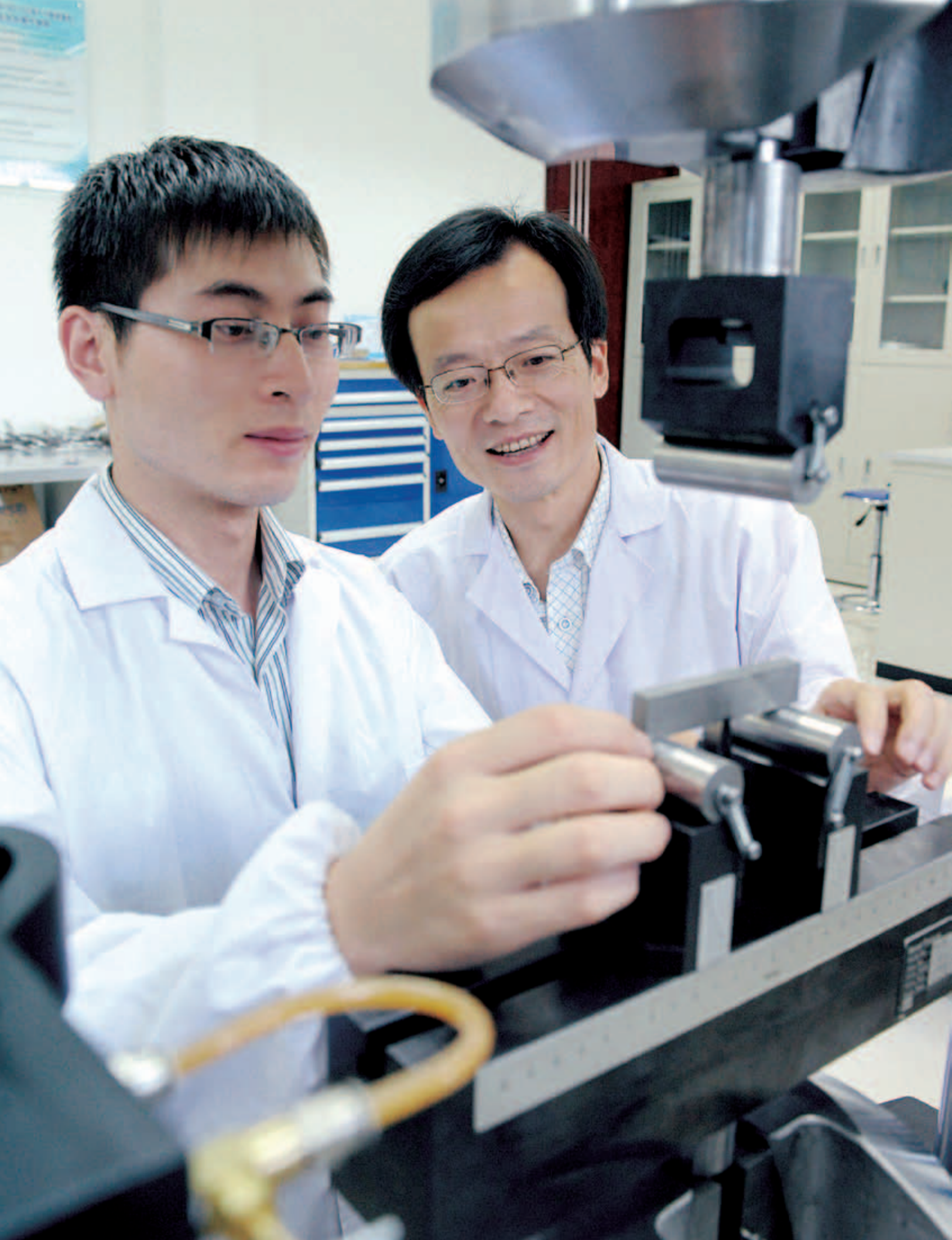

Technology · Innovation

With implementation of innovation strategy, we strengthen the combination of research with production and technology with market, and strengthen an open-mindset and promote knowledge sharing. We forge a new growth engine through all-round innovation driven by technological innovation.

In 2016, we reformed our technological research system and mechanism and rolled out the "Three Major Programs of Technological Innovation" to improve key technologies and to overcome bottlenecks hampering the development of our core business. As a result, we continuously improved our technological capabilities in that we harvested progress from major programs on basic theory and technology; made breakthroughs in key equipment, software and products; and effectively converted research outcomes into applicable technologies. All of these have underpinned the stable growth of our core business.

Construction of Technological Innovation System

We accelerated reform of technological research system and mechanism. We published the *Program to Deepen the Reform of Technological Research System and Mechanism and to Improve Innovation System*, which specified the objectives, key tasks, and measures to enhance reform. Comprehensive reform of our research institutes made substantial progress in business integration and organization optimization. Our technological programs were more business-oriented and focused on production bottlenecks. Research was integrated with production and technological achievements were converted and applied more faster.

By the end of 2016, we had 84 research institutes, 47 key laboratories and test bases, with a total number of 33,092 researchers.

Major R&D Achievements

Breakthroughs and important achievements were made on our key and matching technologies in that we improved exploration discovery rate, producing degree of reserves, recovery rate of oil and gas, as well as localization of high-end equipment manufacturing. We also addressed challenges on inferior crude processing, chemical feedstock cost cut, and clean energy production.

Exploration and Development

Theoretical breakthroughs were made in multi-path hydrocarbon generation from source kitchen in ancient petroleum systems. These included progress on the ancient source rock development mechanism in deep zones, gas generation potential during the high-over mature stage, and the identification of organic-inorganic composite hydrocarbon generation and the natural gas genesis. The breakthroughs effectively supported the fast growth of oil and gas reserves in Sichuan Basin and Tarim Basin.

Innovative geological modeling of salt-related structures and understanding on the forming of deep gas reservoirs resulted in major breakthroughs in exploration depth and engineering technologies of extremely-thick salt layers, supporting the construction of a gas-producing region with a reserve of more than one trillion cubic meters at Keshen tectonic zone in the Tarim Basin.

Discoveries were continuously made in the Mahu sag of the Junggar Basin, guided by the patterning of high-efficiency oil generation in natron-lake source rocks and extensive-reservoir forming in large shallow-water fan deltas, as well as creative matching technologies for conglomerate fracturing.

With an innovative seepage theory of micro-fracture networks in carbonate gas reservoirs, we created core technologies for forecasting high-yield abundance zones in ancient karst reservoirs and built up matching technologies for the development of large carbonate reservoirs. This enabled the efficient development of Anyue Gas Field, China's largest monomer uncompartmentalized carbonate gas reservoir.

An innovative reservoir-forming theory and seismic thin-interbed forecasting technology helped prove new oil and gas reserves in Yanchang Formation of the Ordos Basin. Creative key technologies such as multi-type cluster wells, high-performance fracturing fluids, and low-density proppant reduced operating costs by 30%.

A series of technologies used to stabilize production, control water-cut, and increase recovery in sandstone oilfields following high-speed development under natural drive was created and integrated, significantly improving development and curbing natural depletion at mature oilfields in Kazakhstan and Sudan.

A series of technologies for unconventional oil and gas development helped realize high output from SAGD wells completed as part of our oil sand project in Canada and new high-yield wells drilled as part of our CBM project in Australia.

Refining and Chemicals

Effective gasoline quality upgrading was enabled by technical packages for National V standard gasoline production. Nine grades of catalysts including catalytic gasoline selective hydrogen desulfurization, and five key technologies such as staged hydrogen desulfurization and oriented olefin conversion were created. Two series of technologies including selective hydrogen desulfurization (DSO) and hydrogen desulfurization-modification (M-DSO, GARDES) were developed, addressing the bottleneck in the production of clean gasoline.

Good results were achieved from industrial application tests of PHR residual oil hydrogenation catalysts. The design and preparation methods were developed for catalyst configuration by shape, pore structure and activity. These catalysts provided strong technical support for processing high-sulfur crude oil.

Major breakthroughs were made in the development of commercial production technology and safety evaluation for medical polyolefin resin. The physical and chemical criteria for medical resin packaging products and the safety requirements for medical polyolefin were met. The Good Manufacture Practice (GMP) specifications for medical polyolefin raw material, production, packaging, storage, and management system were formulated. New polyolefin materials for fuel gas pipes, medical devices, vehicles, and premium film were developed and customized for high-end clients.

The technological package for rare earth butadiene rubber and the development of new NBR and SSBR products helped to drive the application of our products in high-performance tires.

Oilfield Services and Storage & Transportation

Geophysical Prospecting: Micro-seismic real-time monitoring software with our proprietary intellectual property was developed, realizing integrated acquisition, processing and interpretation for downhole and surface micro-seismic monitoring data. GeoEast-ESP and GeoMonitor have become the mainstream software for China's micro-seismic monitoring and played an important role in the cost-effective development of unconventional resources. Low-frequency vibroseis and matching processing technologies took shape and the next-generation broadband excitation source was upgraded, increasing the reliability of oil and gas detection and coincidence of reservoir prediction.

Well Logging: Logging evaluation technologies focusing on source rock quality, reservoir quality and operation quality, as well as the corresponding logging data processing and evaluation software were developed. Playing an irreplaceable role in the discovery and production-capacity building of unconventional reserves, these technologies were applied in the development of tight oil in the Ordos, Songliao and Junggar basins and shale gas in South Sichuan. An imaging-while-drilling system generated images by scanning the well perimeter in a rotary manner in a field test, increasing the encounter rate of horizontal wells in complex reservoirs.

Well Drilling: Openhole expansion pipe plugging technology was developed, effectively packing off complex formations and controlling severe lost circulation without changing the casing program, providing a cost-effective and safe approach to the target horizon of design. The creative one-pass drilling of horizontal wells reduced the round-trip time and bit consumption, shortening the drilling cycle by 10%-20%.

Downhole Operations: Horizontal well staged-fracturing with totally soluble bridge plug, which features high strength soluble materials, prefabricated fragment soluble slips, and a bionic structure and material component optimization, saw success in industrial tests at several oil and gas fields in China.

Storage and Transportation: A major breakthrough was made in gas pipeline full-scale burst testing technology. A full-scale pipeline burst testing ground with a maximum diameter of 1,422mm and a maximum pressure of 20MPa was independently completed. Three successful burst tests were conducted for high steel grade and large diameter gas pipelines. The construction of the eastern route of the Russia-China Gas Pipeline and other major projects was facilitated by the innovative X80/Φ1422mm gas pipeline construction technologies and 16 categories of domestically made equipment such as 30MW gas-driven compressor units and heavy-duty oil pump units.

Energy Efficiency

We developed four new types of heating furnaces including a condensing one, and created seven key technologies such as online monitoring of steam-injection boilers, boosting the overall efficiency of the furnaces in our oil and gas fields by 5% and saving 270,000 tons of standard coal.

Technological Cooperation

We conducted technological exchanges and worked with domestic and foreign oil companies, high-end manufacturers, high-tech players, and research institutions in EOR, unconventional oil and gas development, treatment and recycling of oil-containing sludge, and new engineering technologies. Continuous progress was made in R&D projects, international talents training, and technological exchanges. In collaborating with Shell and GE, we made breakthroughs in the in-situ upgrading of shale oil and treatment of heavy oily sludge. We also worked with the Chinese Academy of Sciences (CAS) and the National Natural Science Foundation of China (NSFC) to promote theoretical and technological innovation. Having more international resources in place, our Houston technological research center played a bigger role as a platform for international cooperation and exchange.

Scientific and Technological Awards and Intellectual Property Rights

In 2016, four of our major achievements won China's national science and technology awards. "Innovative Exploration Theory and Technology of Ancient Carbonate Rock and Major Discovery of Super-large Anyue Gas Field" and "Technical Package and Key Equipment of Large-scaled Ethylene Units and Their Industrial Application" were awarded the second prize of National Science and Technology Progress Award. "Special Drilling Fluids for Complex-structure Wells and Their Industrial Applications", which was made with other parties, won the second prize of National Technical Invention Prize. "Quantitatively Calculation Method of Oil Saturation in Fractured Reservoirs" was awarded the China Patent Golden Medal.

In 2016, we applied for 5,017 patents home and abroad in which there were 2,797 invention patents. We were granted 4,855 patents in which 1,205 were invention patents.

Patents applied

5,017

Patents granted

4,855

Effective Deep Zone Exploration Achieved with Theoretical Breakthroughs in Multi-path Hydrocarbon Generation from Source Kitchen in Ancient Petroleum System

Research progress was made in ancient source rock development mechanism in deep zones, the gas generation potential during high-over mature stage, and the identification for organic-inorganic composite hydrocarbon generation and natural gas genesis.

Highlights: 1) Three types of gas-generating materials in an ancient gas bearing system were presented, namely, retained hydrocarbon, ancient reservoir and "semi-aggregated and semi-dispersed" liquid hydrocarbon, bringing more attention to high-over mature zones for gas reservoir formation. 2) Organic matter-rich Proterozoic–Paleozoic shale deposition was controlled by the Earth's orbital force, atmospheric circulation and stratified thalasso chemical environment; the hydrocarbon generating potential of ancient kerogen was determined by the type of microorganism and the redox conditions. The development of seven sets of high-quality source rocks from the Proterozoic Era provided a basis for resource potential evaluation and exploration prospect forecasting of ancient petroleum systems. 3) The organic-inorganic composite hydrocarbon generation mechanism under high temperature and high pressure revealed the hydrogenation reaction mechanism of different water-rock systems and its contribution to gas generation. The transition metal element promoted the reproduction of microorganism and the evolution of hydrocarbon generating. These results provided a new approach to explore the oil and gas generation potential of ancient petroleum system. 4) Late-stage pyrolysis gas generation in multiple-source kitchens of ancient formation was the key factor for large scale gas accumulation in Lower Paleozoic. High-over mature zones had higher exploration potential according to the "multiple golden belts" gas enrichment theory. Pyrolysis gas filling and gas wash fractionation were the key mechanism for secondary condensate gas reservoir formation.

The research results added 220 billion cubic meters of proven gas in place in the Sichuan Basin, and added 2.19 billion tons of oil and gas in place in the Tarim basin since 2013.