million tons. At this stage, as oil is mainly used to produce petrochemical raw materials, the carbon emission intensity of oil processing per ton will increase dramatically. Without emission reduction measures, carbon emissions from crude oil processing will reach 364 million tons. However, at this stage, clean energy will be widely applied in refineries, and technologies such as CCUS and green hydrogen will mature and be commercialized on a large scale, which will greatly reduce carbon emissions from the petrochemical industry. According to the forecast model, carbon reduction technologies can help the petrochemical industry achieve Net-Zero by 2060.

Figure 43: Forecast of carbon emission reductions in the petrochemical industry



Source: RIPP research

Conclusion

Climate change profoundly affects the survival and development of humanity and poses a significant challenge to the international community. In September 2020, China proposed the goals of carbon peaking and carbon neutrality. It is a solemn commitment to the world, demonstrating its important role in building a global community of shared future, and essential guidance for its high-quality economic and social development.

Under the " carbon peaking and neutrality" policy, the petrochemical industry faces both pressure from transformation and decarbonization, as well as great opportunities from changes. Enhanced energy efficiency, improved processes and efficient use of resources can create substantial economic value for petrochemical enterprises and enhance their competitiveness while reducing carbon emissions. The use of renewable energy and the construction of a circular economy gives new impetus to the industry's high-quality development while significantly reducing life-cycle carbon emissions. Low-carbon product design and production, as well as green hydrogen supply and refining are typical inter-industry integrated low-carbon development models, which can maximize the petrochemical industry's contribution to creating a low-carbon value chain and supply chain for the society.

RIPP developed a series of low-carbon technologies based on the current industry situation and the " carbon peaking and neutrality" target, to provide comprehensive technical support and integrated solutions for the high-quality and low-carbon development in the petrochemical industry.

Deloitte sticks to its climate change commitments as a global leading professional services provider. We incorporate internal and external resources to provide petrochemical clients with integrated "end-to-end" solutions, enabling them to cope with a changing and unpredictable external environment and leading to a more sustainable future in the areas of climate change and decarbonization management, sustainable finance, ESG reporting, sustainable supply chain, and circular economy.

Main Staff

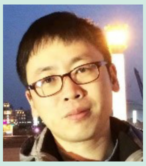
SINOPEC Research Institute of Petroleum Processing (RIPP)


Wu Hao


Wang Qi


Qin Kang


Li Yanjun


Yu Bo


Xu Yun


Xie Zengzhong


Mao Xinye


Wang Yun


Dong Yewei

Deloitte China


Ryan Chieng

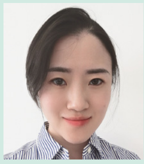

Kevin Guo

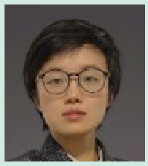

Jill Qu


Kevin He


Robert Hansor


Diane Cao


Olivia Wang


Jamie Deng

Contact

Wu Hao
RIPP Technology Support and Service Center (LCEC)
wuhao.ripp@sinopec.com

Diane Cao
Energy, Resources & Industrials
Deloitte China
tocao@deloitte.com.cn

Acknowledgement

As the goals of carbon peaking and carbon neutrality has taken the transformation of the petrochemical industry to a new level, this white paper dedicated to promote low carbon vision into actions was prepared with the support of outstanding experts in various fields from RIPP and Deloitte China, and we would like to express our sincere gratitude to those who have contributed to this project.

Contributors (sorted by the stroke count of Chinese surname)
Yu Shanqing, Xi Yuanbing, Wang Xi, Wang Chunming, Wang Wei, Wang Huiyu, Ye Sishi, Tian Ya'nan, Shi Xiaodi, Zhu Bingtian, Zhu Jinquan, Zhu Zhenxing, Zhu An, Wu Fenlin, Ren Ye, Liu Bixin, Liu YuJian, Liu Xinyang, Liu Feng, Ji Ke, Yan Jiasong, Lu Zelong, Li Fan, Li Mingyang, Li Qiang, Li Peng, Yang Yinan, Yang Xue, Yang Chao, He Yue, Kuang Chenggong, Zhang Yang, Zhang Xiaoxin, Chen Wenbin, Chen Ying, Fan Yingqi Yu Kun, Zhao Guangle, Zhao Ming, Zhao Nana, Zhao Rui, Gong Bin, Xia Changjiu, Gu Fangwei, Gu Ling, Xu Kexin, Xu Run, Luan Xuebin, Gao Guohua, Mei Hong, Gong Jianhong, Qu Hongliang, Xi Lei, Xie An, Xie Li, Zhen Dongxing, Cai Lile, Cai Kai

We would also thank those staff of RIPP and Deloitte China for providing valuable primary research data and useful comments and suggestions during the preparation and proofreading of the white paper.

The research of low carbon development in the petrochemical industry is innovative and complex, so we sincerely appreciate criticism for any inaccuracies in this white paper. RIPP and Deloitte China will keep working on related studies and propose more low carbon solutions in the future.

About RIPP

中国石化石油化工科学研究院
SINOPEC RESEARCH INSTITUTE OF PETROLEUM PROCESSING

SINOPEC Research Institute of Petroleum Processing (RIPP), founded in 1956, is a comprehensive research and development organization specialized in petroleum refining and petrochemical engineering. Subordinated to SINOPEC Corporation, RIPP is mainly devoted to the development and application of technologies for petroleum refining, while laying stress on refining-petrochemical integration and corresponding petrochemical technologies as well. In recent years, it has been reinforcing its innovation in new alternative fuels and renewable energy fields. RIPP now is on the way of transition to an all-directional energy R&D organization mainly engaged in petroleum refining and refining-petrochemical integration.

The 20 research departments in RIPP have nurtured a comprehensive and professional scientific research team with over 1,100 staff. Among them, there are four members of Chinese Academy of Sciences and Chinese Academy of Engineering. RIPP is equipped with approximately 1,000 sets of bench scale and pilot plant test units together with a large array of advanced analytical equipment engaged in studies of refining, petrochemicals, fine chemicals, additives, petroleum products application and low carbon development. RIPP has many research centers and laboratories, including the National Engineering Research Center for Petroleum Refining Technology and Catalyst, State Key Laboratory of Catalytic Materials and Reaction Engineering, National Energy R&D Center of Petroleum Refining Technology, Industrial Product Quality Control and Technology Evaluation Laboratory, Sinopec Lubricant Evaluation Center, Sinopec Water Treatment Technology Service Center, Sinopec Key Laboratory of Liquid Biofuels, Sinopec Key Laboratory of Heavy (Poor) Oil and Unconventional Oil and Gas Resources Refining Technology, Sinopec Key Laboratory of Molecular Refining as well as Sinopec Key Laboratory of Aromatics Technology. Furthermore, the Secretariat of National Technical Committee for Standardization of Petroleum Products and Lubricants, the State Center of Quality Supervision & Testing of Petroleum Products, and Petroleum Refining Branch of Chinese Petroleum Society are based in RIPP.

After over 60 years of development, RIPP has become a well-equipped R&D organization integrating petroleum refining and petrochemicals technologies research and development with technology licensing, technology consulting and technical service. By the end of 2020, RIPP has made 987 scientific and technical achievements with awards above ministerial level as well as 134 State Prizes, and has applied for 9,814 domestic patents with 6,701 granted, and 1,436 foreign patents with 889 granted. It has won eight Gold Awards, one Silver Awards and 19 Excellence Awards jointly issued by China National Intellectual Property Administration and World Intellectual Property Organization (WIPO).

Looking into the future, RIPP, with the goal of becoming a world-class **low-carbon energy and chemical research institute**, will continue to enhance its innovation capability, fully play the role of a propeller in science and technology innovation, and endeavor to provide all-around technical support to the high-quality and low-carbon development of the petrochemical industry.

RIPP established the Low-Carbon Economy Research Center of Petrochemical Industry (LCEC) in July 2021, which focuses on building a low carbon database and delivering low-carbon technology services in the petrochemical industry. It is responsible for developing a "carbon peaking and neutrality" platform for the petrochemical industry as required by the Ministry of Industry and Information Technology, and providing enterprises with systematic low-carbon technology services, such as carbon emission inventory, carbon footprint accounting, carbon reduction potential analysis and diagnosis, energy efficiency improvement technology services, resource efficient utilization study, low-carbon technology application planning, as well as carbon peaking and carbon neutrality roadmap design to facilitate high-quality and low-carbon development of the industry.